



FARMING SYSTEM DESIGN FOR SUSTAINABLE AGRIFOOD SYSTEMS: THEORIES AND PRACTICES

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Can diversification and technical innovations improve the sustainability of farming systems? SYPPRE, a French network of 5 system experiments

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Introduction

The main path for agriculture to reconcile production and environmental preservation is to move from farming systems mainly based on external inputs to biodiversity-based systems that rely more on ecosystem services. One way is to increase the level of diversification in farming systems, using practices such as rotation extension, intercropping, multiple cropping and/or multi-services cover crops implementation. The French technical institutes on arable crops ARVALIS, Terres Inovia and Institut technique de la Betterave, launched a collaborative project called Syppre in 2016 which objective is to investigate to what extent the combination of diversification practices and technical innovations could contribute to the enhancement of the sustainability of current French conventional farming systems.

Methods

The Syppre experimental network is implemented in five platforms that are representative of France's major regions for arable crop production: Picardie (PIC), Champagne (CHA), Berry (BER), Lauragais (LAU) and Béarn (BEA), (Longis et al., 2024). Since 2016, each platform has been testing at least two systems, a reference, representative of local farming practices, and an innovative system, more diversified, co-designed with local stakeholders. Sustainability improvement was assessed against a multi-performance target defined as: profitability and productivity greater than or equal to the reference with improved environmental performance. The innovative systems combine diversification practices based on a systemic approach, with introduction of legumes as main and cover crops, reduced tillage and the use of decision tools, when possible. The experimental set-up is based on blocks repeated two or three times depending on the platform with all crops of the rotation of both systems present each year in each block. All crop management practices are recorded in SYSTERRE tool (Weber et al., 2019) which calculates the performance indicators.

Results

At the network level, the environmental indicators achieved their expected objectives on average over the 7 years of experimentation, with a reduction in Treatment Frequency Index (TFI) application, mineral nitrogen application, primary energy consumption and Greenhouse gases (GHG) emissions (Table 1). However, these results were achieved at the expense of productivity and economic performances which are lower in the innovative systems compared to their respective reference.

At system level, the BEA innovative system reached the multi-performance from the start of the experiment, and the BER innovative one from 2021. The other three innovative systems still lack productivity and economic performances compared with their reference.

Criteria	Objective (Innovative vs. Reference)	Results (Innovative vs. Reference)				
		BEA	BER	CHA	LAU	PIC
TFI	-20 %	-26 ± 29 %	-21 ± 20 %	-6 ± 13 %	22 ± 14 %	-21 ± 9 %
Mineral nitrogen application (kg ha ⁻¹)	-20 %	-34 ± 6 %	-30 ± 15 %	-25 ± 12 %	-25 ± 15 %	-9 ± 11 %
Primary energy consumption (MJ ha ⁻¹)	-20 %	-23 ± 6 %	-19 ± 11 %	-11 ± 6 %	-1 ± 6 %	-20 ± 4 %
Greenhouse Gases emissions (t eq.CO ₂ ha ⁻¹)	-20 %	-28 ± 5 %	-25 ± 12 %	-19 ± 9 %	-19 ± 10 %	-18 ± 8 %
Gross energy production (MJ ha ⁻¹)	≥	1 ± 14 %	-20 ± 7 %	-7 ± 4 %	-8 ± 10 %	-23 ± 7 %
Direct margins with aids (€ ha ⁻¹)	≥	23 ± 33 %	-11 ± 27 %	-32 ± 25 %	-38 ± 12 %	-40 ± 21 %

Table 1: Results of the multi criteria analysis made with Systerre tool from 2017 to 2023. The results are the performance of the innovative system compared to the reference one. The colors indicate that the objective has been reached, not reached but the indicator is improving and not reached, for dark green, light green and orange respectively, for the innovative versus the control system

Discussion and perspectives

The lower productivity and economic performances of most innovative systems is mainly due to the unstable productivity of diversification crops (legumes mainly) and the lower share of profitable major crops in the innovative systems compared to the reference. In addition, the complexity of innovative systems whose rotation duration has been greatly increased has led to several experimental failures which have also hampered their performances. However, the higher environmental performance of innovative systems is mainly due to the diversification practices introduced, confirming the need for further experimentation to improve knowledge of farming practices related to minor crops and other innovative practices such as MSCC. The presentation will detail the mechanisms underlying the performances of innovative systems, as well as their specific features, which must be considered to understand the issues involved in the diversification of farming systems.

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Insights from a 10-year trial network of pesticide-free cropping systems

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Keywords: pesticide-free, cropping system design, crop diversification, agroecological crop protection

Introduction

Reducing pesticide reliance is a major priority due to their well-documented negative effects on human health and agroecosystems, including biodiversity loss, contamination of soil and water, and the emergence of resistant pest populations (Leenhardt et al., 2022). While Integrated Pest Management (IPM) and organic farming offer practical alternatives, their overall impact remains limited often constrained by partial adoption, yield penalties, and persistent dependence on certain harmful substances.

Achieving a deeper transformation of agricultural systems requires a shift toward pesticide-free cropping systems (Jacquet et al., 2022), grounded in knowledge-based crop management. This approach goes beyond input-driven models, favoring dynamic, adaptive, and site-specific strategies. Instead of relying on standardized technologies, it builds on continuous observation, iterative learning, and the integration of farmers' knowledge (Meynard et al., 2023). It promotes the active management of biodiversity, ecological processes, and biological regulation to support crop health and system resilience (Deguine et al., 2023). More than a technical framework, it represents a socio-ecological paradigm that repositions farmers as co-designers and stewards of agroecosystems (Berthet et al., 2016).

Despite growing global interest in pesticide-free agriculture, large-scale experiments testing its feasibility in temperate regions, particularly in non-organic cropping systems, remain scarce. To address this, the RésOPest network was launched in France to design and evaluate pesticide-free cropping systems for arable and livestock farming across diverse socio-economic and climatic contexts. Over ten years, it tested agroecological strategies to improve soil health, diversify rotations, and enhance natural pest control. This paper presents the system designs and multicriteria evaluations, highlighting key insights and challenges for scaling pesticide-free agriculture as part of a broader transition to sustainable food systems.

Methods

The RésOPest cropping systems were co-designed through participatory workshops involving researchers, farmers, and technical advisors. Systems were built around two core constraints: the complete exclusion of pesticides (including biopesticides), while permitting synthetic fertilizers, and the inclusion of regionally representative crops. The design was further guided by three objectives: maximizing marketable yield, ensuring economic viability, and reducing environmental risks beyond pesticide use. To ensure comparability across the network, all

sites followed common methodological rules: a minimum plot size of 0.48 ha, at least 50% of the rotation present each year, and cropping sequences spanning 5 to 9 years.

Each system included decision rules to guide technical operations based on weather, pest pressure, and agronomic conditions. These were adjusted annually through iterative learning loops, informed by monitoring results and field observations. Standardized protocols were applied across sites to collect data on pest dynamics, soil health, weather conditions, and crop management. Multicriteria sustainability assessments were conducted using Criter 5.4 and MASC® 2.0, allowing for robust evaluation of environmental and socio-economic outcomes over time.

Results

Nine cropping systems were designed and tested over 10 years under diverse socio-economic and pedoclimatic conditions across France. Each system was adapted to its region using locally representative crops. Six systems focused on arable farming, and three on mixed crop-livestock systems (Figure 1), with sites spread across agroecological zones such as northern France (Estrées-Mons), the west (Lusignan, Le Rheu), and the Mediterranean (Mauguio).

Rés0Pest demonstrated that pesticide-free systems can deliver satisfactory agronomic, environmental, and economic outcomes, though site-specific challenges persisted. Cultural control strategies were key, particularly crop diversification, mechanical weeding, and resistant cultivars. These systems introduced more diverse rotations, often including crops like soybean or hemp. Yields varied: 74% of crops met at least 75% of targets, and pesticide-free sugar beet notably matched conventional yields despite pessimistic forecasts. In terms of economic viability, Estrées-Mons achieved net incomes above three minimum wages per work unit, while mixed systems reported lower profitability.

Multicriteria analyses covered results from 2013-2023 (except Grignon: 2013-2020; Auzeville: 2013-2017; and Purpan, excluded due to late inclusion and system changes). Environmental performance was strong across all sites, but economic and social scores were uneven (Cellier et al., 2024), with some systems hampered by a lack of market incentives. Weed control remained a major constraint, particularly in dry years that limited cover crop establishment. Still, the network fostered significant learning and a shift toward knowledge-based management, offering key insights into scaling pesticide-free systems and the policy support needed to sustain them.

Discussion and perspectives

The Rés0Pest network shows that pesticide-free cropping systems can be agronomically viable and environmentally beneficial, though economic barriers remain a key constraint. While all systems achieved strong environmental outcomes, economic performance varied by crop type, region, and market access. High-performing systems, such as those at Estrées-Mons, combined crop diversification with efficient resource use to ensure profitability. Yet, the absence of targeted incentives such as subsidies, insurance mechanisms, or value-chain differentiation, hampers wider adoption. Weed control also emerged as a major challenge, particularly during dry seasons when cover crops failed to establish effectively across sites. Addressing these gaps through supportive policies and markets is crucial. Beyond technical fixes, transitioning to pesticide-free farming requires embedding agroecological principles into system design, integrating biodiversity, fostering biological regulation, and strengthening farmers' adaptive capacity. Scaling these approaches depends on public investment in farmer training, collaborative innovation networks, and replication of long-term experiments across diverse contexts to validate and refine practices.

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Keywords: pesticide-free, cropping system design, crop diversification, agroecological crop protection

Introduction

Reducing pesticide reliance is a major priority due to their well-documented negative effects on human health and agroecosystems, including biodiversity loss, contamination of soil and water, and the emergence of resistant pest populations (Leenhardt et al., 2022). While Integrated Pest Management (IPM) and organic farming offer practical alternatives, their overall impact remains limited often constrained by partial adoption, yield penalties, and persistent dependence on certain harmful substances.

Achieving a deeper transformation of agricultural systems requires a shift toward pesticide-free cropping systems (Jacquet et al., 2022), grounded in knowledge-based crop management. This approach goes beyond input-driven models, favoring dynamic, adaptive, and site-specific strategies. Instead of relying on standardized technologies, it builds on continuous observation, iterative learning, and the integration of farmers' knowledge (Meynard et al., 2023). It promotes the active management of biodiversity, ecological processes, and biological regulation to support crop health and system resilience (Deguine et al., 2023). More than a technical framework, it represents a socio-ecological paradigm that repositions farmers as co-designers and stewards of agroecosystems (Berthet et al., 2016).

Despite growing global interest in pesticide-free agriculture, large-scale experiments testing its feasibility in temperate regions, particularly in non-organic cropping systems, remain scarce. To address this, the Rés0Pest network was launched in France to design and evaluate pesticide-free cropping systems for arable and livestock farming across diverse socio-economic and climatic contexts. Over ten years, it tested agroecological strategies to improve soil health, diversify rotations, and enhance natural pest control. This paper presents the system designs and multicriteria evaluations, highlighting key insights and challenges for scaling pesticide-free agriculture as part of a broader transition to sustainable food systems.

Methods

The Rés0Pest cropping systems were co-designed through participatory workshops involving researchers, farmers, and technical advisors. Systems were built around two core constraints: the complete exclusion of pesticides (including biopesticides), while permitting synthetic fertilizers, and the inclusion of regionally representative crops. The design was further guided by three objectives: maximizing marketable yield, ensuring economic viability, and reducing environmental risks beyond pesticide use. To ensure comparability across the network, all

sites followed common methodological rules: a minimum plot size of 0.48 ha, at least 50% of the rotation present each year, and cropping sequences spanning 5 to 9 years.

Each system included decision rules to guide technical operations based on weather, pest pressure, and agronomic conditions. These were adjusted annually through iterative learning loops, informed by monitoring results and field observations. Standardized protocols were applied across sites to collect data on pest dynamics, soil health, weather conditions, and crop management. Multicriteria sustainability assessments were conducted using Criter 5.4 and MASC® 2.0, allowing for robust evaluation of environmental and socio-economic outcomes over time.

Results

Nine cropping systems were designed and tested over 10 years under diverse socio-economic and pedoclimatic conditions across France. Each system was adapted to its region using locally representative crops. Six systems focused on arable farming, and three on mixed crop-livestock systems (Figure 1), with sites spread across agroecological zones such as northern France (Estrées-Mons), the west (Lusignan, Le Rheu), and the Mediterranean (Mauguio).

Rés0Pest demonstrated that pesticide-free systems can deliver satisfactory agronomic, environmental, and economic outcomes, though site-specific challenges persisted. Cultural control strategies were key, particularly crop diversification, mechanical weeding, and resistant cultivars. These systems introduced more diverse rotations, often including crops like soybean or hemp. Yields varied: 74% of crops met at least 75% of targets, and pesticide-free sugar beet notably matched conventional yields despite pessimistic forecasts. In terms of economic viability, Estrées-Mons achieved net incomes above three minimum wages per work unit, while mixed systems reported lower profitability.

Multicriteria analyses covered results from 2013–2023 (except Grignon: 2013–2020; Auzeville: 2013–2017; and Purpan, excluded due to late inclusion and system changes). Environmental performance was strong across all sites, but economic and social scores were uneven (Cellier et al., 2024), with some systems hampered by a lack of market incentives. Weed control remained a major constraint, particularly in dry years that limited cover crop establishment. Still, the network fostered significant learning and a shift toward knowledge-based management, offering key insights into scaling pesticide-free systems and the policy support needed to sustain them.

Discussion and perspectives

The Rés0Pest network shows that pesticide-free cropping systems can be agronomically viable and environmentally beneficial, though economic barriers remain a key constraint. While all systems achieved strong environmental outcomes, economic performance varied by crop type, region, and market access. High-performing systems, such as those at Estrées-Mons, combined crop diversification with efficient resource use to ensure profitability. Yet, the absence of targeted incentives such as subsidies, insurance mechanisms, or value-chain differentiation, hampers wider adoption. Weed control also emerged as a major challenge, particularly during dry seasons when cover crops failed to establish effectively across sites. Addressing these gaps through supportive policies and markets is crucial. Beyond technical fixes, transitioning to pesticide-free farming requires embedding agroecological principles into system design, integrating biodiversity, fostering biological regulation, and strengthening farmers' adaptive capacity. Scaling these approaches depends on public investment in farmer training, collaborative innovation networks, and replication of long-term experiments across diverse contexts to validate and refine practices.

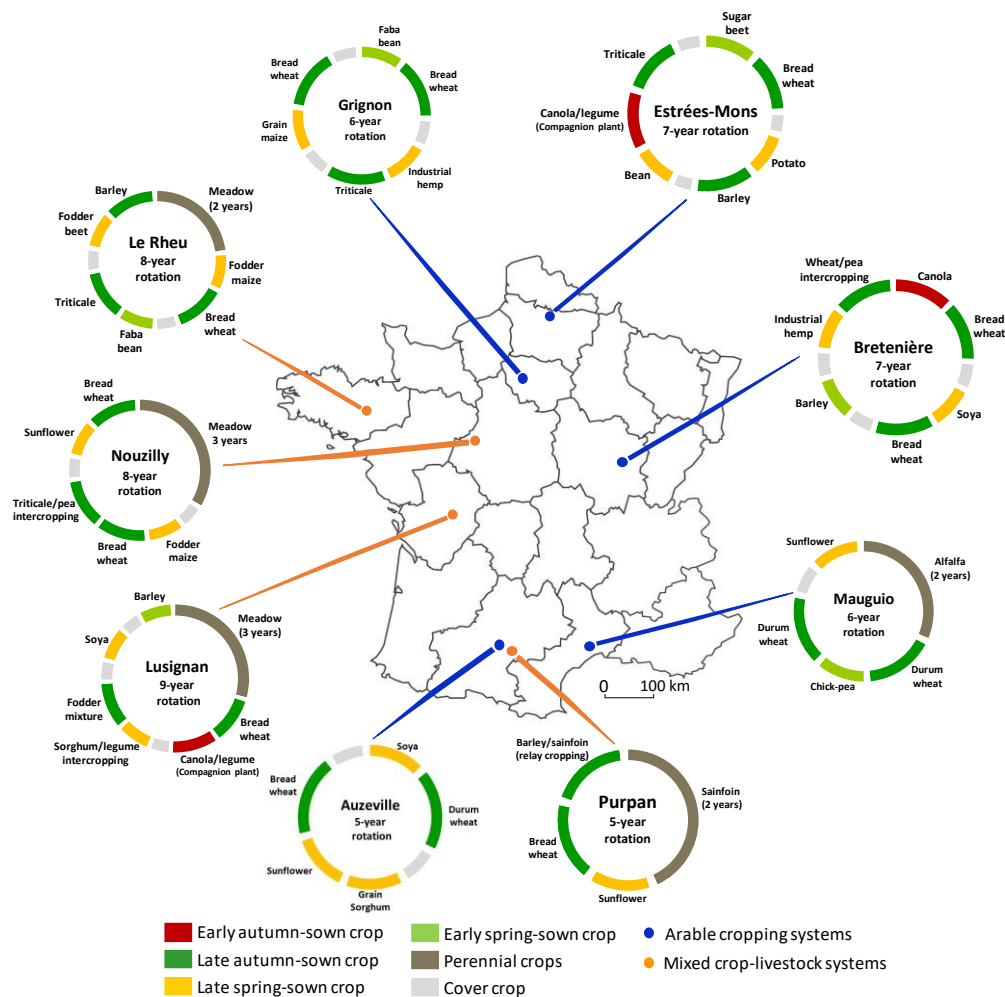


Figure 1. The nine sites of the Rés0Pest network spread across France. Each site has tested a unique cropping system. Circles indicate diversification examples in terms of crop sequence rotation and the sown season tested for each site.

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Test of the step-by-step design approach to study the transition of an organic farm located in a marshland area (France)

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Keywords: Organic agriculture, step-by-step design, staple food, climate variability

Introduction

In French Atlantic marshland, farming systems are operating in a complex socio-pedo-climatic environment characterized by grazing livestock systems on wet meadows but also cropping systems on drained heavy clay soils. Managing farming systems supposes to manage trade-offs between key ecosystem functions of wetlands: food production, biodiversity conservation, water quality regulation and flood buffering. Therefore, switching from conventional to agroecological cropping systems is a major challenge in these areas. This transition is constrained by the limited numbers of days with adequate soil conditions (constraint exacerbated by the greater climate variability, especially high levels of winter rainfall events). It is also due to weed species adapted to the hydromorphic conditions of these environments. The aim of this study is to test a theoretical framework for the progressive design of farming systems (Meynard et al, 2023), applied to an entire organic farming system seeking to diversify its food production. Here we present the learning feedback loop during the implementation of this farming system after 5 years of cultivation. We focus on analyzing the pathway to move from the initial situation to the targeted one.

Methods

This study is conducted in an experimental farm (INRAE) located in the marshlands of Rochefort-sur-Mer (France) in a temperate oceanic climate (coldest month above 0°C; heaviest precipitation in winter, fairly distributed throughout the seasons). The soils, calcareous fluvisols, have high clay content (50-60%) and over 90% fine elements, with no textural differences between horizons. The farming system experiment, called Transi'marsh, design and implement an organic mixed crop-livestock system with 45 suckler cows and is composed of 100 ha of grasslands and 60 ha of arable land (Durant et, al., 2020). Arable land comprises 50 ha of drained heavy clay with surface (10 ha) or subsoil (40 ha) drainage, and 10 ha of sandy loam. Since 2019, the experiment aims to achieve four main goals: 1) restoring wildlife biodiversity, 2) producing local staple foods, 3) reducing the impact of climate change and 4) being profitable. This cropping experiment constitute a major challenge in such environment, as there is few, if none, comparable example in commercial farms. The learning feedback loops consist of four steps from the initial diagnostic to the assessment (Figure 1). In our case, we analyze the decision, practices and outcomes that emerged during each step of the loop.

Results

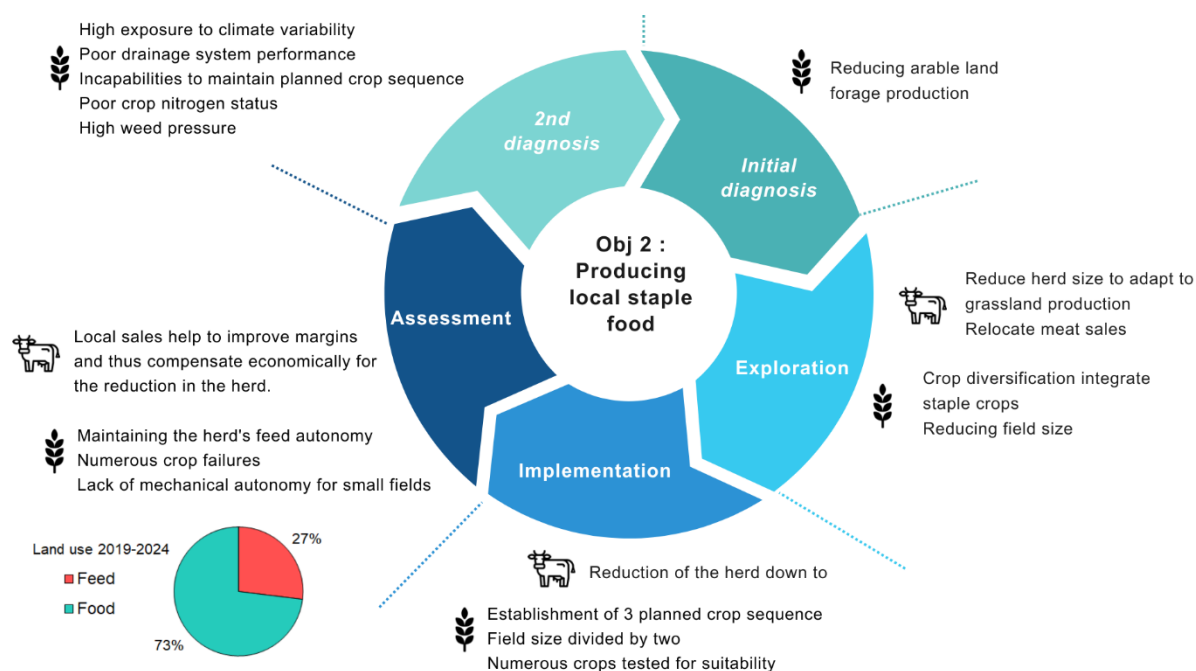


Figure 1. Steps of the learning feedback loops and the key decisions, achievements or learnings that emerged during the process.

At the farm level, the aim was to diversify food production by growing organic crops and therefore to reduce the area of arable land producing fodder (Figure 1). The transition from a forage-based farming system to an organic food system was explored by reducing the size of the cow herd to reduce feed requirements and relocating meat sales to increase margin. Three principals were applied to the cropping system: 1) diversifying the crop sequence and introducing staple crops, 2) improving biological soil fertility by incorporating straw, cover crops and applying cow manure and 3) reducing soil mechanical management (i.e. deep tillage, subsoiling). Crop diversification led to the implementation of three planned crop sequence. One sequence was made to feed the cows composed of 2-3 years perennial legumes -- cereals/grain legumes intercrop. A second crop sequence with 2-3 perennial legumes followed by 5 years of alternance of winter and spring summer staple crops. A third sequence with a cereals/grain legumes intercrop followed by 4 years of alternance of winter and spring summer staple crops (Tricheur et al, 2022).

On average, 73% of arable land were devoted to the production of staple crops, with variations from year to year. The high climate variability limited crop production during those 5 campaigns. In particular, heavy rains leading to high soil water content in 2019 and 2024 has prevented from sowing autumn and winter grain crops. This is reflected by the high variability of the date of last sowing of winter crops (i.e., last possible entrance in the fields) and of spring crops (i.e., first possible entrance) (Table 1).

Crop operation	2019-2020	2020-2021	2021-2022	2022-2023	2023-2024
Winter last sowing	11/10/19	30/11/20	30/10/21	07/11/22	12/09/23
First spring sowing	03/04/20	29/03/21	08/03/21	13/04/23	25/04/24

Table 1. Last winter and first spring sowing date (Transi'marsh farming system experiment).

Crop production was also limited by summer droughts particularly during the 2021-2022 campaign. This climatic variability prevented the implementation of the planned crop sequences. In particular, the date of sowing variability was found to be a high constraint as it

prevents key management practices such as 1) maintaining the alternance of winter-spring crops, 2) choosing appropriate crop species in the crop sequence (legumes), 3) increasing the risk of late summer harvest and 4) preventing late seeding to reduce grassy weeds density. In response, we decided to stop implementing the planned crop sequence but to conduct an opportunistic cropping system based on agronomic principles and soil conditions (Figure 1). With an average wheat yield at 2.5 t/ha (min-max: 0.8 -- 4.0 t/ha) and sunflower at 1.0 t/ha (min-max: 0.3 -- 1.8 t/ha), these results highlight the relative potential of this agronomic context but also the remaining constraints that limit crop production. The combination of a high climate variability, poor nitrogen supply at key crop stage and high weed pressure led to numerous crop failure. These five campaigns also emphasized the lack of drainage efficiency in our fields and the need for rehabilitation in order to reduce waterlogging and improve soil structure and fertility. Numerous crop species were tested (9 forage species and 22 food crops), such as millet and sorghum, which appeared to be well adapted to these soil conditions. The cow herd was reduced progressively from 65 cows in 2017 to 45 in 2024. The herd feed autonomy was maintained during almost the five campaigns. In 2024, the autumn-winter climate conditions prevented the cultivation of cereals-leguminous intercrop and leguminous forage, forcing the farm to rely on stocks, which coupled with the poor quality of the natural grassland hay did not allow us to be completely self-sufficient. Consequently, to maintain the herd feed self-sufficiency, it may be necessary to increase the target of 25% devoted to animal feed.

Discussion and perspectives

The step-by-step design framework was found to be a relevant research approach to study the transition of the farming system while maintaining a high level of flexibility in the design and implementation of the cropping system. This conceptual approach permitted to 1) stimulate the process of adaptation and generate many learnings (e.g., crop choices, crop sequence), 2) highlight pitfalls and blockages and fostered a systemic understanding (e.g., drainage performance, feed-food ratio, crop nutrient efficiency) and 3) was source of technical and systemic changes (e.g. reduction in the size of the herd). In particular, improved drainage performance, crop nitrogen supply and weed management have emerged as key objectives for the future. This is to be achieved through dynamic management of the cropping system to ensure adaptability and responsiveness to this marsh farming context, while striving for a higher level of production and better performance (Tanaka et al., 2002).

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Testing and accompanying agroecological transition relying on a systemic experiment in a research station

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Keywords: mixed crop-livestock, transdisciplinarity

Introduction

The European Green Pact highlights society's high expectations of agriculture, particularly with regard to food safety, climate neutrality and reducing nutrient losses to the environment through the promotion of circularity. Within the transdisciplinary co-design SPoT project, we defined and pilot three systems addressing the synergies between food crops and cattle to answer those multiple challenges. Within these systems, we test innovative technical and systemic solutions that can contribute to local agroecological transition. This contribution aims to give an overview of the methods and tools used throughout these co-design processes.

Methods

On the CRA-W experimental site, in the Belgian Ardenne, we set up an experiment to test the ability of three mixed crop-livestock systems to reach expectations emphasized by the Greenddeal within the frame of agroecological transition. To design them, researchers and advisors were mobilized in the first step to define the systems' purposes, components, and interactions. Then, the first proposals were validated with local actors and additional advisors. Next, tools and methods were defined by a transdisciplinary team (Tress et al., 2005) to drive the systems, analyse their transition and integrate them in a larger perspective of territorial and value chain transition.

Results and Discussion

The systems

In 2022, three (S1, S2 and S3) independent evolutive contrasted crop-livestock systems were designed and set up to question innovations and the synergies at system levels to answer three main targets co-defined: (i) optimize the circularity of flows, (ii) maximize food production, and (iii) meet climate challenges. The three systems are contrasted in terms of crop (Cr) to permanent grassland (PG) ratio (S1: 70% PG - 30% Cr; S2: 30% PG - 70% Cr; S3: 0% PG - 100% Cr). S1 is representative of the current regional spatial distribution of land use. S2 was chosen as a contrast to S1 regarding grassland-cropland proportion and, consequently, cattle density at the system level. In S3, only crops are grown. All crop rotations were designed to maximize food production. In S1 and S2, ruminant herd size was defined according to the area of PG and crop co-product availability to meet their dietary requirements. Raise and fatten crossbred bulls were chosen for their ability to valorise forage and lower environmental burden than males from suckling cow systems. The tested systems are strongly in rupture with the current production systems in Belgian Ardenne: suckler beef systems relying on grassland and cropped land nearly exclusively used for feed production.

Tools developed and mobilized

To sustain co-creation and knowledge sharing we allow independent step-by-step evolution of the three systems with a particular governance. It implies researchers (anthropologist, bio-

engineer, physician, geographer, agro-ecologist, economist), experimentation technicians, some of whom are also farmers, and external experts (scientist, value chain, administration, value chain actors, advisers). Those actors have different roles and intervene on different frequencies in the project within three committees (Figure 1).

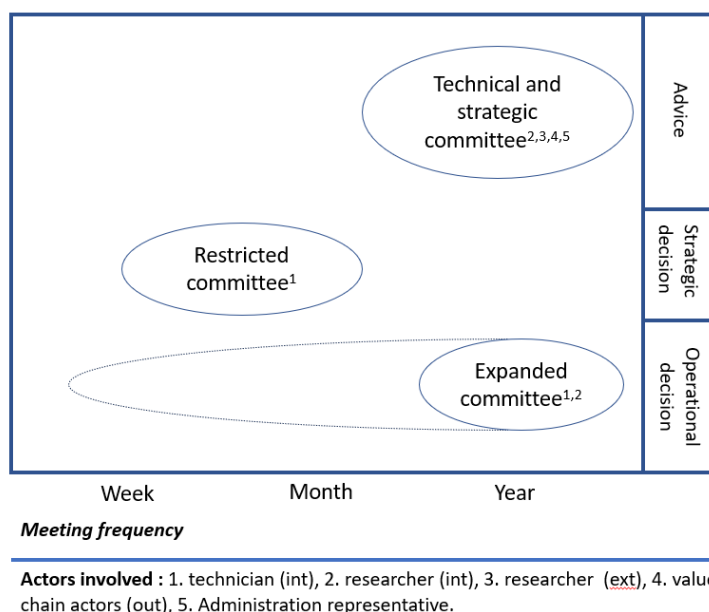


Figure 1. Governance representation. After consulting other external scientists, value chains, and institutional players, the restricted committee initially defined the experimentation. It provides starting points to co-construct practical solutions. It establishes decision trees for day-to-day practice to guide decisions taken by the expanded committee. The expanded committee co-constructs practical solutions to implement the experimentation, relying on frequent informal (dotted line) involvement of the members of this committee. This committee is regularly informed or consulted to validate the restricted committee's decision. The strategic committee provides an external opinion to ensure coherence between purpose and means and long-term guidance for the project.

Other tools, such as decision trees, are developed and improved during the project to guide decisions (Figure 2).

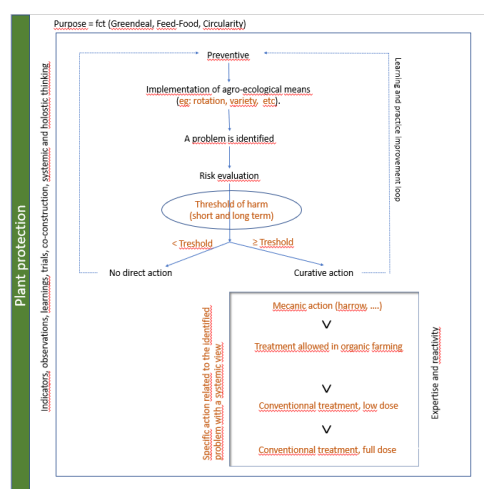


Figure 2. General example of decision tree regarding plant protection schemes

We sustain and encourage regular visits to the experimental site to initiate reflection regarding the local transition of farming systems.

With chrono-systemic timeline (Bergeret et al., 2005), we target to visualize dynamic processes and the interconnection between the multiple components of the project. It delivers transversal perspectives across the system's different components, linking seemingly disparate elements to reveal nodes to be investigated, obstacles to be overcome, levers to be activated, and successes to be highlighted. This timeline is based on records of decisions taken by the three committees and inputs from experts and visitors.

We plan to organise workshops with local actors to (1) co-design solutions to the particular problems encountered for each of the systems and (2) develop product storytelling (also with consumers), based notably on their degustation, to explore particular valorisation schemes. Those actions will rely on a preliminary mapping of the local stakeholders concerned.

To further support the transition of local agriculture, operational groups and farmers implementing the innovations tested are and will adopt them on their own farms.

Perspectives

Some tools used during the first 2 years of experimentation had already evolved, like the governance to adapt to the barriers encountered. Other tools must be developed for internal use and potentially support other initiatives (ex: decision trees). Thanks to the tool mobilized, we have already identified barriers and levers to the shift from "factorial" to "systemic" experimentations and the implementation of some innovations (raising crossbred cattle). We propose to look again at this 'agri-environmental governance assemblage' (Sutherland and Calo, 2020) that constitutes this system experimentation. We will unfold the various relationships and tensions between the multiple human and non-human components of each form of relationship between livestock and crop farming. This experimental system helps to accompany the transition by supporting, promoting and experimenting with the agroecological transition, in accordance with the transdisciplinary.

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Does Plantago (Plantago lanceolata) as understorey in maize improve N uptake and reduce nitrate losses?

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Keywords: plantain, soil nitrate, maize, nitrogen uptake

Introduction

In Germany, silage maize (*Zea mays* L.) production is characterized by high N inputs with negative environmental implications, such as nitrogen (N) losses (Komainda et al., 2018). Hence, there is an urgent need to design sound management practices to reduce N losses. Currently, ribwort plantain (hereafter referred to as plantain) is recognized as a nitrate-leaching mitigation option. The presence of plantain has been found to significantly affect soil N mineralization and nitrification due to its major secondary metabolites (Dietz et al., 2013). Therefore, establishing plantain as an understorey in silage maize could be a promising approach to mitigate N losses. As such, research about the effect of selected genotypes grown as understorey in maize, where competition for light is key, should be investigated.

This present study is based on first-year data of a two-site experiment located in Northern and Central Germany, testing the effect of six plantain genotypes compared to a control without understorey on the N uptake of maize and soil nitrate levels at harvest. We hypothesized that the incorporation of plantain reduces soil nitrate (NO_3^-) and improves maize N uptake, compared to the control.

Methods

A field experiment was conducted in 2024 at two distinct sites with sandy soils containing 90% sand and a silt loam soil containing 68% silt, located in Northern (54.63°N, 9.99°E) and Central Germany (51.49°N, 9.92°E), respectively. Maize was grown after tillage of a previous grass-red clover mixture established several years before the experiment to provide a highly reactive N source. An early maize hybrid was sown in May at a density of 100,000 plants ha^{-1} . The fields were later harrowed twice, and the plantain cultivars were broadcast seeded in June at the six-leaf stage of maize at a sowing density of 500 seeds m^{-2} plus 250 seeds m^{-2} broadcasted in July. No chemical herbicides and no additional N fertilizer were applied. The setup referred to a randomized block design with four replicates of each treatment and a plot size of 9 x 12 m. Treatments were six plantain genotypes (Agritonic, Boston, Captain, Diversity, Hercules, and a breeding population named PL2023V004) in combination with one control (no understorey). In September, the maize was harvested at BBCH 85 by cutting 10 plants manually at ground-level from two center rows. Subsamples were taken to determine the dry matter (DM) content after drying in a forced air oven at 60 °C until constant weight. Subsamples were milled, and N content was estimated by Near-Infrared-Reflection by scanning each sample twice. The N uptake was calculated as the product of total aboveground biomass yield and N content. At maize harvest, soil mineral N samples were collected. The interaction of treatment x site on maize N uptake and the topsoil (0-30 cm), maize dry matter (DM) yield, soil NO_3^- were tested using analyses of variance with the block as a random effect using the R studio software.

Results

Results indicated that the plantain genotypes did not influence soil NO_3^- levels (Figure 1) ($P>0.05$), nor did they significantly influence maize DM and N uptake (Figure 2) ($P>0.05$). However, the site had a major effect on maize DM, N uptake, and soil NO_3^- levels ($P<0.05$).

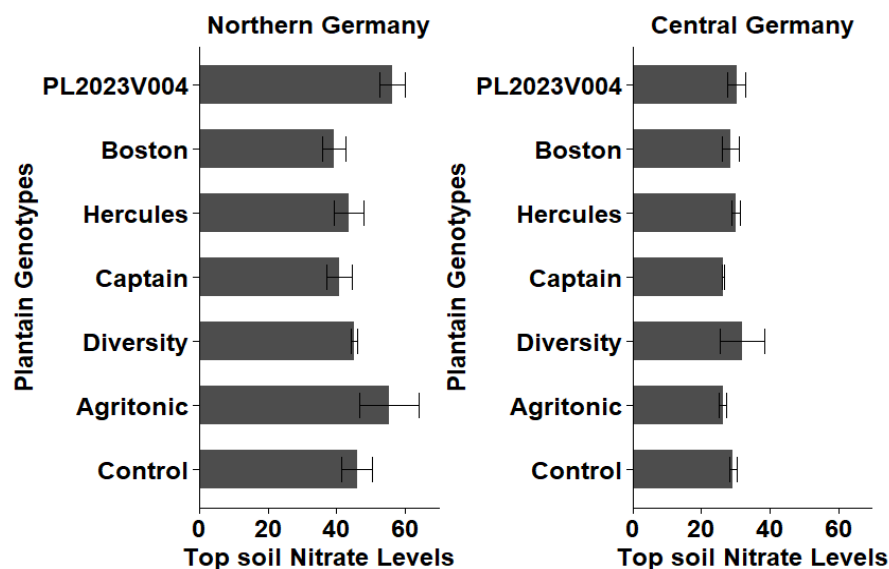


Figure 1: Top soil (0-30 cm) nitrate levels ($\text{kg NO}_3^- \text{ ha}^{-1}$) with different plantain genotypes against the controls without understorey.

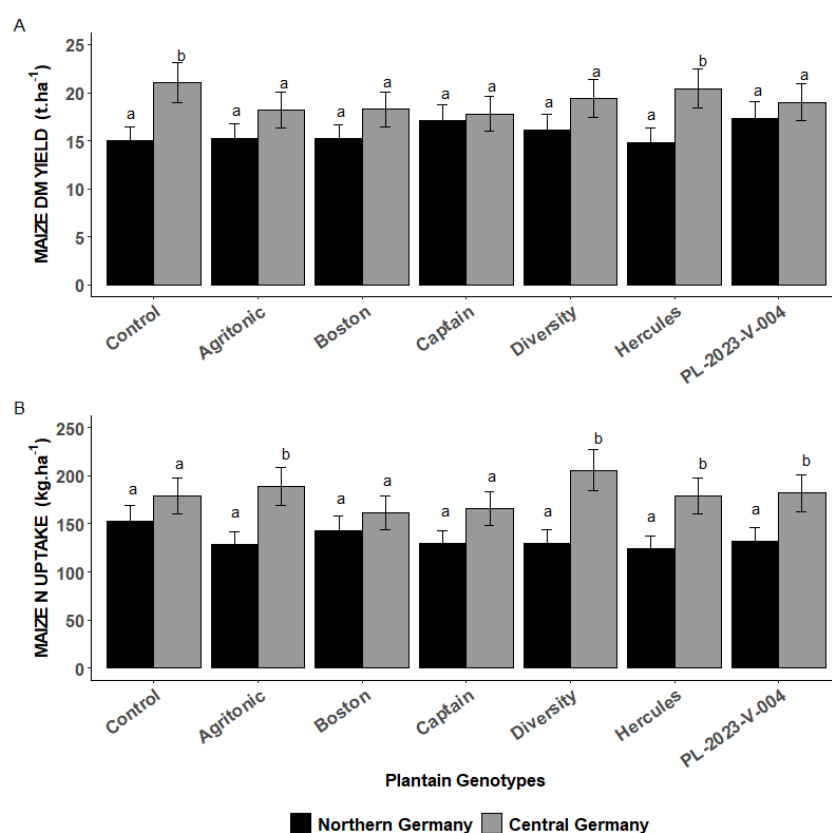


Figure 2: Final maize dry matter yield (A) (t ha^{-1}) and maize nitrogen uptake (B) (kg ha^{-1}). Different lowercase letters denote significant differences between sites for each plantain genotype

A comparison of means indicated variation in maize DM and N uptake among plantain understorey genotypes (Figure 2) at the Central site. Maize DM yield was significantly higher in the control and the treatments with Agritonic (Figure 2A) and maize N uptake was lower in the control, Boston and Captain treatments compared to the other treatments (Figure 2B).

Discussion and Perspectives

Within the conditions of this field study, soil NO_3^- and maize N uptake between plantain genotypes were similar within each site. The spatial variability indicates that higher NO_3^- levels and lower maize N uptake at the Central site were associated with site-specific conditions (e.g., soil type, weather, organic matter, soil microbiology) influencing the processes of mineralization and nitrification. An earlier work by Dietz et al. (2013) showed that soil N mineralization and nitrification are significantly affected by the presence of plantain leaf, but the effect on N uptake and soil NO_3^- may be site-specific (Pijlman et al., 2020). According to Pijlman et al. (2020) plantain had no effect on nitrification processes on a loamy soil. On a sandy, Dietz et al. (2013) observed lower NO_3^- levels through the presence of plantain compared to the control. In the current study, results are so far limited to the first year and do not suggest an increase in N uptake or a decrease in NO_3^- levels when plantain is undersown in silage maize. However, as indicated by the comparison of maize N uptake at the central site, the plantain genotype can have a significant effect. In effect, the association between maize and plantain may be potentially beneficial i.e., controlling N losses without limiting maize DM yields. Whether or not this is related to a better establishment or an actual effect on nitrification inhibition is yet to be clarified in the next year.

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Effects of herbicides spot-spraying on weed management

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Keywords: precision agriculture, weed community analysis, field trials, herbicide savings

Introduction

Conventional chemical weed control often leads to unnecessary herbicide use and ecological damage, as treatments are applied uniformly across entire fields regardless of weed presence. This reduces biodiversity and generates economic losses. For patchily distributed perennial weeds like thistle (*Cirsium arvense*), localized spraying offers a promising alternative. Using advanced detection technologies, it targets only infested areas, optimizing herbicide use and limiting environmental impact (Parven et al., 2025). Although several studies highlight its benefits (Anne et al., 2024; Leise, 2024), field trials remain scarce and rarely repeated over time.

This PhD project aims to evaluate spot versus broadcast spraying under real farm conditions across diverse soils, climates, and cropping systems. The objective is to compare key indicators: herbicide savings, weed control efficiency, and crop yield. Particular attention is given to weed community dynamics over time to understand long-term effects of reduced inputs.

Beyond performance, this research supports the development of low-input systems by exploring how localized spraying complements agroecological practices (crop rotations, targeted tillage, crop associations). Multi-year monitoring of weed communities and treatment efficiency will help to evaluate the sustainability of this approach in real-world conditions.

Methods

Experimental setup

Trials are conducted at three geographically distinct sites in France: Guer (56), Grignon (78) and Dijon (21) to encompass a range of crops, soils, and climatic conditions. Five fields (sunflower, grain maize, silage maize) are tested in the first year, in partnership with local farms and cooperatives.

Fields are divided into strips (2 to 4 per field) comparing spot and broadcast spraying modalities. Weed density is measured in ten 12 m² geolocated quadrats per modality, before and after treatment (Figure 1). Each sprayer is equipped with real-time weed detection sensors. For spot applications, spray maps are retrieved after treatment to spatially link weed presence with treated zones (Figure 2).

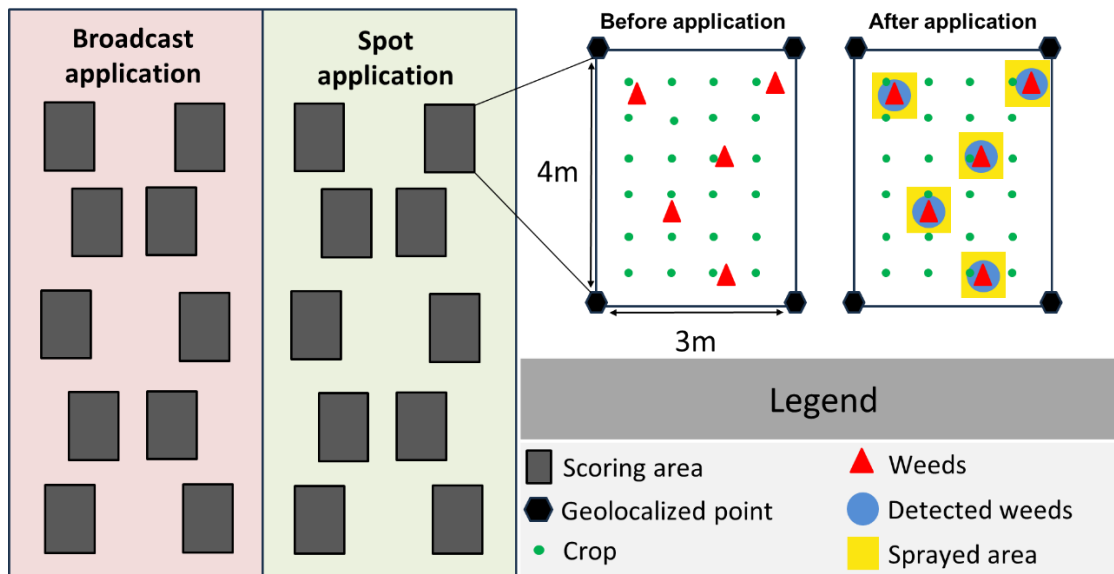


Figure 1. Trial layout. Each field is divided into strips (2 to 4 per field), each corresponding to a spraying modality: broadcast or spot application. Each modality consists of 10 quadrats (3 x 4 m) distributed in one or two strips.

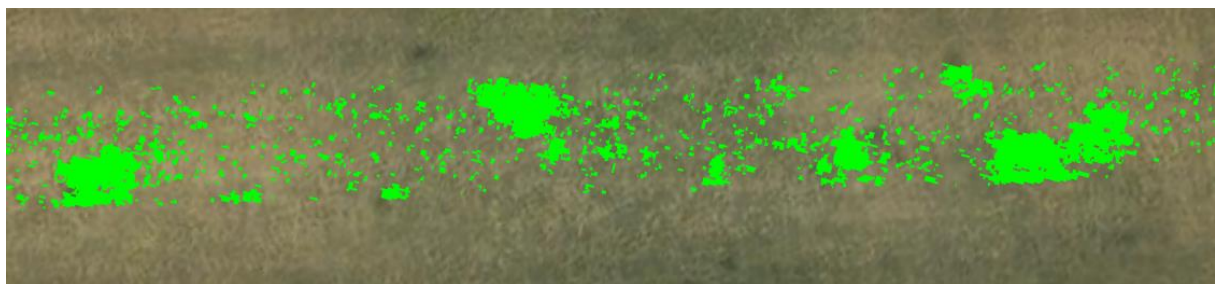


Figure 2. Post application map. An example of a post-treatment spray map used to estimate detected weed coverage. These maps are processed with GIS tools (e.g., QGIS) to calculate treated areas and quantify herbicide savings.

Herbicide and water savings

Herbicide and water savings of spot spraying are estimated by calculating the percentage of unsprayed areas using post-application spray maps.

Weed rating

Weed recognition, density, and growth stage are assessed in all quadrats of a field 1 to 3 days before herbicide application, and again 2 to 3 weeks after treatment, depending on the herbicide used. These observations are conducted across all quadrats and fields. Complementary drone flights are performed to validate field counts and assess weed biomass.

Statistical analysis

We analyzed weed density using the following model: $\text{Density} \sim \text{Modality} * \text{Timing} + (1|\text{Field}/\text{Strip}/\text{Quadrat})$ (glmmTMB function in R). Here, "Density" refers to weed counts per quadrat, "Modality" distinguishes the application type (broadcast vs. spot), and "Timing" indicates whether the observation was before or after spraying. The nested random effects (Field/Strip/Quadrat) reflect the trial's hierarchical structure.

Results

Herbicide application significantly reduced weed density after treatment in sunflower, grain maize and silage maize. No significant difference in weed density after treatment was observed between broadcast and spot spraying modalities.

High variability in weed species and densities was observed within and across fields, suggesting that spot spraying effectiveness may depend on site-specific factors such as weed pressure, crop type, and sensor calibration (Gerhards et al., 2006).

Additional years of data and broader sampling are needed to confirm these preliminary results (Blank et al., 2023). Average herbicide savings across the five fields reached 40.7%.

Discussion and Perspectives

The first trial-year showed that no significant differences in weed densities were observed after broadcast and spot spraying after a one-year period.

These results echo Leise et al. (2024), who found comparable weed control efficiency between spot and broadcast spraying in maize and soybean.

Moreover Leise et al. (2024) showed that spot spraying can reduce herbicide use by up to 90% without compromising weed control.

While this study has focused on weed density and herbicide savings, future analyses will consider long-term weed control efficiency, crop yield (data pending), environmental impact, and contextual factors (soil, weather, cropping history) to identify and explain factors influencing treatment success.

This systems-based approach aims to design innovative and resilient farming systems, by optimizing the use of chemical inputs and reinforcing agroecological levers (crop rotations, targeted tillage, crop associations). To assess ecological impacts, biodiversity indicators of weed communities (e.g., species richness, Simpson's and Hill's indices, evenness) will be included.

Ultimately, this research seeks to provide a scientific basis to help farmers and advisors in adopting precise, sustainable weed control practices, thereby helping to reduce inputs and preserve agroecosystems.

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Soybean-buckwheat intercropped systems to support grain production and pest control in North-Eastern Italy

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Keywords: intercropping, agroecosystem services, *Halyomorpha halys*, soybean

Introduction

In Northern Italy, soybean-based cropping systems (SBCSs) are highly simplified and usually fall into short rotations. These cropping systems are vulnerable to both abiotic and biotic stresses, including infestations by the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Owens et al., 2013). Diversification through intercropping has the potential to enhance pest control by introducing physical barriers to pest dispersal and by sustaining beneficial arthropods (Gurr et al., 2017). However, intercropping remains limited among farmers, highlighting the need for innovative and practical diversification strategies.

The aim of the ECO-DRESS project is to explore strip cropping with buckwheat, *Fagopyrum esculentum* (Moench), as an innovative strategy to limit soybean pests and to increase land use intensity. Buckwheat is a high-value melliferous crop, but its adoption remains limited due to unstable yields and seed loss due to lodging (Virili et al., 2024). Therefore, strip intercropping of soybean with buckwheat is hypothesized to 1) increase the pest control in soybean; 2) reduce buckwheat lodging through the adjacent soybean strips.

Methods

Five cropping systems (Fig. 1) were tested in two parallel trials in Padua and Udine in 2024, named: 1) pure soybean, 2) pure buckwheat, 3) alternate soybean-buckwheat strips (strip1), 4) two soybean to one buckwheat strip (strip2), 5) a buckwheat frame around soybean (frame). The innovative strip systems, co-designed by agronomists and entomologists, aimed to introduce a gradient of ecosystem services (Fig. 1). Each cropping system was replicated three times in a completely randomized design without fertilization. Plant inspection with visual sampling was performed in September to assess *H. halys* infestation on plants. The detection of insects was performed for one minute at three distances from the plot border (0 m, 3 m, 6 m), since this pest is known to have a border distribution (Venugopal et al., 2015). Buckwheat height (vertical distance between the ground and the highest point of the plant) and length (measured along the stem from collar to apex) were recorded on ten plants/plot at peak biomass; their ratio provided buckwheat resistance to lodging (1 = no lodging; < 1, decreased resistance to lodging; Virili et al., 2024). At harvest, three 0.25 m² areas were collected for each crop to measure grain yield. These values were used to calculate the actual soybean and buckwheat production in each cropping system and their Land Equivalent Ratio (LER).

Yield and buckwheat lodging resistance were analyzed with a two-way Anova (including cropping system and location), and *H. halys* abundance data with a negative binomial generalized linear model. A Tukey's post-hoc test followed were significant.

Results

Soybean production was affected by location * cropping system ($p < 0.0001$). It was in line with the proportion of soybean in the cropping systems but was significantly higher in Padua compared to Udine (Fig. 1), where soybean was affected by staygreen syndrome. Buckwheat production was affected by both location and cropping system ($p < 0.0001$), with a higher production in Udine ($703 \text{ kg ha}^{-1} \pm 49.1$) compared to Padua ($411 \text{ kg ha}^{-1} \pm 43.4$) and proportionate to its ratio within the plots.

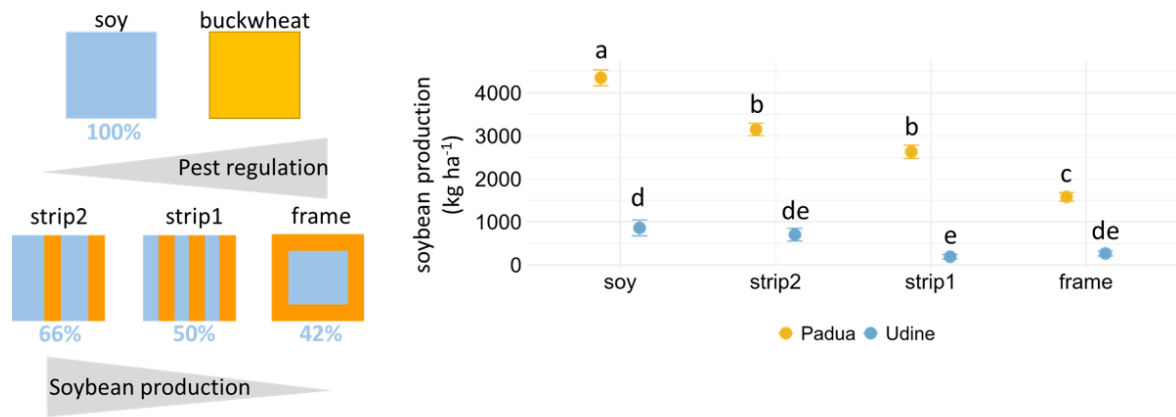


Figure 1. (Left) Pure crop controls and innovative layouts, percentages indicate soybean proportion in each system. (Right) Soybean production (kg ha^{-1}) at both sites. Letters represent significant differences between means ($p < 0.05$); bars show standard error.

The LER was significantly affected by cropping system * location ($p = 0.004$). Strip2 in Udine had the highest LER (2.3 ± 0.8 , a), followed by strip2 in Padua (1.9 ± 0.8 , ab), strip1 in Padua (1.9 ± 0.7 , abc), frame in Udine (1.8 ± 0.8 , abc) and frame in Padua (1.5 ± 0.8 , bc). The lowest LER was produced by the strip1 layout in Udine (1.2 ± 0.7 , c).

Buckwheat lodging was affected by both location and cropping system ($p < 0.0001$). In Udine, lodging resistance was higher in the strip plots and lower in the pure buckwheat plots, while in Padua the pure buckwheat plots resulted in a higher lodging resistance compared to the intercropped plots (Fig. 2).

Halyomorpha halys density on September 30th, 2024 was affected only by the cropping system ($p = 0.002$) and the lowest counts were observed in the frame layout (Fig. 2). Sampling in late September captured differences at a time when *H. halys* populations were stable.

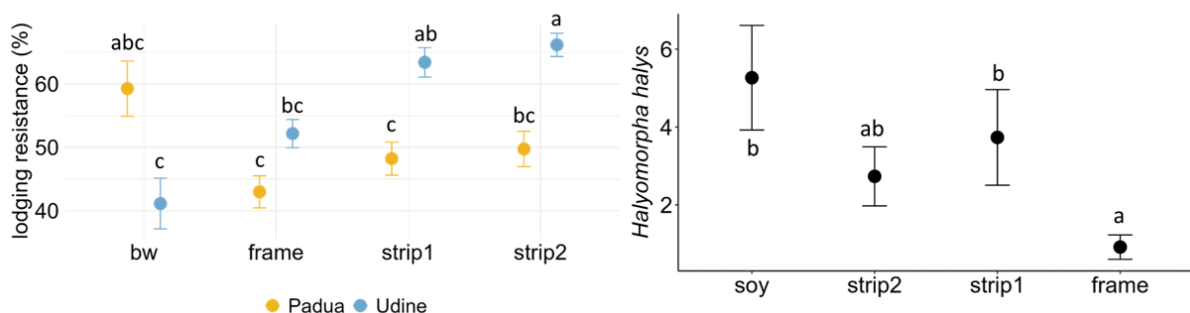


Figure 2. (Left) Buckwheat lodging resistance in the different cropping systems. (Right) *Halyomorpha halys* count on soybean plants averaged across locations in the different cropping systems. Letters represent significant differences between means ($p < 0.05$); bars represent the standard error.

Discussion and Perspectives

Frame was the best for pest control, indicating the effectiveness of buckwheat as a barrier. Although soybean production in the frame was halved than for sole crop, the loss was balanced with buckwheat production and showed a discrete resistance to lodging in both sites. In Padua, lower summer precipitation limited buckwheat lodging compared to Udine. The repetition of the twin experiments in 2025 together with a set of On Farm Experiments will contribute to testing the farmers' preferences and the scalability of the proposed innovative cropping systems.

Funding:

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Innovating water management for rice cropping system to reduce CH₄ emissions from fields and Cd level in grains

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Keywords: food security, methane emission, cadmium contamination, paddy fields

Introduction

Climate change will not only decrease crop yields but may also exacerbate risks such as greenhouse gas (GHG) emissions, heavy metal contamination and water shortages (Yin et al., 2024; Jing et al., 2023; Muehe et al., 2019). As a staple food source for billions, global rice cropping systems are responsible for more than 20% of global agricultural methane (CH₄) emissions and 70% of agricultural fresh water consumption (Wu et al., 2022; Jiang et al., 2019). Compounding this environmental challenge is the issue of Cadmium (Cd) contamination in rice production, especially in Southeast Asia (Lei et al., 2020). Southeast Asia, which produces over 90% of the world's rice, has become a global focal point due to issues such as CH₄ emissions from paddy fields, excessive Cd levels in rice grains, and freshwater scarcity. Addressing these interconnected risks requires an integrated optimization of rice cropping systems, adopting a multi-objective approach to achieve innovative water management solutions. Therefore, based on previous studies on rice variety screening and cropping mode optimization, the objectives of this study focus on investigating the effects and their mechanisms of water management innovation on CH₄ emissions, Cd levels, and rice yield. This field experiment research aims to provide theoretical and technical support for establishing a green, low-carbon, and climate-smart rice cropping system in Southeast Asia.

Methods

A comprehensive field experiment was conducted over three consecutive growing seasons (i.e., the seasons of late rice, early rice, and late rice) in Jiangxi Province, China. The field experiment was conducted using a two-factor randomized block design, which included two distinct water management strategies (i.e., flooded irrigation and controlled irrigation) and two critical implementation stages (i.e., rice tillering and grain-filling stages). This design led to the establishment of four specific irrigation treatments: (1) FTCG: flooded during the rice tillering stage and controlled irrigation (CI) during the grain-filling stage; (2) FTFG: flooded during both the rice tillering and grain-filling stages; (3) CTCG: CI during both the rice tillering and grain filling stages; and (4) CTFG: CI during the rice tillering stage and flooded during the grain filling stage (Fig. 1). Flooded refers to maintaining a 3-5 cm water layer on the field surface, while controlled means the field is drained with no standing water. A Controlled Irrigation (CI) cycle consists of 4 days Controlled and 3 days of Flooded. Due to variations in the length of each period of rice growth, CI was applied twice during the tillering stage and three times during the grain-filling stage. Throughout other growth stages of each growing season, the water management practices across all four treatments remained consistent. The field CH₄ emissions were measured using the closed-chamber method.

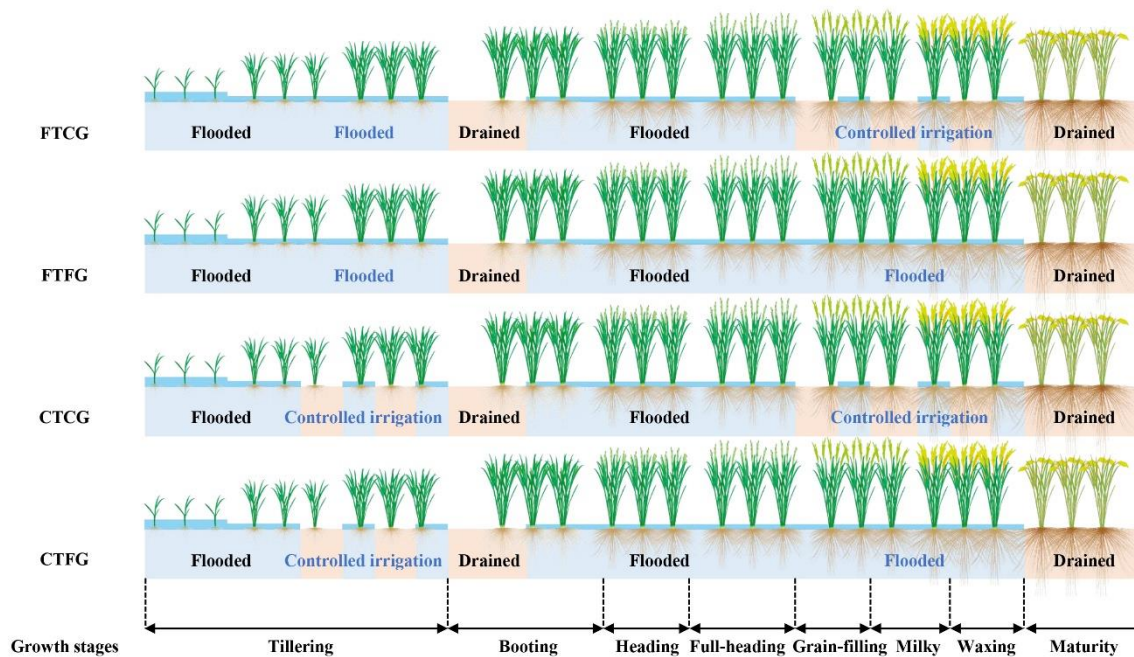


Figure 1 : Schematic diagram of water management strategies implemented in the test field

Results

The CTFG treatment—a novel approach combining controlled irrigation (CI) during rice tillering stage with continuous flooding (CF) during rice grain-filling stage (Fig. 1)—demonstrated remarkable consistent efficacy over the three seasons. Compared to high-yielding irrigation practice, this regime achieved a 33% reduction in CH_4 emissions and a 42% decrease in Cd content in brown rice, without compromising rice yield. Furthermore, when benchmarked against specialized irrigation regimes, CTFG outperformed a Cd-minimizing regime by reducing CH_4 emissions by 39%, and surpassed a CH_4 -reducing regime by lowering Cd levels in brown rice by 40%, while maintaining comparable performance in each targeted area. CI implementation during tillering stage effectively suppressed methanogen activity while enhancing methanotroph populations, thereby significantly reducing CH_4 emissions. Conversely, CF during grain filling stage decreased soil redox potential and promoted sulfate-reducing bacteria, consequently limiting Cd mobility and its subsequent uptake by rice plants. These findings provide valuable scientific insights for developing more sustainable rice production systems through optimized water management strategies.

Discussion and Perspectives

In summary, the refined irrigation approach of applying CI at the tillering stage followed by flooding at the grain-filling stage can substantially curtail CH_4 emissions from fields and Cd levels in rice grains without compromising yield. This innovative water management offers significant potential for mitigating climate change risks in Southeast Asia. High-yield water-saving rice cultivation is critically important in South-east Asia, as it is not only vital for food security, but also closely linked to water resource utilization and methane emission reduction. For example, SRI intensification system which is precisely based on the alternative of aerobic and anerobic phases in paddy fields, has played an important role in improving rice yield and water use efficiency (Uphoff et al., 2010). However, with the increasing severity of climate change and the growing issue of Cd contamination in rice, innovations in paddy field water management must also consider multiple objectives such as CH_4 emission reduction and Cd content mitigation. This is essential for establishing a green, low-carbon, and climate-resilient agrifood system. The findings of this study are based on well-established field infrastructure.

Therefore, when demonstrating and promoting this innovating irrigation, the government needs to improve irrigation facilities—such as through high-standard farmland construction—and ensure a stable irrigation water supply. Additionally, the government could consider implementing agricultural water pricing reforms based on irrigation quotas, establishing water-saving incentives, so as to raise farmers' awareness of water-saving as well as its economic benefits. Meanwhile, some other supporting practices are also important for the system design, such as crop cultivar screening and planting model optimization.

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FLORSYS: a mechanistic model bridging scientists, advisors and farmers in order to design agroecological weed management strategies

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Keywords: ecological intensification, mechanistic model, cropping system design, weeds

Introduction

Arable weeds are a major obstacle for reducing pesticide use because they are highly damaging to crop production. So far, no non-chemical curative weed-control option used alone is as efficient as herbicides. Because their seeds can survive for several years in the soil, weeds must be managed at the rotation scale to limit damage to the current and following crops. In European farming landscapes, weeds are also essential for biodiversity, as they host and feed pollinators and crop auxiliaries.

Weed management must therefore undergo a major paradigm shift, from a single highly efficient cropping technique (i.e., herbicides) to a combination of multiple, partially efficient, and interacting techniques. This shift requires a change of perspective from cure to prevention, from chemical suppression to biological and mechanical regulation, from single-minded control to reconciling damage and benefits resulting from weeds. To make these new weed-management strategies efficient and acceptable to farmers, they must be adapted to the pedoclimatic conditions, production contexts and socio-economic specificities of their farms.

The objective of this paper was to demonstrate how a mechanistic process-based model was developed and used to co-design crop ideotypes and cropping systems for weed management, thus to bridge the gap between research on biophysical processes and agroecological weed management in real-life farms.

Methods

The methodology comprises three steps:

1. **experiments** in controlled conditions, experimental stations and farmers' fields to understand **biophysical processes** that drive weed dynamics and impacts in agroecosystems, in relation to cropping techniques,
2. synthesize this knowledge into simulation **models** and **decision-support systems** to produce emergent knowledge on agroecological levers,

3. **design cropping systems and crop ideotypes** adapted to different goals and local contexts.

This paper summarizes how steps 2 and 3 were conducted with **farmers and crop advisors** to ensure the operational nature and adoption of weed management strategies. To illustrate step 3, the tools of step 2 were used to evaluate and design crop ideotypes and cropping systems for agroecological weed management. Three types of stakeholder implication were illustrated: (1) define the objective of the simulation study, (2) provide existing farm practices for simulations via surveys and agricultural databases (DEPHY), (3) propose prototypes for simulations. In addition, Cavan et al. (2025, in this conference) describe (4) iterative cropping-system design in workshops with farmers. To analyse simulation outputs, various statistical methodologies and algorithms were used, among which Latin Hypercube Sampling (LHS) to determine simulation plans, machine learning (classification and regression trees, random forests) to build decision trees, meta-models and optimisation algorithms to identify solutions reconciling contrasting objectives and constraints.

Results

The FlorSys model to synthesize knowledge in a virtual experimental field

The FlorSys simulation model started twenty years ago as a research tool (Colbach et al., 2021). Its inputs list all cultural operations in detail over several years, together with daily weather data (past or future), soil characteristics and a regional weed species pool. The 3D individual-based multispecies model simulates biophysical processes that are essential for non-chemical crop management and biological weed regulation. It is parameterized to date for 34 weed species and 33 crop species (including different varieties for wheat, pea and faba bean).

To tailor FlorSys to stakeholders' requirements and to simplify the multi-criteria comparison of cropping systems, the detailed model outputs were aggregated into **indicators** of crop production and weed impacts on crop production and biodiversity, together with advisors and farmers. Moreover, FlorSys has evolved over time to account for **stakeholders' questions** and the **changing context**, adding (1) processes such as plant--plant competition for water (to include tropical conditions and climate change), weed seed predation and vegetative reproduction of perennial weeds (which increase in conservation agriculture), (2) species and varieties to evaluate crop diversification, (3) innovative management techniques (e.g., topping, agroecological infrastructures).

Use FlorSys to co-design decision support systems

FlorSys was used as a virtual farm-field network, simulating thousands of cropping systems with different soils and weather records. The simulation outputs were used to (1) check whether the decision-support systems OdERA was fit for climate change and (2) add a function for estimating weed soil seed banks from field history and observed weed flora.

FlorSys's importance for making process-scale knowledge available to different stakeholders was best illustrated with the development of DeciFlorSys. This faster and easier-to-use metamodel was built from FlorSys simulations using machine learning techniques. DeciFlorSys was co-designed with farmers and crop advisors via surveys and participatory workshops testing successive versions to identify (1) key functions, applications and input/output formats, and (2) how to shift stakeholders' weed perception from eradication (focusing on weed abundance) to agroecological management (based on weed impacts).

Co-design cropping systems and crop ideotypes

Table 1 shows how numerical methods were used to explore virtual crop varieties and cropping systems in answer to stakeholder objectives (case studies A and B). The resulting ideotypes and ideal systems were often very different from existing varieties and cropping systems. Evaluating existing practices in study C identified key techniques and rules for combining them but even the best 0-herbicide no-till systems still had a weed-related yield loss of 41%. Conversely, 0-herbicide systems with well-timed false-seed-bed operations and occasional mouldboard ploughing reduced yield loss to 4%. These results and rules were then used to accompany experts in study D and farmers in participatory workshops to design new cropping systems (Cavan et al., 2025).

Case study	Objective	Level of stakeholder implication	Methodology (simulations always over 30 years and 10 weather series)	Results (examples)
A	Weed-competitive ideotypes	Define objectives and constraints	LHS plans simulating existing and virtual varieties in thousands on cropping systems	Key pea parameters and rules for combining them to maximise potential yield and weed suppression depending on pea–wheat intercrop management
B	Yield and trophic resources for bees		Optimization algorithm to identify a Pareto front of optimal rotations from iterative simulations	Maximum yield and lowest bee food in wheat monocultures; medium yields and medium biodiversity in diverse rotations with legumes
C	Weed suppression, low herbicide use, and low tillage	Recorded farming practices via surveys	Simulate cropping systems with regional soils, weather records and weed species pools	Best systems have diverse rotation, permanent cover, roll & shred during fallow, weed mechanically, mow weeds above crops and no irrigation
D	Weed suppression and low herbicide use	Propose crop-diverse systems		+717% weed-caused yield loss in spring pea vs winter cereals, but –11% in average over 4-year rotation with pea and –19% herbicide TFI

Table 1. Four case studies using FlorSys to evaluate and design crop ideotypes and cropping systems for agroecological weed management

Discussion and Perspectives

The case studies demonstrated how the FlorSys model complements field experiments and local expertise via long-term evaluations with different climate scenarios, disentangling the effects of correlated practices and predicting the effects of interacting techniques as well as giving access to difficult-to-measure state variables on soil, crops and weeds needed to understand how the agroecosystem functions. The benefits, crop ideotypes and optimal agroecological cropping systems depended on the production contexts and the scale (field vs farm vs landscape, year vs rotation) at which objectives should be reconciled. Flexible rules are thus required to account for local specificities as well as models to establish these rules.

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Simulating farm-level yield for sorghum cultivars in a low-input west African semi-arid systems under climate change

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Keywords: climate change adaptation, sorghum cultivars, low-input cropping systems, food security

Introduction

Climate change intensifies challenges for smallholder sorghum production in West Africa's semi-arid regions, where erratic rainfall and rising temperatures threaten food security. Agriculture employs about 65% of the population in this region, yet climate variability has severely impacted the sector and biodiversity (Nantongo et al., 2023). West Africa's dependence on rain-fed agriculture makes it particularly vulnerable to climate change (Akinseye et al. 2020), as limited economic and institutional capacity hampers adaptation efforts (Zagre et al. 2024). High climate variability and rapid population growth exacerbate food insecurity in this region, which is one of the poorest globally (Roudier et al., 2011; Defrance et al., 2020).

The West African monsoon, which occurs between May and September, brings annual rainfall ranging from 200 to over 1,200 mm (Defrance et al., 2020). However, global warming-induced changes in temperature and precipitation patterns pose significant threats to food production. Projections indicate that by 2050 the region's population could triple, intensifying pressure on rain-fed agriculture. However, the study found that historical climate change has led to a grain yield decline of 5–15% for sorghum in West Africa, resulting in financial losses between \$0.73 and \$2.17 billion annually (Sultan et al., 2019). Adaptation strategies are critical to counter these challenges. These include improving crop resilience to heat stress through better cultivars, increasing fertilizer use, and adopting climate-smart agricultural practices (Defrance et al., 2020; Maccarthy et al., 2021). Without such measures, the region faces worsening food insecurity due to declining agricultural productivity amidst growing demand. As a result, the study seeks to identify effective farm-level adaptation strategies, specifically focusing on optimizing planting date and targeted fertilization. The objective is to determine context-specific contrasting sorghum cultivars under future climate scenarios (SSP5-8.5) within the prevalent low-input farming system of West Africa.

Methods

This study employed the APSIM model to simulate sorghum yield for three contrasting cultivars (Nganda(late-maturing), Faourou(Medium), Payenne(Early)) under typical low-input management in representative farming system in West African countries, Mali (Bamako, Bougouni, Cinzana), Nigeria (Kano, Bauchi, Niger), and Senegal (Bambey, Niore, Velingara). Model calibration, performed using on-station experimental trial data from ISRA research station in Sinthiou maleme and Bambey, Senegal, utilizing data from the cropping seasons of 2016, 2017, 2018 and 2023, derived from experiments that included different planting dates and nitrogen fertilizer application rates, revealed yield sensitivity to radiation use efficiency (RUE) and phyllochron (PHYL), with a 10% RUE increase boosting Faourou yields by 18.8%, while a 10% PHYL rise led to complete yield failure in Nganda, highlighting cultivar-specific physiological responses. Long-term simulations under the SSP5-8.5 climate scenario were

conducted over a (2040-2069) period using a continuous simulating approach incorporating site-specific soil data using ISRIC soil data and climate projections. We investigated the impact of a range of planting windows PW1(early, Jun15-29), PW2(Jun 30-Jul 14), PW3(Jul15-29) and PW4(late Jul30 -Aug 14), and different fertilization rates (23, 60, 120kg NPK) as climate-smart management practices.

Results and Discussion

Planting date optimization emerged as a tactical adaptation strategy to minimize the risk, with early sowing (PW1) enhancing yields through better alignment with rainfall patterns, while delayed planting (PW4) exacerbated terminal drought impacts. Site-specific water use efficiency ranged from 8.98 kg/mm in Nioro to 4.54 kg/mm in Sinthiou Malem, reflecting stark agroecological contrasts that demand localized adaptation. Climate projections under SSP5-8.5 reveal divergent rainfall trends of 15-20% in Senegal's peanut basin, coupled with universal temperature rises of 2.5-4.2°C by mid-century. These changes could shorten grain-filling periods by 8-12 days, with HadGEM3-GC31-LL and UKESM1-LL models projecting the most severe warming in Mali and Senegal. Simulated yields declined 10-25% across sites, with Nigeria experiencing the greatest losses due to compounded heat and moisture stress. Nitrogen use efficiency fell 18-32% in low-input systems, while soil organic carbon decreased 0.4-1.2% annually, threatening long-term fertility. Although fertilization mitigated yield losses by 12-15% in some areas, its effectiveness varied with soil type and rainfall reliability.

Perspectives

Our findings highlight three key adaptation pathways to enhance sorghum resilience under changing climatic conditions. These include breeding programs that prioritize RUE optimization and thermal tolerance in late-maturing cultivars like Nganda, dynamic planting calendars informed by localized seasonal forecasts, and integrated soil management combining organic amendments with precision mineral fertilization. Successful implementation of these strategies requires strengthening extension services to disseminate climate-smart practices and improving access to drought-tolerant seeds. The target strategies could enhance cropping system resilience while maintaining sorghum's critical role in regional food security. The perspective of this study suggests a need for integrated climate-smart strategies that combine heat-tolerant breeding targets, soil fertility management, and localized seasonal advisories to ensure sorghum continues to play a vital role in food security amidst population growth and warming trends.

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Assessment of climate risks on the industrial crops of Northern France using ecoclimatic indicators

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Keywords: climate risks, ecophysiology, ecoclimatic indicators, industrial crops

Introduction

Industrial crops, such as garden pea, sugar beet, linen or chicory, are characteristic of Northern France agriculture. Those crops are grown to supply the local agrifood processing industry. They provide a substantial return to the farmers. Over the past five years, a combination of extreme droughts and excessive rainfall showed the vulnerability of these crops to climatic risks. To date, there are few tools to assess climate risks for industrial crops with little in the way of literature or models for these crops, which are a minority on the French scale. This lack of tools makes it challenging to raise awareness among farmers and to design adaptation pathways. Using expert knowledge and literature when available, we applied the EcoClimatic Indicators (ECI) based approach (Caubel J., 2015) to assess the climate suitability of various crops. This method accounts for local climate conditions, which makes it relevant for farmers. These indicators can easily be used in a co-design process involving stakeholders.

Methods

Climate data

We used a climate projection model which is commonly used in ECI approach, the global model CNRM-CM5 coupled with the regional model Aladin63 with the Adamont correction. The model has a spatial resolution of 8 x 8 km. The chosen greenhouse gas emission scenario is RCP 8.5. We defined three time periods. The historical period (HP) expands from 1976 to 2005. The near and far future (NF and FF) expands respectively from 2031 to 2060 and from 2056 to 2085. These climate data are available on the "Drias climat" website (<https://www.drias-climat.fr/>).

Defining the phenological periods

For spring crops, we employed a growing degree-day (GDD) model. The parameters (stages threshold, minimum growth temperature) for each crop were determined from the literature.

Defining the ECI and other parameters

For each crop, relevant ECI were initially identified through literature and then reviewed by crop experts. The most recurrent ECI assesses the risks of stresses from frost, heat and water deficit. Water deficit was estimated using potential evapotranspiration (PET), maximum evapotranspiration (MET) and real evapotranspiration (RET). MET was calculated by multiplying the crop coefficient (Kc) to the PET. This Kc is specific for each crop and each phenological period and was defined through literature and expert knowledge. The RET was calculated by multiplying a daily water stress coefficient (Ks) to the MET. Ks is calculated using the method proposed by Allen (1998) (equation 1) and assuming that the Readily Available Water (RAW) is equal to two thirds of the Total Available Water (TAW). The TAW of the various environments studied were defined by experts using soil depth and texture.

Equation 1: If Available Water > (TAW - RAW), $K_s = 1$

If Available Water < (TAW - RAW), $K_s = \text{Available Water} / (\text{TAW} - \text{RAW})$

Results

The ECI were calculated with different TAW values and different sowing dates. We present the results for garden pea with two sowing dates in a low TAW soil near the city of Amiens which has an oceanic climate (Cfb on Köppen climate classification). The annual average temperature is 11°C and the annual average precipitation is 785 mm (data from climate-data.org).

Water deficit stress

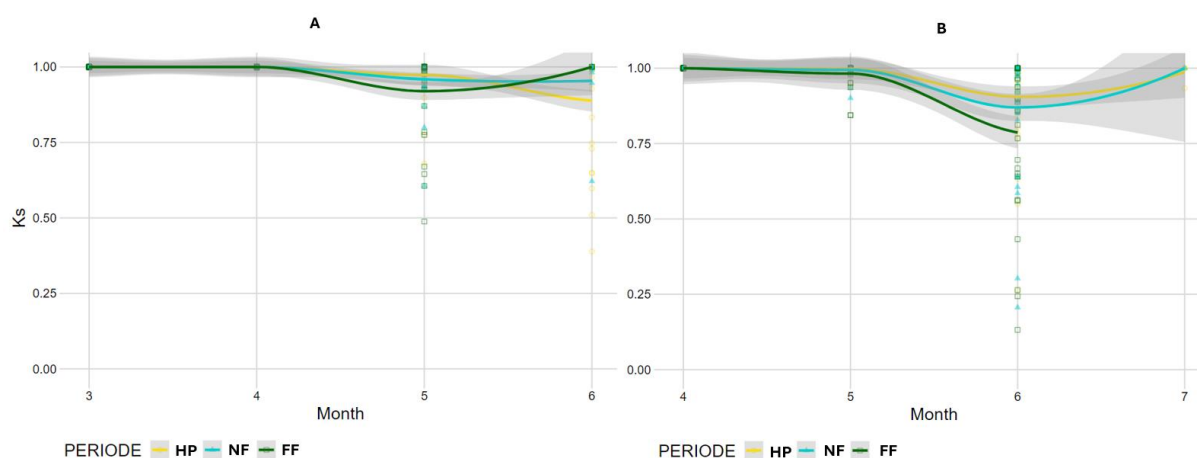


Figure 1 : Estimation of water stress coefficient (K_s) during the growth cycle of a garden pea sown the 5th of March (A) and the 15th of April (B) by period (HP: 1976-2005, NF: 2031-2060, FF: 2056-2085)

For the April 15th sowing date, water stress intensifies during the summer period in future scenarios, especially in the far future, compared to early sowing (March 5th).

Heat Stress

Indicator	Time Period	March 5 th sowing	April 15 th sowing
Frequency (number of years with heat stress over the time periods)	HP	21/30	22/30
	NF	21/30	25/30
	FF	22/30	27/30
Intensity (mean number of days per year with heat stress)	HP	2	4
	NF	3	5
	FF	4	6

Table 1: Heat stress indicators (number of days with daily maximum temperature exceeding 25°C) during the grain filling period of garden pea in Amiens (HP: 1976-2005, NF: 2031-2060, FF: 2056-2085)

Heat stress increases in frequency and intensity for the sowing date of April 15th. For early sowing on March 5th, only the intensity increases.

Discussion and Perspectives

This method does not provide an estimation of the impacts on yield, but it provides a first approach of the evolution of climate risk for a wide range of crops, especially for industrial crops in Northern France. These ECI can evaluate the effects of potential adaptations like adjusting sowing dates or varieties precocity levels. These ECI can be used to raise awareness about the future climate risks and the necessity to change accordingly the agrosystems. It has proven useful in a co-design initiative with local stakeholders to build resilient agrosystems.

The ECI approach is flexible enough to easily create new ECI as crops knowledge improves. The growing degree-day (GDD) model to calculate the phenological periods can be used only for crops mainly responding to heat. The approach needs to integrate other factors such as photoperiod or dormancy to encompass a wider range of crops. The use of a single climate model helped to not overwhelm the non-academic stakeholders with complex data. But state of the art of climate projections recommends a multi-model approach (Duan et al, 2018) and so further consideration of how to use multi-models and/or multiple projections while retaining simplicity are required to achieve both scientific rigor and understandability to non-academic stakeholders.

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Greenhouse gas mitigation: impacts of low-emission manure management practices in the Münsterland, Germany

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Keywords: bio-economic modelling, manure management, greenhouse gas mitigation, nutrient surplus

Introduction

Livestock production is a major contributor to global greenhouse gas and ammonia emissions (Herrero et al., 2011). Several regions in Germany (e.g. Münsterland) have high livestock densities, causing nutrient surpluses, water pollution, and elevated gaseous emissions (Qu et al., 2023). Mitigating these emissions is crucial to keeping global warming below 2°C and establishing an environmentally friendly food system (Méité, Bayer, et al., 2024). Reducing emissions from manure management through introducing emission reduction measures is one approach for improving the environmental impact of livestock production (Méité et al., 2024).

Current research often evaluates individual measures in isolation, overlooking potential emission trade-offs across production stages or the combined effect of multiple practices (Fangueiro et al., 2015; Gioelli et al., 2022). Therefore, the environmental-economic effects of various reduction strategies across production stages and different farm types remain understudied.

The main objective of this research is to explore how different manure management practices interact and influence emissions and economic outcomes across various farm types using bio-economic modelling. The specific research questions are:

- What are the economic and environmental impacts of different emission reduction strategies introduced at farm-level across farm types?
- What are the differences of reduction strategies between farm types?
- What are the economic-environmental trade-offs of these technologies across different farm types?

Methods

We focused on the Münsterland region in North-West Germany. The region is a global player in livestock processing, particularly pigs, alongside cows. Relevant agricultural activities include arable farming, primarily cereals and maize. The livestock density is very high with >2.5 livestock units/ha (Thorsten et al., 2022). Bio-economic farm modelling (MODAM; Zander and Kächele, 1999) was used to investigate the economic-environmental impacts of a range of novel emission reduction technologies. The model was calibrated to reflect observed cropping and livestock patterns, ensuring an accurate baseline representation. We focused on farms with cattle and pigs, as they cause the highest emissions, excluding relevant livestock, e.g. poultry. We simulated different farm types to represent the farming systems in the Münsterland. In the baseline scenario, the manure management consisted of broadcast manure application, open tank storage, loose housing, and slatted floor barn types.

The alternative scenarios captured various low-emission manure management practices, e.g. trailing hose, manure storage with concrete cover, manure acidification, nitrogen-reduced feeding of animals, seaweed as feed additive, cow toilet, and chemical scrubber. The implemented economic indicators include farm-level and production-specific gross margins and labor requirements. Environmental indicators involved farm-level and production-specific emissions, and the farm-level N-balance.

This research utilized a combination of available public data, e.g. from the Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) database or farm structural data from the Integrated Administration and Control System (IACS), and a synthetic farm population (Pahmeyer et al., 2021).

Results

Results show that integrating manure management practices across farm types could significantly reduce greenhouse gas (GHG) and ammonia emissions by 15-30% in the Münsterland, compared to the baseline scenario. The highest reductions in emissions occurred in mixed farm types. Scenarios combining multiple technologies across various stages of manure management achieved the most substantial GHG reductions while also incurring high on-farm costs.

Discussion and Perspectives

Our results demonstrate an economic-environmental trade-off, as low-cost strategy combinations are less effective in achieving GHG and ammonia reduction targets. Higher emission reduction requires the implementation of more costly combinations of measures. Among the different farm types in the Münsterland region, mixed farms achieved the highest emission reduction, however, they are also responsible for the highest amount of emissions overall and had the highest on-farm costs.

The variability in results across farm types underscores the importance of tailored manure management strategies to optimize emission reductions and improve nutrient management across diverse livestock systems (cf. Varma et al., 2021).

Farmers have a central role in ensuring that the desired transformation of agriculture towards sustainability is successful, therefore their needs and capacities require special attention to ensure that policy measures are tailored and effective. A more fundamental transformation of farming systems beyond technology adoption, though certainly desired, is hampered by various socio-economic factors, including path-dependency due to past investments or low returns on investments in emission technologies (Méité et al. 2024).

Policymakers should prioritize funding mechanisms that take a holistic perspective on farms as well as the manure management chain and consider cross-effects between gaseous emissions. Preference should be given to practices that prevent the formation of emissions in the first place, e.g. through protein-reduced feeding, instead of a priority on end-of-pipe technologies such as chemical scrubbers.

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Towards climate robust farming systems with agronomic measures

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Keywords: farm redesign, participatory co-design, multi-objective optimization, ex-ante scenario analysis

Introduction

Climate change-induced weather extremes severely threaten farming systems globally (Lesk et al., 2016). The increasing frequency and intensity of droughts and wetness place farming systems under increasing pressure (Malhi et al., 2021). Such conditions negatively affect crop productivity, soil health, and biodiversity, threatening the sustainability of agroecosystems (Sharma & Gobi, 2016) and the livelihood of agricultural producers (Howden et al., 2007). In recent years, prolonged dry spells and excessive wetness have also severely affected agricultural production in the Netherlands (Bartholomeus et al., 2023). Farming systems must become more climate robust to withstand the increasing negative impact of these weather extremes (Li et al., 2019).

In this study, we focused on improving passive robustness (Urruty et al., 2016) by introducing agronomic measures (AMs) to an existing farming system and evaluating their effects on the productive, environmental, and socio-economic performance indicators. Under AMs, we refer to alternative (cover) crops, crop rotations, land-use, and farm management practices recommended for improving the climate robustness of farms (DAW, 2024).

In the Netherlands, several pilot projects study the effects of AMs on reducing the negative impact of weather extremes (DAW, 2024). However, the farm-level effects of AMs, such as impact on farm performance indicators and potential trade-offs, remain insufficiently researched (Schipper, et al., 2022)

To address this knowledge gap, we evaluated the impact of AMs on the farm-level performance indicators and analyzed the arising trade-offs between farm performance indicators (when implementing AMs) using a modeling approach. The De Marke experimental farm, representative of dairy farms in the East of the Netherlands, was chosen as a case study farm.

Methods

This research employs a mixed-methods approach, combining participatory co-design and integrated farming system modeling. The De Marke case study farm provided an extensive dataset of multi-year farm data, including crop rotations, crop yields, and livestock numbers as the basis for the farm modeling. Of the data, we created a digital version of the farm using the FarmDESIGN bio-economic farm model (Groot et al., 2012). Suitable AMs were identified from the scientific and grey literature, considering recommendations of the Delta Plan Agricultural Water Management (DAW) national program (DAW, 2024). The selected AMs were categorized into (cover) crops and farm management scenarios, parameterized according to FarmDESIGN's input requirements, and implemented into the digital case study farm.

Stakeholder engagement was facilitated through co-design methods with decision-makers of De Marke. They identified suitable AMs based on (future) farm objectives. The chosen AMs

were added to the baseline farm configuration in FarmDESIGN. Their impact on farm productivity, environmental performance, and economic viability was evaluated. Next, we used the FarmDESIGN-integrated Pareto-based multi-objective evolutionary algorithm (Groot et al., 2012) to explore alternative farm configurations based on selected AMs and farm objectives identified before. Preliminary results were presented and discussed with the stakeholders in a participatory session. Their feedback was used to refine farm objectives and repeat the optimization. Final results were analyzed for promising alternative farm configurations and trade-offs between farm performance indicators when introducing AMs to the baseline farm. The robustness of AMs was evaluated by observing changes in the Pareto frontiers and knee points under different climate conditions. AMs were considered robust when changes in the shape of the Pareto frontier and position of knee points were minor.

Results

In the preliminary findings, the Pareto frontiers indicate gradual trade-off relationships between the pair-wise objectives of Operating Profit vs. SOM Content, Operating Profit vs. Leisure Time, and SOM Content vs. Leisure Time (Figure 1). During a visual inspection, several knee points were identified, indicated by red arrows along the Pareto frontiers (Figure 1). These knee points indicate where the cost-benefit trade-offs flip, which can guide stakeholders in making strategic decisions when implementing AMs. Participatory sessions revealed that while stakeholders acknowledge the potential of AMs in improving the climate robustness of a farm, adoption is often hindered by economic constraints, knowledge gaps, and policy misalignment.

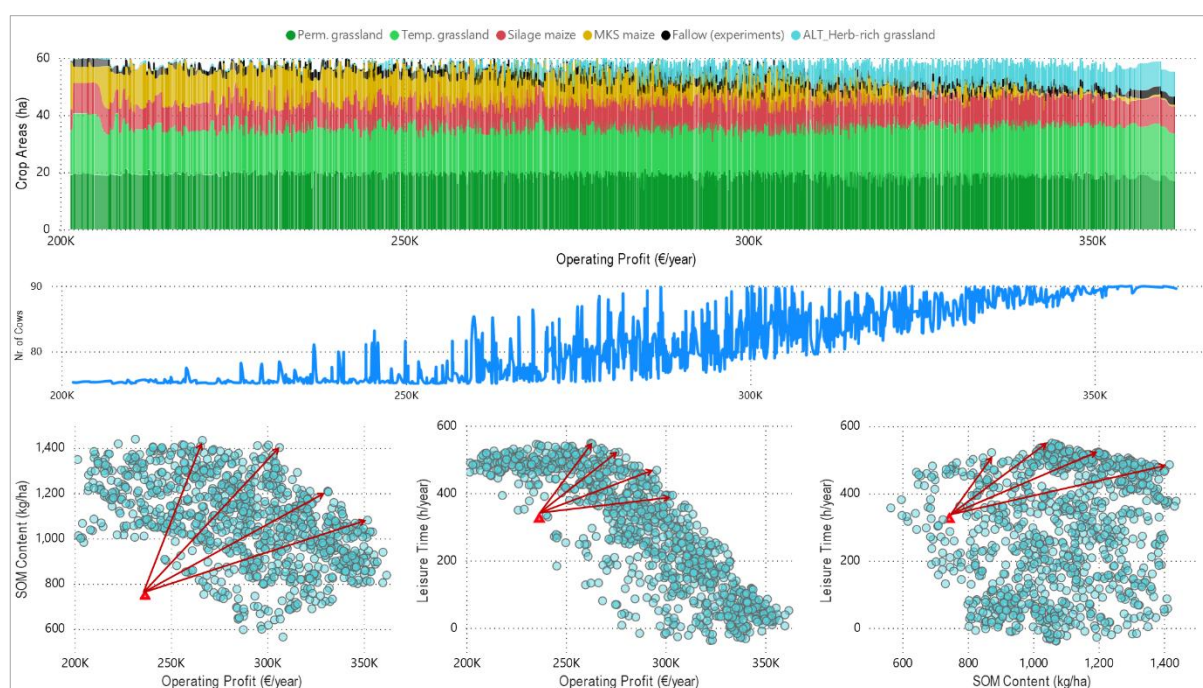


Figure 1. Preliminary results of an ex-ante scenario analysis, illustrating the changes in farm management after introducing AMs (MKS maize, ALT_Herb-rich grassland). Top chart: crop areas in the rotation (y-axis) vs. operating profit (x-axis); blue line = Number of Cows vs. Operating Profit; the solution spaces in the bottom show alternative farm configurations resulting from the multi-objective optimization; red triangle = baseline configuration; red arrows indicating knee points along the Pareto frontier.

Discussion and Perspectives

The study underscores the need for a holistic approach that bridges agronomic innovation, participatory co-design, and modeling insights to drive climate-robust agricultural transformation. The findings contribute to the broader discourse on climate-robust agriculture by offering alternative farming system designs. Future research should focus on fine-tuning transition pathways by integrating economic assessments and policy recommendations.

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Integrated agricultural system modelling for farm-level carbon, soil, and economic analysis

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Keywords: agricultural modelling, carbon footprint, soil health, farm economics

Introduction

Agriculture, while key for global food security, is a major contributor to climate change and environmental and ecosystem challenges. Achieving carbon-neutral farms by 2050, alongside ambitious biodiversity and soil health goals, necessitates a sustainable transformation. This transformation hinges on effective greenhouse gas (GHG) mitigation, enhanced carbon sequestration, and improved soil health while minimising ecosystem degradation. However, accurately measuring and monitoring the complex biogeochemical and ecological processes vital to this change across diverse land uses and management practices is often challenging.

Agricultural modelling offers a powerful solution to overcome these limitations and drive informed decision-making. The system/landscape models like HOLOS-IE, under development (Khalil et al., 2024), address the complexities of agricultural systems. By simulating interactions between diverse farm components, the HOLOS-IE enables assessments of sectoral GHG emissions, carbon footprint, soil health indices, and economic performance to provide farmers and policymakers with actionable insights. While the holistic nature of the model requires significant data input and computational resources, the resulting insights are invaluable for guiding sustainable agricultural practices and achieving our 2050 goals. Our objective is to develop an agricultural system model that facilitates a balanced approach to farm management, optimising for: climate mitigation and adaptation, a reduced environmental footprint, sustained productivity, and enhanced ecosystem health.

Methods

To address the limitations in agricultural system assessment, we have developed HOLOS-IE (www.ucd.ie/holos-ie), evolving into HOLOS-EU, now at version 4.0. This platform utilises extensive datasets, machine learning for data gap filling, GIS, and C#.NET programming. Our ongoing efforts refine model components (crops, grasses, livestock, agroforestry, and infrastructure) and their sub-components, driven by key soil and climate variables (automated or user input). This enables comprehensive assessments of sectoral GHGs, energy usage, soil organic carbon (SOC) density changes, soil health indices and economic outcomes. A core focus is capturing the intricate interactions between agricultural practices and eco-environmental system services. We enhance model accuracy using field trials and literature data, with iterative feedback guiding the integration process. This ensures the development of a robust tool that supports soil health (e.g. Feeney et al., 2024) and fosters sustainable farm management from the land parcel, including plot through farm to regional scales. The economic analysis utilises enterprise budgeting to break down farm operations into distinct categories. Both revenues and costs are determined to calculate key financial metrics such as gross margins and net profit.

The HOLOS-IE model operates using a combination of user-collected inputs and activity data, supplementing any missing information with predefined defaults. We used a 30-hectare farm, ranging from monoculture to mixed systems (arable, grasslands, dairy, and agroforestry with oak and hedgerows with sycamore trees), as a test case to run the model. These include:

- **W30:** Spring wheat only (full area: 30 ha);
- **WC30:** Spring wheat + cover crop (full area: 30 ha);
- **S30:** Grass (silage, full area: 30 ha) only;
- **G30D:** Grazed grass (30 ha) + dairy cow
- **W3G27D:** Wheat (3 ha) + grazed grass (27 ha) + dairy cow;
- **W3S3G24D:** Wheat (3 ha) + silage (3 ha) + grazed grass (24 ha) + dairy cow;
- **W3G24DA3:** Wheat (3 ha) + grazed grass (24 ha) + dairy cow + agroforestry (3 ha);
- **W3M24N/2DA3:** Wheat (3 ha) + mixed grass (rye + clover) with 50% N (organic/inorganic) fertiliser (24 ha) + dairy cow + agroforestry (3 ha); and
- **W3M24N/2D0.9A3:** Wheat (3 ha) + mixed grass with 50% N fertilizer (24 ha) + 10% fewer dairy cows + agroforestry (3 ha)

Results

The model effectively simulated sectoral outputs for GHGs, SOC, biomass carbon, and farm energy (Figure 1). In dairy farm simulations, enteric CH₄ was the dominant contributor (71-84%), increasing with agroforestry implementation. Direct N₂O emissions (2-41%) were highest from arable and grassland areas without dairy, while manure CH₄ (1-8%) decreased with agroforestry. Indirect N₂O contributed 6-18%, with lower emissions under agroforestry. SOC density showed a decreasing trend over time, varying with land use and management and the model enabled the assessment of Soil Health Indices using Observed and Typical SOC values. Dairy cattle initially increased the total carbon balance, but agroforestry significantly reduced it. Notably, reducing dairy cattle numbers had a greater impact on lowering the farm's carbon footprint than introducing agroforestry, offering substantial GHG offsetting potential and pathways to carbon neutrality. While agroforestry reduced the net carbon balance (Figure 2), it significantly increased overall farm profit. Land use and management options generally showed positive economic outcomes; importantly, mixed dairy farming exhibited a higher profit margin than either monocrop or specialised dairy farming.

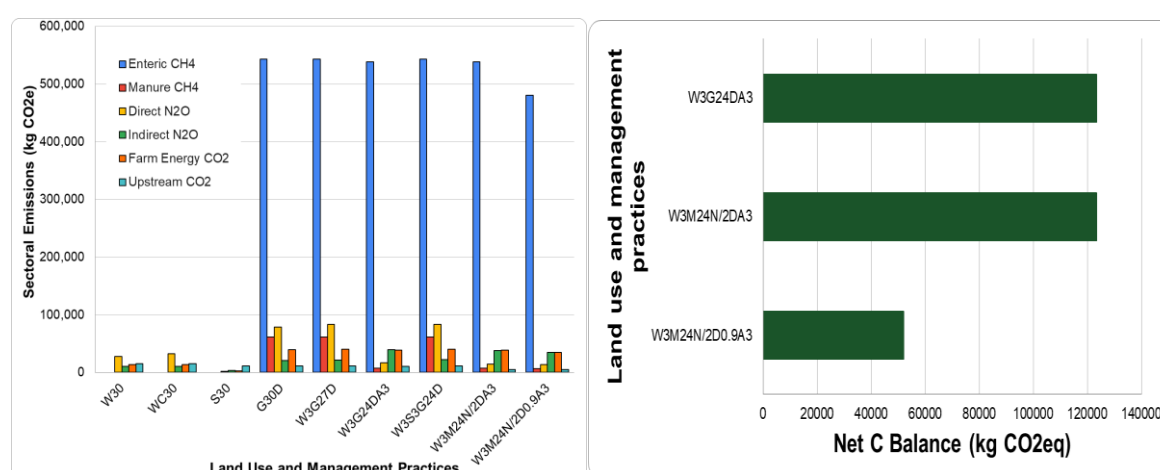


Figure 1 (left). HOLOS-IE simulated sectoral emissions of greenhouse gases across land use and management practices.

Figure 2 (right). HOLOS-IE simulated the net C balance of a dairy farm occupied by agroforestry and hedgerows.

Discussion and Perspectives

The HOLOS-IE model effectively simulated farm-level GHGs, SOC, biomass, and energy, revealing key insights into dairy farm emissions and mitigation strategies. Enteric CH₄ dominated, while agroforestry reduced manure and indirect N₂O, though it increased enteric CH₄. SOC density decreased over time, though unexpected from grassland with or without trees, requiring refinement of the algorithms. Importantly, reducing dairy cattle numbers proved more effective in lowering carbon footprint than agroforestry alone, despite agroforestry boosting farm profits. This highlights the need for balanced mitigation approaches. The model's capacity to assess Soil Health Indices adds value to understanding soil health. These findings underscore the model's potential for informing sustainable farm management and policy. Most models, despite their limited outputs for direct comparison with HOLOS-IE, nonetheless demonstrated that diverse dairy farm management (from mono to mixed systems, including agroforestry) effectively reduces carbon footprint and yields economic benefits (Díaz de Otálora et al. 2024; Varela et al. 2024). The study's limitations stem from relying on farm-level input and activity data for validation and calibration.

This paper presents HOLOS-IE as an essential precursor to HOLOSEU. While still evolving, the model lays the groundwork for comprehensive scenarios. Future development will incorporate sustainability indices, detailed production metrics, biodiversity assessments, and bioeconomy, including circularity considerations, refinement of model components and validation of outputs for enhanced accuracy and applicability. Stakeholder feedback will be integral to refining the model, ensuring its practical relevance. Subsequent validation and calibration efforts will focus on producing a robust and reliable HOLOSEU platform. This digital platform has the broader implication of empowering farmers, advisors, researchers, policymakers and other stakeholders with data-driven insights to achieve carbon neutrality, enhance agroecosystem services, and foster sustainable production across various scales.

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Establishing plant species compatibility rules based on plant-traits for complex agroforestry systems

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Keywords: agroforestry, plant compatibility, plant traits, farming system design

Introduction

Enhancing productivity and ecosystem services in multi-species agrifood systems relies on optimizing plant-species combinations. Complex Agroforestry Systems (CAS), characterized by high structural and species diversity (Schroth & da Mota, 2014), serve as a bridge between natural forests and agricultural land, providing ecosystem services more effectively than simpler agroforestry practices (Fahad et al., 2022; Kuyah et al., 2019).

A key challenge in designing CAS and other multi-species systems lies in assessing plant compatibility and establishing functional plant-communities. As part of his EngD research, Jordy van Eijk is developing a Plant-Community Configuration Tool (PCCT), designed to assist practitioners in selecting compatible species for co-cultivation in CAS design.

This study consolidates plant compatibility rules from literature to inform decision-making in agroecosystem design and plant-community configuration, contributing to the development of this tool. Moreover, this research supports the co-design of resilient agrifood systems, fostering more efficient and ecologically sound species selection in agroecosystem design. Through this approach, practitioners and researchers can develop multi-species systems that optimize land-use, enhance biodiversity, and strengthen agricultural resilience.

Methods

A Systematic Literature Review (SLR) was conducted to synthesize academic knowledge on abiotic and biotic factors influencing plant performance and interspecies interactions shaping these factors. The review aimed to identify the plant-traits responsible for these dynamics, forming the basis for developing plant-compatibility rules.

Scopus was selected as the primary database, yielding 136 unique publications. After applying inclusion/exclusion criteria, 32 were retained, with 22 added via snowball sampling—totalling 54 publications. Across the reviewed literature, interplant compatibility was assessed based on plant survival, growth, and productivity, which served as proxies for performance in the presence of neighbouring species. These outcomes were linked to trait combinations involving spatial (e.g., rooting depth) and temporal (e.g., flowering period) resource differentiation. Compatibility was evaluated qualitatively based on whether trait-combinations were associated with facilitative or competitive interactions across different studies.

Results

The SLR identified several abiotic and biotic factors influencing plant performance, including water and nutrient availability, mycorrhizal fungi, and pollinators. It also highlighted facilitative and inhibitive interspecies interactions impacting these factors—such as microclimate enhancement (Jacobs et al., 2022) and resource competition (Fitch et al., 2022)—along with the underlying spatial and temporal plant-trait combinations that drive them (Figure 1).

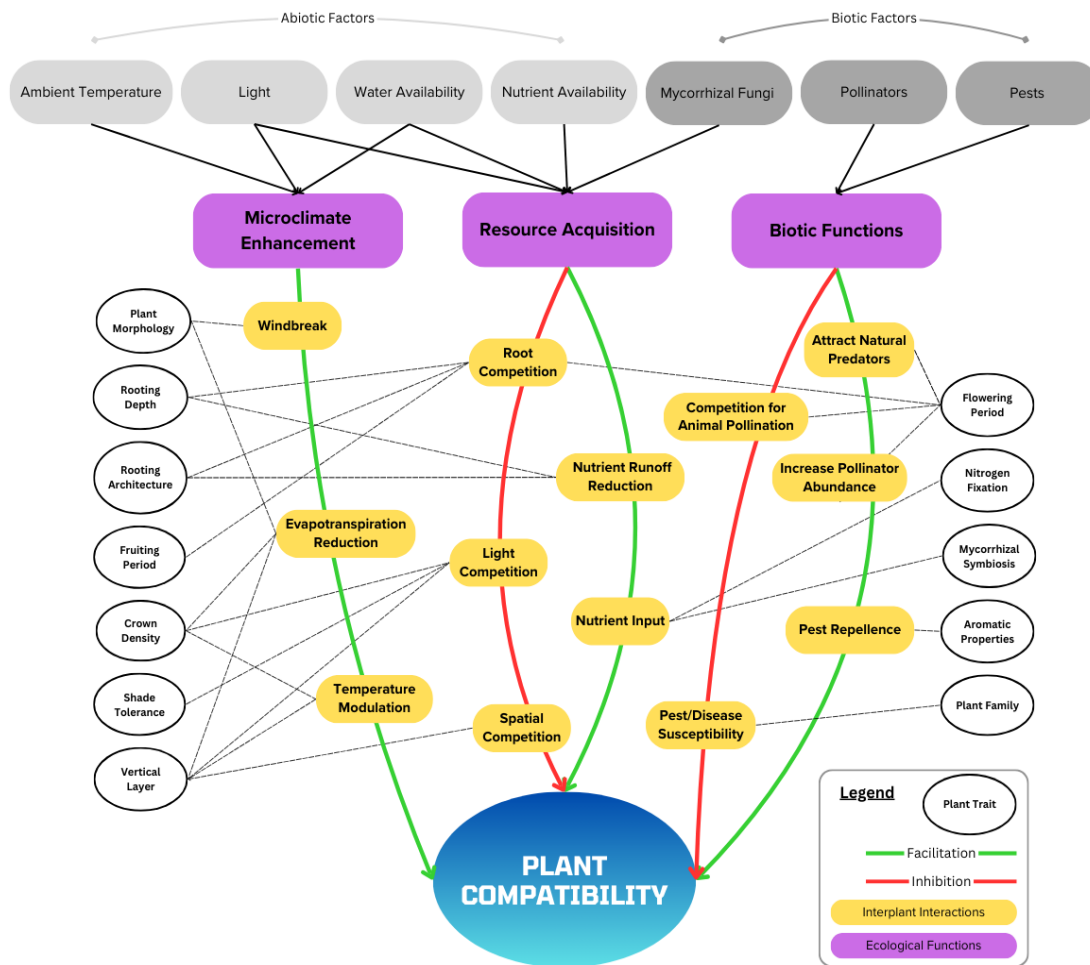


Figure 1. Connections between abiotic/biotic factors, ecological functions, interplant interactions and their underlying plant-traits; green lines indicate facilitation, red lines inhibition.

The synthesis of this information produced eight Plant-Compatibility Rules (Figure 2), providing a systematic and practical framework for evaluating compatibility in agrifood-system design.

Primary Rules					Secondary Rules				
Plant Trait	Plant A	Plant B	Compatibility	ID	Combination	Plant A Traits	Plant B Traits	Compatibility	ID
Rooting Depth	Shallow	Shallow	-1	PR1	1	Low Vertical Layer	High Vertical Layer	-1	SR1
	Shallow	Deep	1			Low Shade Tolerance	High Crown Density		
	Deep	Shallow	1		2	Low Vertical Layer	High Vertical Layer	1	
	Deep	Deep	-1			Low Shade Tolerance	Low Crown Density		
Rooting Architecture	Similar		-1	PR2	3	Same Rooting Depth		-1	SR2
	Different		1			Same Rooting Architecture			
Fruiting Period	Same		-1	PR3	4	Same Rooting Depth		1	
	Different		1			Different Rooting Architecture			
Flowering Period	Same		-1	PR4					
	Different		1						
Vertical Layer	Same		-1	PR5					
	Different		1						
Plant Family	Same		-1	PR6					
	Different		1						

Figure 2. Primary and Secondary compatibility rules based on single or multiple plant-trait combinations; 1 indicates compatibility, -1 indicates inhibition.

Discussion and Perspectives

The compatibility rules developed in this study stem from a systematic review of interplant interactions in multi-species agroecosystems, bridging academic research and application. They offer a preliminary framework for species pairing, reinforcing spatial and temporal niche differentiation as key indicators for coexistence (Hinsinger et al., 2011; Wang et al., 2023).

These rules provide a semi-quantitative structure for evaluating species compatibility, scoring trait combinations as facilitative (+1) or inhibitive (-1), forming the basis for species-pairing logic in the PCCT. However, their application is constrained by the availability of trait data and the plasticity of traits in response to environmental variability. Future work should expand trait databases and integrate context-dependent trait responses to improve robustness.

This study presents a systematic, academically grounded approach to evaluating plant compatibility through plant-traits, advancing the conceptual knowledge required to design successful multi-species systems (Ardanov et al., 2023). By providing research-based guidelines, it contributes to the development of Jordy van Eijk's PCCT which will enhance decision-making for CAS practitioners.

The compatibility rules serve as a core element of the tool's species-pairing logic. As the tool is developed and tested, ongoing collaboration with agroecosystem designers is expected to refine its effectiveness, while future research includes field-based monitoring to evaluate the performance of trait-based configurations in real-world contexts to guide model improvements.

Integrating spatial and temporal dynamics introduces a novel lens on plant-interactions and ecosystem dynamics, conceptualized as an agroecosystem's "space-time continuum". This approach opens new avenues for dynamic modelling that more effectively reflect the complexity of multi-species systems.

Incorporating Ecological Network Analysis (ENA) and Agent-Based Modelling (ABM) can further increase the adaptability and precision of compatibility assessments, supporting more dynamic, and context-sensitive decision-making in agrifood system design.

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Despecialization through diversification: trade-off needed to strike a balance between benefits and farm management

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Keywords: agriculture specialization, hyper-diversification, trade-off for designing

Introduction

The specialization and intensification of agriculture resulted in biodiversity loss, although this biodiversity provides several essential services in agroecosystems, including soil fertility maintenance and natural pest regulation. Diversifying cropping systems presents a promising solution to these challenges within the framework of agricultural agroecological transitions, yet it encounters significant resistance and systemic lock-ins (Duru et al. 2015; Meynard et al. 2018). The constraints that have driven specialization are both internal (such as economies of scale, practical skills and knowledge, and the simplicity of cultivation and operational planning) and external, including sales volumes and market dependence (Morel and Léger 2016; Dupré et al. 2017). Various studies have examined hyper-diversified systems to identify transferable levers for initiating despecialization on other farms. However, since hyper-diversified systems differ from specialized systems in attributes like farm size and marketing channels, the applicability and combinations of these levers must be critically assessed (Paut 2020; Bosshardt et al. 2022). An intermediate level between specialized and hyperdiversified systems could help initiate despecialization. We aim to understand how the level of diversification or despecialization, ranging from a few species to a very large number, can achieve an acceptable balance between diversification and its implications. This level of diversification has an impact on farmers' risk-taking, as well as the transformations in cropping systems and the socio-technical adaptations required.

Methods

Our studies combined modeling, surveys, and experimentation. From 2019 to 2024, we have conducted several experiments in the Mediterranean region (Southern France). As part of an experiment conducted at INRAE Avignon in collaboration with the organic farming research group, we set up an initial system in a tree-vegetable system that incorporated chickens. We also carried out surveys with farmers to assess their level of satisfaction and the risks associated with the tree-vegetable systems. We further explored the question of risk by modeling the vulnerability of diversified farms.

Results

The results of these studies showed that:

(i) Working time is a central limiting resource in diversification, especially for fruit production. Although the care given to the perennials during the first years is crucial for their long-term performance, the most profitable activities in the short term are often prioritized to the detriment of others. For example, in tree-vegetable systems, the working time is multiplied by 2 during the vegetable growing period.

(ii) Beyond a certain number of species, the benefits of diversification stabilize while the constraints on farm management keep increasing. This may lead farmers to come back to a

less diversified system after a first phase of over-diversification. Moreover, some benefits of diversification are hardly measurable or observable (regulations, soil fertility for example), thus increasing the feeling that diversification is a burden.

Discussion and Perspectives

These results illustrate how benefits from diversification do not follow a linear pattern and that defining the right level of diversity is crucial to manage the trade-off in resource allocation. The transferability of these results implies finding the right balance between the farmer's objectives and situation, the socio-technical implications and the optimal level of diversification that would be sustainable in the long term. Specialization through diversification will require the design and management of agricultural systems in which the level of diversification will bring diverse benefits, while keeping the workload and economic effort for farmers at an acceptable level (Garreau et al. 2024). Additionally, designing diversified agricultural systems requires co-design with stakeholders in the supply chain. As shown by Vialatte et al. (2025), more specialized systems are differently connected to both upstream and downstream of the supply chain. These systems show a strong path dependency regarding the high level of financial investment made, which will eventually impact the suitable levels of diversification.

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Using a serious game to engage agrifood system actors for unlocking the production of local neglected legume crops: a case study in South Eastern Senegal

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Keywords: serious game, co-design, legumes, Senegal, neglected crops

Introduction

Food insecurity in West Africa, particularly in the Sahel, is worsened by reliance on major crops like groundnut and millet. Underutilized indigenous legumes offer a solution for diversifying cropping systems, improving soil fertility, reducing water needs, enhancing nutrition, and promoting gender equity and economic stability. In South Eastern Senegal, diverse legume crops are cultivated, including Bambara groundnut (*Vigna subterranea*) and cowpea (*Vigna unguiculata*). Despite their benefits, these crops only represent small production volume and have no dedicated value chains. Such contradiction raises questions about possible lockers that bend down the development of such crops. It also emphasizes the need for an approach that combines multilevel and dynamic processes, engaging diverse stakeholders across scales—from the farm level to national or regional food systems. Fostering such a change requires to create the conditions for an endogenous process in which the different actors share their questions and knowledge to apprehend complex reality into a systemic thinking, to reflect and collaborate to create and achieve scenarios of change (D'Aquino et al. 2023).

This study investigates the application of a serious game, TerriStories®, to engage multi-stakeholder commitments for increasing the production of underutilized legume crops (Bambara groundnut and cowpea) in South Eastern Senegal.

Methods

The study adapted TerriStories®, a game framework developed from the earlier Self-Cormas model (D'Aquino et al, 2003). Five decision-making units were defined: farmers, market vendors, food processors, household cooks, and restaurant owners. These units interacted in two spaces: one on field management and household consumption, and another on market dynamics (Figure 1).

Game sessions were held in two villages, Saré Bilali (Kolda) and Ethiolo (Kédougou), each gathering about 50 participants including producers, representatives of agricultural services, NGOs, etc. Sessions began with participants evaluating local legume varieties, followed by shared diagnosis of cropping systems. The game then simulated change scenarios, assessing feasibility in real-world conditions.



Figure 1: photo of a game session: participants are representing the village space on the game board at the beginning of the sessions. Example of game board. Wooden chips represent soil type (below) and crop species (above). Participants exchange commodity against virtual money around the game boards.

Results

The game revealed that cowpea and Bambara groundnut are present in all farms but occupy small areas. Cowpea is grown in intercropping systems, while Bambara groundnut is cultivated as a sole crop. Cropping is labor-intensive, with minimal mechanization. Pesticide and herbicide use is rare in Kédougou but more frequent for cowpea in Kolda region.

Farmers produce legumes both for consumption and as seeds. Bambara groundnut is used exclusively for household consumption, while surplus cowpea is sold for income. Cooking habits reflect regional preferences: Bambara groundnut is key in Kedougou dishes like "Tô," while cowpea features in a broader range of dishes in Kolda. Cowpea is integrated into street food, whereas Bambara groundnut has no commercial presence.

Seed markets are unstructured. Farmers purchase cowpea grains from local food markets to be used as seeds, while Bambara groundnut seeds are maintained within families or exchanged through kinship networks. Cowpea trading is minimal, and Bambara groundnut virtually lacks commercial outlets. In Kolda, women-led units produce flour mixes including cowpea, but no Bambara groundnut processing exists in Senegal.

Decision-making units expressed varied varietal preferences. Red cowpea was favored by all units except processors, who preferred white or gray varieties for aesthetic reasons. For Bambara groundnut, processors preferred mixed grain colors, cooks preferred red and purple types, and producers prioritized red types followed by white.

Challenges included pest control, limited mechanization, and inadequate technical support. Farmers emphasized the need for guidance on comparing and exchanging varieties. Household cooks rather pointed out the availability and cost of other ingredients like spices needed to agree cowpea and Bambara groundnut, while retailers noted the difficulty to achieve minimal trading volume for profitability.

Identified levers for improving legume integration included improving mechanization, access to credit, and investing in cash crops to boost farm revenue and support legume production.

Discussion and Perspectives

The participatory TerriStories® approach effectively engaged stakeholders, fostering dialogue and promoting innovative solutions. Participants identified challenges, reconsidered practices, and proposed actionable strategies.

This case study, conducted using the TerriStories® game, explores a dimension that has received limited attention in serious gaming to date. While serious games have been applied in agriculture to reflect on cropping systems within farm boundaries (Speelman et al., 2014; Jeuffroy et al., 2025), this study extends beyond such scopes and the domain of territorial conflict, from which serious gaming and participatory approaches originally emerged (Aubert et al., 2017). Although the game facilitated the initial identification of potential solutions, only a limited number of integrated change scenarios could be developed. Additional game sessions would be necessary to expand the range of scenarios and assess their robustness across the territory. Furthermore, analysis of the sessions indicated that decision-making processes within rural households require greater attention and should be more explicitly addressed through modifications in the game's structure and rules.

Sustained engagement with the TerriStories® approach is crucial for building momentum and ensuring lasting change. Establishing strategic collaboration with local actors will support autonomous and durable improvements in legume production.

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Co-design of diversified cropping systems in Mediterranean Europe: stakeholder perspectives and adoption potential

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Keywords: indicator, performance, adoption, stakeholder

Introduction

In Mediterranean Europe, farming systems are highly specialized and predominantly based on cereal rotations. Policy and agricultural sector supported these systems, making them favored choices by farmers, and these processes have proved difficult to reverse. Specialized systems have increased production, but at the expense of other ecosystem services. Soil degradation, biodiversity loss, and extreme weather events jeopardizing food production are among the current concerns. Diversification of cropping systems across time (e.g. rotations) and space (e.g. intercropping) is explored as a means for achieving sustainable production (Hufnagel et al., 2020), requiring a coordinated vision, and actions on the part of different stakeholders. The objective of this study is to:

1. Co-design diversified systems and assess the performance of legume (ES~Leg~; GR~Leg~) and rapeseed (ES~R~; GR~R~) systems in comparison to reference systems of continuous cereals (ES~RS~; GR~RS~) in Spain and Greece, respectively. Vetch-barley intercropping was also considered in Greece (GR~IC~).
2. Explore regional stakeholders' perceptions of the assessed systems and the need to change the design.
3. Predict the rates of adoption of these diversified systems and discuss the implications for the regions.

Methods

A typology of common rotations in the Thessaloniki (Greece) and Ebro valley (Spain) regions was established based on national statistics and farmer surveys. During the 1st workshop with local stakeholders, i) the typology's results were discussed; ii) SWOT of current systems was conducted; and iii) options for diversifying cereal systems with rapeseed and pea were designed (Hossard et al., 2024). A set of agri-environmental, social, and economic indicators was selected in a participatory approach to assess the performance of diversified (DIV) and reference systems (RS). The indicators were computed using regional average data collected primarily from local experts. These experts used field experiments, modelling, and surveys to design crop management data. During the 2nd workshop, stakeholders were presented with the ex-ante assessment and asked to rate the importance of indicators and the performance of the assessed systems. We used this to create an Importance-Performance Matrix (IPM) that measures stakeholders' satisfaction towards DIV and RS. The IPM is the intersection of performance and importance medians, with the coordinates (median performance, median importance). In the 3rd workshop, we used the Adoption and Diffusion Outcome Prediction model to predict the likelihood of the co-designed systems being adopted in their regions. The

model is based on 22 variables, considering practice and population-specific factors, known to influence adoption outcomes, and they were answered by stakeholders.

Results

DIV often outperformed the RS but not for all indicators and not in both countries (Fig.1). Generally, DIV outperformed RS in terms of energy indicators. Compared with Spanish systems, Greek systems had the lowest pesticide use (lower TFI) and the lowest toxicity to non-target organisms (lower PLI). Agri-environmental performance was better for ES~Leg~, GR~Leg~ and GR~Ic~ compared to those with rapeseed. DIV had lower workload than RS in both countries due to the reduction in management practices. Economically, ES~Leg~ and GR~Ic~ were the only systems to have lower costs with higher profits. Despite the importance of economic indicators to Greek and Spanish stakeholders, they rated the economic performance as low. Thus, economic aspects are important for stakeholders, but diversification did not improve them. In contrast, agri-environmental indicators performed consistently better but were of low significance to stakeholders. Similarly, stakeholders generally placed little importance on social indicators despite rating them as highly performing. The adoption rate for diversified systems was low. Legume systems had a higher adoption rate (from 23% to 28%) in a shorter time (from 8 to 10 years) compared to rapeseed systems, which had a lower predicted adoption percentage (from 4 % to 5 %) and were expected to take longer (9 to 11 years) to reach those levels. Meanwhile, GR~Ic~ was positioned in the middle between legume and rapeseed systems, with 14% in 17 years. The low adoption of rapeseed may be due to high pesticide demand, lower and more variable yields resulting in lower economic returns. Rapeseed cultivation becomes less suitable in the Mediterranean region due to increasing climate change (Jaime et al., 2018).

	Indicator/case study system	Ebro valley-Spain		Thessaloniki-Greece		
		ES _{Leg}	ES _R	GR _R	GR _{Leg}	GR _{Ic}
Agro-environmental	Energy Use Efficiency (EUE)	42	5	11	11	0
	Non Renewable Energy (NRE)	-70	-52	11	-11	-12
	Renewable Energy (RE)	10	-8	-30	6	12
	Treatment Frequency Index (TFI)	-14	15	-20	-33	-33
	Pesticide Load Index (PLI)	151	15	-23	-34	-34
Social	Grain Quality (GQ)	8	9	22	-4	-18
	Work Load (WL)	-29	-29	-9	-9	-9
Economic	Grain Yield (GY)	-13	-12	5	-17	-25
	Costs (C)	-32	-20	8	2	-9
	Profits,subsidies excluded (P)	9	-1	-10	-12	17

Fig. 1: Heat map of the relative change of indicator values compared to the corresponding values in the reference system.

Discussion and perspective

Diversifying Mediterranean farming systems can result in divergent impacts. The ex-ante assessment showed that diversification improved social, followed by agri-environmental and economic impacts, with notable variations between Spain and Greece. High performance in social or environmental impacts may not be sufficient to lead to the adoption of diversification with legumes and rapeseed as long as it fails to generate profitable returns. Working with stakeholders to evaluate diversified systems and to determine whether these systems would

be adopted or not, allowed us to gain a deeper understanding of on-farm realities and their impact on crop diversification uptake. Since average regional data was used, this study is based on a set of impact indicators, which may not reflect all issues in the Mediterranean region or all variations in systems. Finally, our study serves as a foundation for co-designing practical and available options for farmers and informing policymakers in the Mediterranean region.

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Knowledge generation routes for diversification

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Keywords: minor and multipurpose crops, value chain creation, agronomic diagnosis, knowledge generation routes

Introduction

The diversification of agricultural systems has long been advocated as supporting sustainability (Duru et al., 2015; Reckling et al., 2023). In this paper, we address the diversification within agrifood systems as the (re)introduction of new crop species (often minor, flex crops) onto farms, combined with the associated transformations in value-chains and socio-technical arrangements. According to such framing, agronomists have largely detailed the socio-technical lock-ins that hinder diversification processes (Clapp, 2021; Meynard et al., 2018), and showed that trajectories of changes rely on specific knowledge depending both on the contexts and types of diversification initiatives (Leclère et al., 2024), and on innovation processes in various interconnected domains. Such diversification processes have also been studied in terms of valuation processes, and institutional logics alignment and bricolages (Aare et al., 2023; Osei-Amponsah et al., 2018). However, few case-studies or theoretical proposals directly allow agronomists to connect the prioritization of knowledge generation with the way these institutional dynamics unfold. While the aim is often to produce, in the same process, knowledge relating both to the cultivation of minor species and their uses, this remains uncommon in agronomists' approaches. Based on previous case-studies, we reflect around the notion of "knowledge generation routes for diversification". The term 'route' directly refers to the need for dynamic and adaptive ways of knowing, built throughout the multi-actor value-chain design process, and the contextualization that this requires. With this proposal, we intend to better connect the issues linked to new knowledge needs, new diagnostics combinations and new forms of collective experimentation, all anchored in the dynamics of innovation. We present hereafter these three aspects synthetically.

Results — Renewed "knowledge production routes for diversification"

New forms of knowledge called by diversification-oriented innovation processes

To support diversification at the cropping system level, the literature recommends making more knowledge and information available to farmers (e.g. on grain legumes, Zimmer et al., 2015), but also generating different, more systemic knowledge based on a variety of practices (Ditzler et al., 2021; Magrini et al., 2016). To fuel these systemic requirements, we support the idea that such knowledge should address dynamics and transformations of agroecosystems induced by new crops at multi-year scales (e.g. pre-crop effects after one or few years of cultivation; what risks for maintaining other crops' pathogens, namely for grain legumes and their maximum proportion in the sequence). New forms of knowledge should also better enable anchoring production with downstream activities: the impacts of various cultivation and harvest practices on product qualities for transformation are still relatively undermined (e.g. Aare et al. 2023); for instance, for grain legumes, cultivar choices, timing and techniques for harvesting, may largely impact the oil or protein content, as well as conservation ability, and interact with the processing. The new forms or combinations of knowledge may be identified and prioritized only throughout innovation process engaging the value networks actors, which directly calls for specific diagnoses of agronomic, environmental and socio-technical dimensions of situations.

Renewed diagnoses for contextualization of diversification knowledge

More often than not, technical knowledge on new crops is poorly contextualized, i.e. generic recommendations are not combined with variations depending on the characteristics of the situations. However, the insertion of a minor crop within cropping systems and local sociotechnical systems relies on specific knowledge according to their particularities, e.g. other crops in the sequence or the landscape, existing processing and commercialization actors, innovation cultures of incumbent actors, types of uses of the products and their requirements. Regional agronomic diagnosis (Doré et al., 1997) may help explaining the often wide variations in little known crops' yields (or quality, see for instance Belmin, 2016), and help identifying decisive stages of crop management (e.g. Lesur-Dumoulin et al., 2016). However, this well-proven methodological field needs to be complemented to allow shifting from the identification of mean effects and trends on few indicators at regional scales to the better understanding of the great variability at farm or even plot scales. Inspired by clinical agronomy approaches (e.g. Delof, 2024; Kockmann et al., 2019), diagnoses should make possible to rely on various expertise (including farmers') and numerous variables in particular situations, in order to cope with the wide variety of ways in which minor crops are cultivated and processed, to be able to explain unexpected failures (i.e. without yield data), while requiring little means. Also, diagnoses focused on qualities of products are still rare and could lead to further methodological developments (Belmin, 2016). These changes are also linked to two other types of diagnosis. One corresponds to the situated and dynamic assessment of relevant states of the agroecosystem for the functions that the new crop is expected to provide (e.g. initial weeds populations, soil physical and biological fertility). The other corresponds to the sociotechnical arrangements that exist or develop during the diversification process, which may require to prioritize the areas of knowledge on crops. This also questions the possibility for assessing new sociotechnical arrangements in itinere, and to keep experimental processes open ended (Leclere et al., 2024).

Renewed experimentation practices from the plot to the multi-actor project scales

The two preceding aspects directly invite agricultural scientists to reinvest experimentation concepts and methodologies in line with these needs for contextualization of knowledge, prioritization of what to know given limited means, and openness to emergent topics and actors' requirements. If debates in such directions have already emerged in relation with On-Farm Experiments (Toffolini and Jeuffroy, 2022), option by context approaches (Sinclair and Coe, 2019), and real-world experimentations (Schäpke et al., 2018), we suggest to push these works further regarding the adaptive progress of collective experimentations engaging multiple actors (Salembier et al., 2023; De Sainte Agathe et al., this conference). This calls for methods to consider qualitative experiences of various actors into the problematization and analysis of data collectively produced, but also for reflexivity and monitoring of learnings in itinere. Such development can, for instance, rely on theoretical framework that better combine various experimentation activities (e.g. collaborative workshop, innovation tracking) within an innovation process, including experimentation in the processing sector (Leclère et al., 2024).

Discussion and Perspectives

These three components of what we propose to call "knowledge generation routes for diversification" enable us to highlight specific ways of approaching diversification within agrifood systems. First, we insist on the need for considering diversification as an innovation process: initial situations are to be characterized according to the various actors' perspectives and regarding the common target of the innovation process, the emergence and multiple possible trajectories are intrinsic to this process, innovation targets and experimentation practices may evolve adaptively. Second, the space and time scales at which to apply certain knowledge production methods, namely diagnoses, should be considered as evolving

throughout the process (e.g. to integrate emerging new pests and their spatial dynamics, to repeat sociotechnical diagnoses along the building of new value-chain segments). Third, we invite to consider that relevant knowledge is often largely distributed among actors, and that coupling sectors usually innovating and problematizing situations or technologies separately is decisive.

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Ecological intensification of cereal-legume intercropping in sub-Saharan Africa. A systemic approach

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Keywords: intercropping, ecological intensification, N fertilizer

Introduction

Mixed crop-livestock farming systems under subhumid to semi-arid climates of Sub-Saharan Africa are predominant and the main economic activity for the rural population. Farmers managing these systems are massively food insecure and below the extreme poverty threshold (Dzanku, Jirström and Marstorp, 2015). The yield gap of cereals, key staple crops, remains high, mainly due to nutrient deficiencies in soils, particularly nitrogen, after decades of continuous cropping without adequate fertilization. Despite this, farmers have long adopted agroecological principles, such as integrated fertility management, promoting nutrient cycling between livestock and crops, plant and animal diversity for pest and disease regulation, agroforestry for nutrient recycling and microclimate mitigation, and the use of nitrogen-fixing legumes. However, these practices have not significantly closed the yield gap (Falconnier et al., 2023). In these systems, an 'Ecological intensification' pathway would boost productivity, reduce the yield gap, and maintain high levels of ecosystem services beyond provisioning (Bommarco, Kleijn and Potts, 2013; Tittonell and Giller, 2013). Here, we study a typical case from a Mozambique region where rainfed maize, groundnut, cowpea, and cassava are grown in intercropping systems with extremely low yields within a multi-layer agroforestry park. While participating in the national strategy to transition from subsistence to market-oriented farming, extension agents advise farmers to move from intercropping to input-intensive sole crops. Our study aims to co-design 'modern intercropping solutions' that align with an ecological intensification pathway, as opposed to the conventional intensification approach, which is likely to be unsustainable in the long term.

Methods

Our approach follows an iterative assessment and design loop. The design phase involves stakeholder engagement through mapping, surveys, and workshops to explore perceptions of intercropping and crop intensification and to co-design alternatives to conventional intensification. The assessment phase includes a literature review, and on farm trials and modeling methods to evaluate the agronomic and environmental performance of current cropping systems and both conventionally and ecologically intensified alternatives.

A systematic literature review was conducted focusing on studies with experimental data considering varying nutrient inputs on cereal-legume intercropping in smallholder farms across Africa. An experiment was conducted over two consecutive rainy seasons, comparing sole and intercropped maize and cowpea under different water and nitrogen stress levels that will enable to calibrate the STICS-Intercrop model against observed data. A network of plots in farmers' fields (32 plots from 8 farms) was established and is being monitored to assess the agro-environmental performance of current farming practices

Results

The design loop led to a workshop with key stakeholders, where participants agreed to recognize intercropping as a valid traditional practice and promote modern, profitable intercropping systems over sole cropping.

The literature search identified 404 papers, of which only 12 contained original experimental data comparing low vs. high nitrogen input (above 40kg/ha) for cereal-legume intercropping systems in SSA. The data indicate that intercropping's overall yield benefit compared to sole cropping was not significantly affected by nitrogen fertilization on the cereal (Figure 1). However, intercropped cereals had a lower relative yield under fertilized conditions (1.00) compared to non-fertilized ones (1.07) (Figure 1). We also observed that the intercropping benefit decreased as seasonal rainfall increased.

Figure 1. Schematic representation of the agroecological intensification effect on intercropping benefits.

Discussion and Perspectives

The data from the literature suggest cereal fertilization-induced yield increases are lower in intercropped systems than in sole crops. In such cases, the message from extension services supporting conventional intensification with sole crops may seem economically rational at the field, farm, and country levels, particularly in a country with limited agricultural policy resources, where poverty reduction may be preferred over environmental preservation.

The very few studies dealing with the intensification of intercropping in SSA indicate a surprising gap in the literature, with most studies looking at the benefits of intercropping only in low N input conditions. As a result, it remains unclear which environmental or management factors drive the impact of fertilization on the benefits of cereal-legume intercropping.

In the absence of a policy (e.g., payment for ecosystem services) to address the tradeoff between short-term economic and environmental sustainability, the agreement among stakeholders to support ecological intensification through 'modern intercropping options' may not lead to widespread adoption if these systems offer lower short-term benefits than conventional intensification options (Affholder et al., 2010).

We expect the data from our trials and the network of plots in farmers' fields will help calibrate and evaluate the accuracy of the STICS-Intercrop model for our study context, addressing the knowledge gap mentioned above. The model will then be used in virtual experiments across diverse soil types and selected 'modern intercropping' prototypes to assess their performance under current and predicted future climate scenarios. The results will inform a new round of discussions with stakeholders in the next iteration of our assessment and design loop, focusing on the role of intercropping in buffering interannual climate variations.

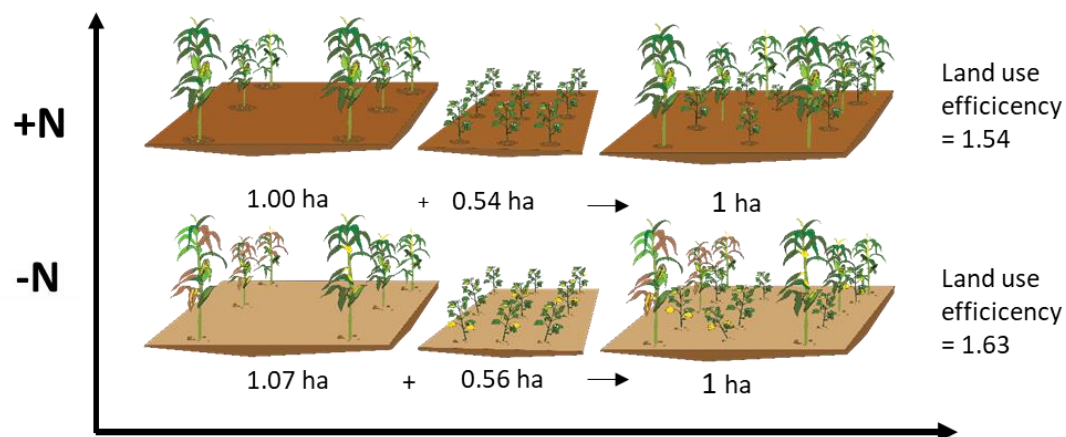


Figure 1. Schematic representation of the agroecological intensification effect on intercropping benefits.

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Expanding chickpea cultivation area towards northern Italy: effects on yield and yield stability

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Keywords: grain legumes, *Cicer arietinum*, crop modelling, diversification

Introduction

Yield stability of grain legumes in Northern Europe is as stable as that of the major crops (Reckling et al., 2018). Many minor pulses have the potential to be introduced into new environments, but the reduced breeding activity has caused a lock-in of the supply chain (Ayerdi Gotor and Marraccini, 2022). The challenge in scaling up pulses production includes ensuring yield stability through adapted cultivars and developing optimized production systems.

We evaluated the adaptability of five chickpea cultivars in two pedo-climatic areas of Italy: Tuscany (Central Italy), where chickpea is widely cropped, and Friuli Venezia Giulia (FVG, Northeast Italy), where it is not cultivated at all. Additionally, we used the MONICA crop model to simulate shifts in potential cultivation areas for chickpea under future climate change scenarios.

This is the first assessment of chickpea outside its common production areas in Central/Southern Italy. The screening aims to support sustainable agrifood systems by enhancing crop resilience, climate adaptability, diversification, and farmer livelihoods. Ongoing efforts are being made to implement crop models to forecast chickpea performance at cultivar level and under various scenarios. Future goals include integrating these findings into a decision support system to assist local farmers design productive, environmentally sustainable, and economically viable farming systems.

Methods

Trials were conducted in 2023 and 2024 in Udine (Northeast Italy) and Pisa (Central Italy). Both locations have a Mediterranean climate but differ in temperature and precipitation patterns, with Pisa being warmer and drier.

Tested cultivars of chickpea were Castor, Castellano, Lambada, Nero della Murgia and Sultano. Crops were tested following a randomized block design with four replicates. Sowing was conducted at the end of winter and harvest took place in mid-summer. The coefficient of variation of yield was calculated for each cultivar at each site based on the yearly average yields. Differences between cultivars were tested using a mixed-design analysis of variance implemented through linear mixed models. Fixed effects were cultivar, location and block. The random intercept was the year.

In parallel, the suitability for chickpea cultivation across Italy was assessed as the relative attainable yield to the maximum value predicted in the whole peninsula by the MONICA crop model, specifically calibrated with data from trials conducted in Italy and Germany and validated with data from Antichi et al. (2023). Simulations were conducted under low-input agricultural conditions. Sowing was scheduled between January and March, dynamically

triggered by climatic conditions. Two simulations were conducted, one representing historical conditions (1980-2020) and another projecting future scenarios (2060-2090).

Historical data came from the JRC Meteorological Database, while climate projections were based on five CMIP6 Global Circulation Models under the IPCC's SSP2-4.5 'middle of the road' scenario, which anticipates a 2.7°C temperature rise by 2100.

Results

Chickpea yields are represented in Figure 1. The growing season 2024 was more productive in both locations, as yields were consistently lower in 2023 than in 2024. This led to lower yield stability (higher coefficients of variation). No statistical difference was assessed between cultivars. The location factor was significant in all analyses ($p < 0.001$).

Modeled suitability for chickpea is represented in Figure 2. Based on historical conditions, the current chickpea cultivation areas align with the most suitable territories, predominantly located in the southern regions up to Tuscany along the western coast of the peninsula. Future projections suggest a shift towards northern areas, where abiotic stress, mostly drought, is expected to be less severe.

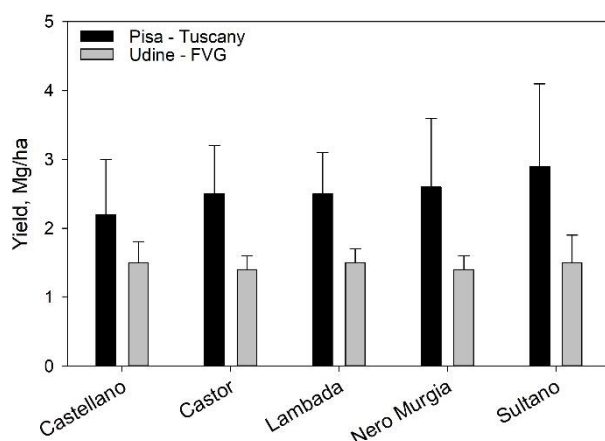


Figure 1. Mean values of yield with standard error for the tested cultivars of chickpea.

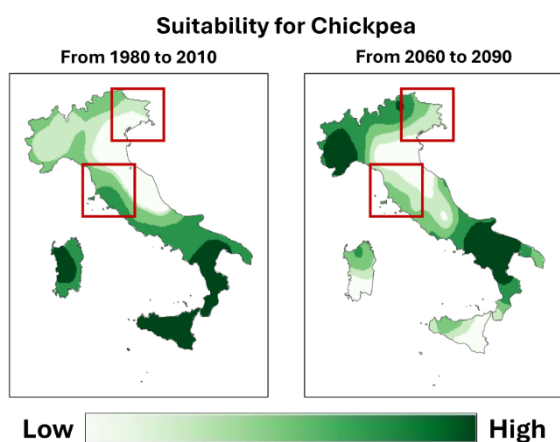


Figure 2. Modelled areas of climate suitability for chickpea cultivation in Italy. Framed areas indicate Friuli Venezia Giulia (NE) and Tuscany (Centre).

Discussion and Perspectives

No cultivar outperformed the others, as yield was primarily influenced by location. Chickpea yields in northeastern Italy were lower than in Tuscany, where it has been historically cultivated. Yield stability in Udine was higher than in Pisa, probably due to higher rainfall occurrence in late spring, preventing prolonged droughts.

Future projections suggest improved suitability for chickpea cultivation in the northern regions, supporting the ongoing efforts of cultivar-selection and collaboration with farmers to integrate chickpea into crop rotations. Although yields in northeastern Italy remain lower than those in southern regions, they are close to the national average (~1.7 Mg/ha in 2022). The combination of higher yield stability and chickpea's low input requirements makes it a promising candidate for inclusion in the crop rotations of FVG.

This study reinforces evidence that many crops, especially pulses, are underutilized in suitable regions despite their potential to thrive under prevailing and/or foreseen climatic conditions (Ayerdi Gotor and Marraccini, 2022). In this context, sustainable approaches to designing new legume-supported cropping systems should involve stakeholder engagement to better address the feasibility and specific needs of each system (Notz et al., 2023).

These findings are guiding a farm-support strategy for chickpea cultivation, fostering a collaboration between the universities and local farmers. Ongoing efforts aim to design more sustainable and diversified agroecosystems to promote resilient and profitable farming systems.

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A conceptual framework to investigate the conditions of success of a perennial grain crop: the case of intermediate wheatgrass

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Keywords: intermediate wheatgrass, perennial grain, diversification, multifunctionality

Introduction

The development of perennial grains has been a long-standing yet niche field of research, initially centred on breeding. However, recent advancements in intermediate wheatgrass material (Th. intermedium, hereafter IWG) have prompted an escalation in agronomic studies concerning crop management practices and the provision of ecosystem services. Targeting a "multipurpose crop" questions the balance between IWG vegetative growth, associated with most desired ecosystem services (e.g. soil structure, erosion control, N leaching reduction), and its reproductive growth associated with grain production. Thus, the release of early varieties to farmers gave rise to new questions regarding the alignment between farmers' objectives, the crop phenotype, the agroecosystems in which it is introduced, and the management practices that are applied (Ginot et al. 2024). In addition, the broader socio-technical system in which the crop is introduced combined with the specific crop features (e.g., grain size) generate barriers that hinder its development and adoption (Cureton et al. 2023). In this respect, the agronomic study of a new perennial crop seeks to identify the farming system configurations, at the interaction of social and ecological processes, that enable its integration and are compatible with the socio-technical and ecological contexts.

In this study, we propose a conceptual framework based on the literature of socio-technical and socio-ecological systems to identify the conditions for the success of a perennial grain crop. IWG success is conceptualized as the interaction between i) the usages that are expected, i.e., farmers' hierarchized and weighed objectives, ii) the crop stand dynamics and its ability to meet or resist to human intentions, and iii) the social and biophysical resources available for its cultivation. Applying this framework on IWG, we investigated IWG conditions of success through the study of farmers' objectives and the ecophysiology of crop stand.

Methods

In total, 16 semi-structured interviews with IWG growers in the Upper Midwest, USA, were used to investigate their intentions that are associated with the crop. Then, in order to study IWG vegetative and reproductive growth and their potential to meet farmers' objectives, an on-station field experiment was implemented in Clermont-Ferrand, France. The experiment investigated a gradient of planting density (from 10 to 200 plants/m²) in a randomized block design, thereby influencing resource availability and plant-plant interactions. In this study, we focused on one resource, light, as it is the first resource that drives photosynthesis and it is sensitive to the stand density. Tillering, vegetation cover and light interception were followed dynamically from planting in March 2023 to the first harvest in August 2024. Vegetative and reproductive biomasses, and yield components were measured at harvest.

Results

Interviews demonstrated that farmers targeted multiple ecosystem services and agronomic benefits with IWG, but also perceived the crop as a tool for fulfilling the non-commercial functions of agriculture beyond the farm boundaries. The "multipurpose crop" aimed at supporting "multifunctional agriculture" and farmers played the roles of food producers, environmental stewards and citizens. Most services and functions were expected simply by growing and processing the crop locally, rather than by applying specific practices, due to the plant morphological traits (e.g., rooting system, winter hardiness, soil cover). In addition, results indicate that the non-commercial dimensions of the crop were highly promoted and hoped for by farmers but that the crop success was firstly discussed through its commercial dimension, i.e., the grain production, due to socio-technical constraints.

On the other hand, biomass and grain productions were driven by the accumulation of radiations per plant rather than per unit area. Low densities (10 plants/m²) experienced delayed ground cover, resulting in reduced light accumulation per unit area compared to high densities (150 and 200 plants/m²), but in a greater light accumulation per plant. At harvest, biomass production remained stable with increasing density while grain yield slightly declined when measured at stand level. At the plant level, they both declined with increasing density in inverted exponential curves. Aboveground biomass and yields were not strongly correlated with the quantity of accumulated radiations per unit area, but were rather determined by the accumulated radiations at the plant level.

Discussion and perspectives

Despite the fact that this project is still ongoing and a second year of data is currently being collected, the proposed framework shows promising results to study the integration of a novel perennial crop into farming systems. It highlights how the conditions of success are defined, at the crossroad of usages, stand dynamics and resources, and reveals existing tensions between social and ecological dynamics. Results of interviews aligned with the expected services previously reported in IWG literature (Lanker et al. 2020; Ginot et al. 2024), but also the non-commercial functions of farming (Renting et al. 2009) and the different roles played by farmers (Primdahl et al. 2013). The field experiment revealed a trade-off between plant individual fitness and stand performances supporting the hypothesis that the optimal individual strategy and the optimal group strategy are contrasting due to the selfish behaviour of plants (Weiner et al. 2017). Thus, grain and biomass yields, as well as ecosystem services associated with vegetation cover, are assessed for a crop stand by farmers but determined at the plant level through resource acquisition and allocation. It is suggested that such a framework could be utilised and adapted for other minor and novel crops, perennial or annual, in a context of crop diversification.

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Small grains for small farms? Food and nutrition security from maize, sorghum, and millet cropping systems in southern Africa

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Keywords: climate change adaptation, crop diversification, nutrition security, smallholder farming

Introduction

Agriculture in sub-Saharan Africa faces unprecedented challenges, including climate change, land fragmentation, and the need to ensure food and nutrition security. Maize dominates regional cereal production, accounting for nearly half of the calories and protein consumed. Yet, its vulnerability to climate change, especially heat and drought stress, poses significant food security risks. Small grains like sorghum and millet, known for their drought tolerance and longer storage life, have been proposed as alternatives. Despite their potential, the adoption of small grains remains limited due to cultural preferences for maize, lower yields, labor-intensive practices, and limited market opportunities (Alimagham et al., 2024). This study evaluates the performance of sole cereal (maize, sorghum, millet) and cereal-legume intercropping systems in Malawi, focusing on grain and nutritional yields, and land requirements for household-level energy and protein self-sufficiency.

Methods

This study evaluated the food and nutrition security potential of 12 cereal-legume intercropping systems across 72 farms in Dedza and Mzimba, Malawi (2017-2020). Dedza receives 650-1300 mm annual rainfall (16-20°C), Mzimba 800-1200 mm (14-21°C). Farmers were selected based on willingness and peer recommendation. Trials used compost at sowing (0.5 kg/station), urea top-dressing (150 kg/ha), and ridge tillage. Land requirements for energy and protein self-sufficiency were estimated based on the household and farm size of each trial host farm, assuming a daily energy requirement of 2,700 kcal person⁻¹ day⁻¹ and protein requirement of 0.056 kg protein person⁻¹ day⁻¹. Yield variability was analyzed using linear mixed models.

Results

Productivity at crop and cropping systems level

Maize-based cropping systems had higher grain yield than sorghum and millet across districts and seasons, with sole maize yielding 3.4 t ha⁻¹ in Dedza and 2.5 t ha⁻¹ in Mzimba. Sole cereals generally outperformed intercrops in grain yield, except for millet-groundnut in Mzimba. However, cereal-legume intercrops had higher nutritional yields than sole cereals, with maize-groundnut intercrops having the highest average energy yield in both districts (Figures 1C and 1D). In Dedza, cereal-soybean intercrops had the highest mean protein yield, while sole cereals had the lowest (Figure 1E). In Mzimba, maize-legume intercrops had the highest protein yield, whereas sole millet, sole sorghum, and sorghum-bean intercrops had the lowest (Figure 1F).

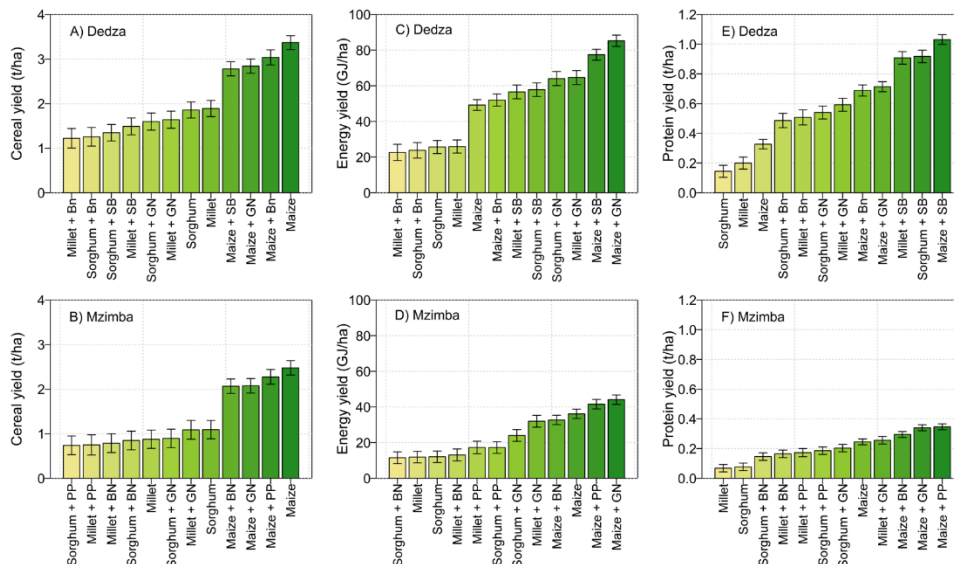


Figure 1. Mean cereal yield, energy yield, and protein yield across twelve cropping systems in Dedza and Mzimba districts, Malawi, over three consecutive growing seasons. GN = groundnut, SB = soybean, Bn = common bean, PP = pigeon pea, BN = Bambara nut.

Land requirements for food and nutrition security

Sole cereals required more land to meet household energy and protein needs than most cereal-legume intercrops (Figure 2). In Dedza, sole maize, sorghum, and millet met energy needs for 74%, 62%, and 55% of the farm-year combinations, sparing 0.76, 0.60, and 0.62 ha farm⁻¹ (Figure 2A). In Mzimba, only sole maize met energy and protein needs for 65% and 76%, sparing 0.61 and 0.67 ha farm⁻¹, while sorghum and millet required 1 to 3 ha more land. Legume integration into cereal systems reduced land requirements, sparing land for most farms (Figure 2). In Dedza, maize-legume intercrops met energy and protein needs for 87% and 96% of farm-year combinations, sparing 0.83 and 0.94 ha farm⁻¹. In Mzimba, they met 70% and 88%, sparing 0.61 and 0.71 ha farm⁻¹. Sorghum-legume and millet-legume intercrops performed worst, requiring 1.3-1.8 ha farm⁻¹ for energy security. Overall, maize-based cropping systems met energy and protein needs with current land ownership for most households, while sorghum and millet benefits varied.

Discussion and Perspectives

The study reveals that maize outperforms sorghum and millet in yield across districts and seasons, possibly owing to its higher yield potential, harvest index, and fertilizer responsiveness (Alimagham et al., 2024; Rurinda et al., 2014). Maize has benefited from substantial research and breeding programs, while small grains like sorghum and millet have made slower progress in crop improvement (Cairns & Prasanna, 2018). Sole cereal cropping yielded more grain than cereal-legume intercrops while intercropping offers nutritional advantages, combining energy-dense cereals with protein-rich legumes (Nyamayevu et al., 2025). Intercropping addresses diverse nutritional needs, making it a strategic choice in nutritional security despite its lower grain yield compared to sole cropping. Integrating legumes into maize-based cropping systems is also promising strategy for boosting productivity and sustainability on land-constrained smallholder farms. By optimizing land use, intercropping addresses nutritional needs while reducing land requirements, contributing to sustainable intensification without expanding cropland. Furthermore, the study suggests that maize based systems are more conservative to land resources for households to satisfy their nutritional needs than sorghum- or millet-based systems.

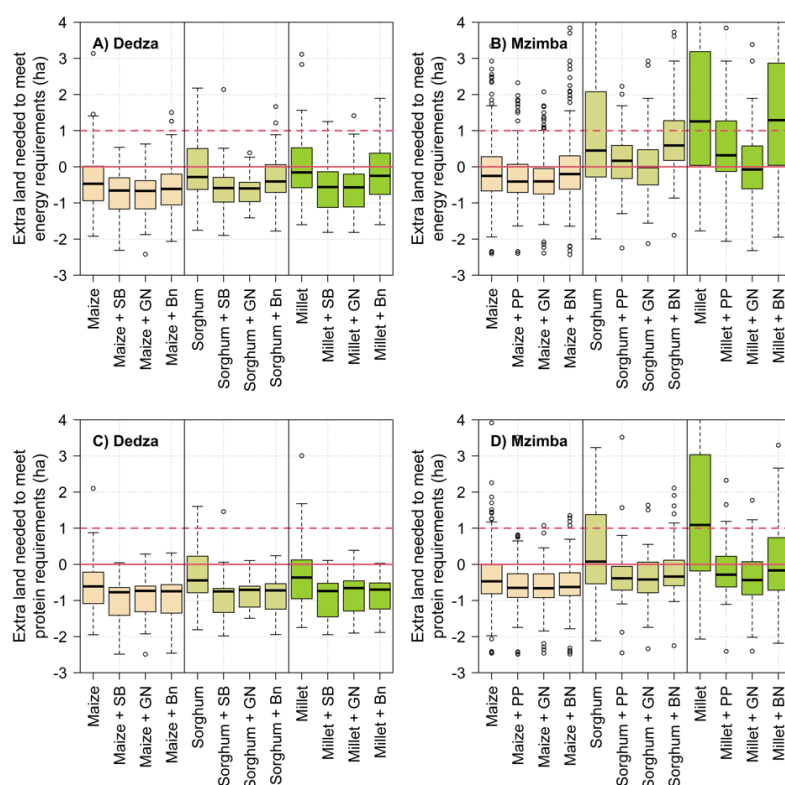


Figure 2. Additional area requirement to meet energy (A-B) and protein (C-D) self-sufficiency at household level over three consecutive cropping seasons in Dedza and Mzimba districts, Malawi. Calculations consider the household size and farm size reported by each household hosting the on-farm trials. The solid and dashed horizontal line display no and 1 ha of additional land required to meet energy and protein self-sufficiency at household level, respectively. Negative values indicate that area requirements for energy and protein self-sufficiency at household level are smaller than reported farm sizes, whereas the opposite is true for positive values. GN = groundnut, SB = soybean, Bn = common bean, PP = pigeon pea, BN = Bambara nut.

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Positive interactions between legume intensification technologies and agronomic management: evidence from participatory on-farm experiments.

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Keywords: soybean, common bean, Rhizobium inoculants, farmer evaluation

Introduction

Smallholder farming in Tanzania is largely maize-based, often intercropped with legumes like soybean and common bean. While legumes can improve soil fertility and productivity, adoption of yield-enhancing inputs like P fertilisers and rhizobial inoculants remains low. This study assessed their performance under diverse field conditions in Songwe, Tanzania, using a co-design approach that engaged farmers in design, testing and evaluation. By incorporating farmer feedback, we identified context-appropriate, scalable technologies to enhance productivity and sustainability in smallholder systems (Lacoste et al., 2022).

Methods

In the 2022/2023 season, 40 farmers in Tanzania's Songwe region hosted on-farm trials to assess the effects of phosphorus (P) fertilisation and Rhizobium inoculation on soybean (*Glycine max*) and common bean (*Phaseolus vulgaris*) yields. Farmers were purposively selected based on prior surveys capturing household characteristics (e.g., family size, gender, fertiliser use, and soil fertility) to reflect diversity in resources and practices.

Each site tested four treatments: a control (farmer's practice), P (20 kg P ha⁻¹ as TSP), inoculation, and P+I. Though unfamiliar with the technologies, farmers co-developed the trial layout and managed the fields using their own practices, including planting time, weeding, and pest control. After harvest, farmers evaluated the technologies using locally relevant criteria—cost, availability, labour needs, and profitability. This participatory approach helped assess both agronomic performance and practical feasibility.

Results

Technology performance varied with environmental and management factors. Control yields ranged widely, influenced by soil pH and nutrient levels (P, K, Zn), confirming the influence of local biophysical conditions. Delayed second weeding, significantly reduced soybean control yields by 75% ($P < 0.05$) (Fig. 1), aligning with Daramola (2020). However, P fertilization, inoculation, and P+I treatments buffered this effect (Fig. 1), showing a positive interaction between technologies and management. These treatments also led to significant yield increases—46% (soybean) with inoculation, ~50% (both crops) with P, and up to 66% (soybean) and 75% (common bean) with P+I (Fig. 2). These inputs improved system resilience and flexibility (Tittonell et al., 2007). Farmers prioritised yield, cost, and labour in technology ranking (Fig. 3). While P+I gave the highest yields, inoculation was favoured for its affordability and ease of use, despite access constraints.

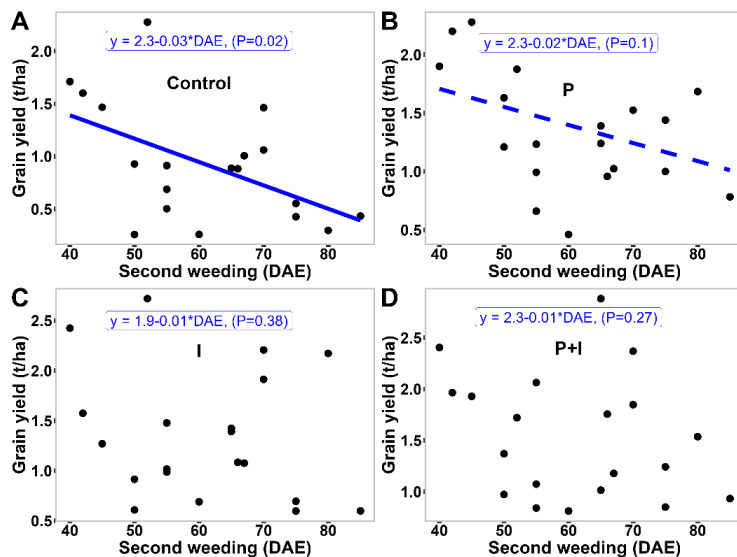
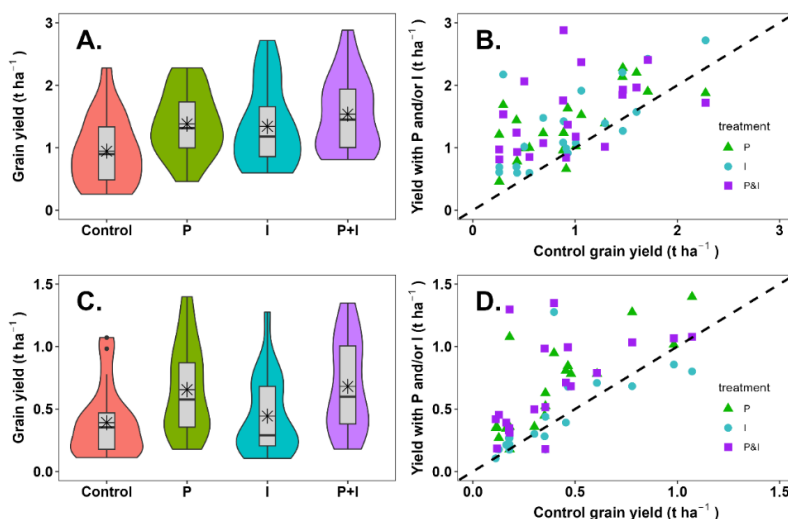


Figure 1. Relationships between soybean grain yield and weeding time (days after emergence, DAE) under four fertility treatments: (A) control (no inputs), (B) P fertiliser (20 kg ha⁻¹), (C) Rhizobium inoculation, and (D) P + inoculation. Solid lines = significant ($P < 0.05$), dotted lines = marginally significant ($P < 0.1$), no line = not significant ($P > 0.1$).



A,B = Soybean (*Glycine max* (L.) Merr.)
C,D = Common bean (*Phaseolus vulgaris* L.)

Figure 2 (left). Distribution and averages of grain yields across treatments for soybean (A) and common bean (C). Control grain yields (t ha⁻¹) and yield responses to treatment P, I and P+I for individual soybean (B) and common bean sites (D). P = 20 kg P ha⁻¹ applied as TSP fertiliser; I = Rhizobium inoculation; and Control = no fertility input treatment

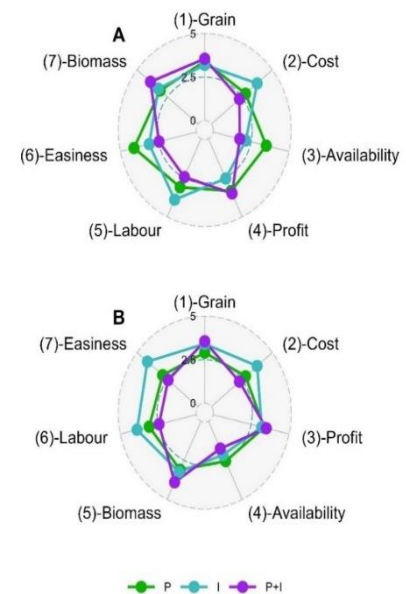


Figure 3 (right). Farmers' evaluation of soybean (A) and common bean (B) technologies—P fertiliser (20 kg ha⁻¹), Rhizobium inoculation, and P + inoculation—based on key criteria. For cost and labour (negatively oriented), scores are reversed so higher values indicate more favourable assessments. Numbers in brackets show ranking of each criterion by farmers in Ipunga (soybean) and Nambala (common bean).

Discussion and Perspectives

This study demonstrates the transformative potential of co-designed legume intensification technologies with smallholder farmers. Farmers prioritised compatibility with existing practices—preferring inoculants over P fertilisers due to lower cost and better fit with local broadcasting planting methods—highlighting that adoption depends on more than yield or profit alone (Nelson et al., 2019). On-farm experiments enabled farmers to evaluate technologies under real conditions, reinforcing the value of participatory, context-specific innovation (Ainembabazi & Mugisha, 2014). However, institutional barriers—limited input access, availability, and affordability—remain critical challenges (Mwangi & Kariuki, 2015). Addressing these through policy and farmer-led extension is essential for scaling (Akudugu et al., 2012). Our findings, in line with (Descheemaeker et al., 2019), demonstrate that co-designed interventions can balance agronomic potential with real-world feasibility, supporting more resilient and adaptable smallholder systems.

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Improving rice-fish farming systems: complexity, heterogeneity, and the promise of co-design solutions

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Keywords: small-scale farming, innovative practices, co-design method, aquaculture, rice

Introduction

In Guinea and Madagascar, rice cultivation plays a central role in the country's food security. 80% of farms in these countries produce rice, and Guineans and Malagasy consume 110 and 120 kg of rice per capita per year, respectively. Fish is also the main protein consumed in Guinea, at 24 kg per capita per year, whereas fish is a rare food in Madagascar. Indeed, on this island, the population can consume only 4 kg of fish per inhabitant per year, compared with a world average of 10 kg per inhabitant.

Rice-fish farming is an Asian model that can improve both rice and fish production and two notable initiatives seem to be spreading in Madagascar (Randriamihanta et al., 2022) and Guinea (Lethimonnier et al., 2022).

The complexity of this system creates challenges for testing and identifying innovations that could improve its efficiency (Khumairoh et al., 2024). One of the obstacles to optimizing the rice-fish system lies in understanding how it operate, which makes it difficult to optimize through conventional agricultural interventions (Fertin et al., 2025).

In light of this context, the study explores the internal mechanisms of these systems: their biological, technical or spatial complexity, and the inter- and intra-regional variability in agricultural performance. The results are discussed in terms of the usefulness of mobilizing farmer experimentation and co-design in the search for agroecological intensification of rice-fish farming systems.

Methods

The analysis of rice-fish farming cycles was conducted as part of the PisCoFam (Guinea, 39 crop repetition) and DINAAMICC (Madagascar, 53 crop repetition) projects (table 1).

	Cropping season	Area 1	Area 2	Area 3	Total N
		Low Water & market access	Intermediate water & market access	Hight water & market access	
Guinea		Kissidougou	Gueckédou	N'Zérékoré	
	1 (2022-2023)	9	6	3	19
	2 (2023-2024)	6	8	4	20
	Total N	15	14	7	39
Madagascar		Manandona	Andronomalelatra	Bétafo	
	1 (2023-2024)	11	13	5	29
	2 (2024-2025)	11	10	3	24
	Total N	22	23	8	53

Table 1: Number of rice-fish cropping cycles monitored per season and per country

We developed a methodology to monitor the agronomic performance of rice-fish systems and describe with a participatory method inspired by the Management Advice for Family Farms (Faure et al., 2004) and co-evaluation methods (Périnelle, 2021) developed for co-design were collected from 16 volunteer rice-fish farmers in Guinea and 42 in Madagascar between 2022 and 2025.

The cycles were tracked according to pedo-climatic differences, which mainly determines the possibility of having access to water all year round, and access to the market. To this end, each region studied in Madagascar and Guinea was divided into 3 distinct zones.

Results

The rice-fish system is multi-specific, open and therefore complex

Rice-fish farming in Guinea and Madagascar are complex systems (Fig. 1) that integrates different fish species, rice cultivation and sometimes market gardening on the same plot. Farmers optimize production by combining different fish species to utilize multiple trophic niches, selecting rice varieties adapted to varying water depths, and adjusting fish feeding and rice-fish fertilization (e.g., rice bran, manure, urea).

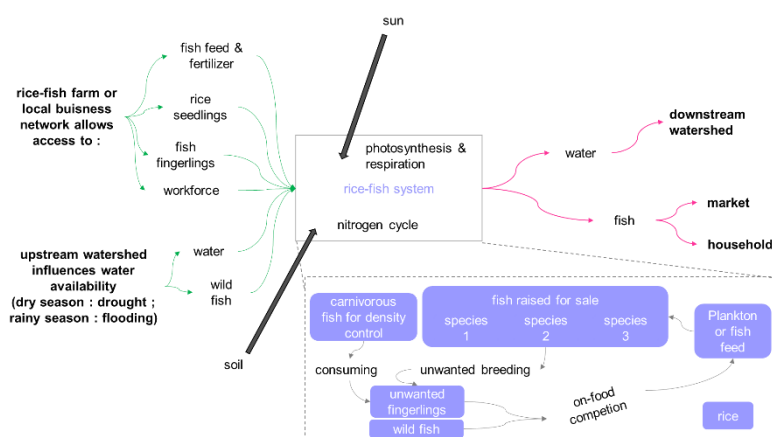


Figure 1. simplified mind-map of the complexity of small-scales rice-fish farming systems in Guinea & Madagascar

This complexity is further heightened by the open nature of these systems. In both countries, water renewal is frequent and often substantial, which introduces additional management challenges. Notably, the inflow of fish from upstream—often unintended—and the downstream loss of nutrients reduce the control farmers have over species composition and fertilization efficiency.

The heterogeneity of plots, even within the same region, makes finding solutions a challenge

Significant differences between farms, even within the same area or irrigation scheme, further complicate the identification of standardized solutions. In both Guinea and Madagascar, intra- and inter-regional variability in plot characteristics and management practices is substantial (Table 2). For example, average plot size in Guinea ranges from 16.9 to 25.8 ares, in contrast, plot sizes in Madagascar are considerably smaller, from 2.2 to 8.1 ares, and both show marked internal variation. Fish yields in Guinea range from 178.6 to 424.3 kg/ha/cycle with high intra-regional variability, while Madagascar exhibits more consistent but still diverse. Rice production highlights even starker contrasts: while Guinea averages around 1,756.1 kg/ha/cycle, yields in Madagascar average nearly triple that amount. Cycle durations and fertilization practices further illustrate these differences

	Guinea				Madagascar			
	Area 1 N=15	Area 2 N=14	Area 3 N=7		Area 1 N=22	Area 2 N=23	Area 3 N=8	
	LW & market access	IW & market access	HW & market access	Tot	LW & market access	IW & market access	HW & market access	Tot
Workers nb	5,1 $\sigma=1,9$	4,8 $\sigma=0,9$	2,8 $\sigma=1,0$	4,4 $\sigma=1,7$	3,7 $\sigma=2,0$	3,6 $\sigma=1,4$	3,6 $\sigma=0,7$	3,6 $\sigma=1,5$
Tot land area (are)	47,8 $\sigma=46,4$	68,9 $\sigma=66,9$	61,6 $\sigma=48,0$	59,1 $\sigma=56,1$	14,0 $\sigma=10,4$	11,6 $\sigma=8,5$	32,4 $\sigma=14,6$	19,3 $\sigma=14,8$
Plot nb	2,3 $\sigma=0,7$	5,5 $\sigma=3,1$	5,0 $\sigma=1,9$	4,2 $\sigma=2,6$	1,4 $\sigma=0,8$	2,2 $\sigma=8,5$	4,8 $\sigma=1,2$	2,8 $\sigma=1,8$
Cropp cycle duration days	155,9 $\sigma=73,1$	155,6 $\sigma=54,2$	194,6 $\sigma=84,1$	168,7 $\sigma=68,6$	117,1 $\sigma=12,5$	117,2 $\sigma=11,6$	115,8 $\sigma=8,2$	116,7 $\sigma=10,7$
Fish yield/cycle kg/ha	424,3 $\sigma=409,4$	178,6 $\sigma=109,6$	304,9 $\sigma=351,3$	305,6 $\sigma=324,3$	389,0 $\sigma=345,2$	371,6 $\sigma=204,4$	360,9 $\sigma=431,6$	373,0 $\sigma=312,4$
Rice yield/cycle kg/ha	1653,4 $\sigma=962,0$	1636,1 $\sigma=759,1$	1978,8 $\sigma=702,8$	1756,1 $\sigma=841,5$	4104,3 $\sigma=1831,3$	4706,2 $\sigma=1860,4$	6454,9 $\sigma=2382,5$	5088,5 $\sigma=2331,2$
Plot area are	23,5 $\sigma=18,9$	25,8 $\sigma=16,1$	16,9 $\sigma=11,1$	22,1 $\sigma=16,5$	8,1 $\sigma=7,2$	2,2 $\sigma=1,9$	3,0 $\sigma=4,3$	5,0 $\sigma=6,1$

Table 2: Main agronomic variables of guinea and Madagascar rice-fish farming system through 3 different area. Standard deviation = σ ; LW = Low Water; IW : Intermediate Water : HW : High Water.

Discussion and perspectives: The key role that co-design approaches can play in complex heterogeneous rice-fish systems

The complexity of rice-fish systems and the diversity in technical trajectories and outcomes reinforces the idea that there is no single model for integrated rice-fish farming. This raises the central question of how to support agro-ecological trajectories in these complex contexts: how can researchers support experiments typical of rice and fish farming systems (varietal tests or fish feeding tests) with this diversity of systems and plots? What tools, methods or forms of advice can help growers design or improve their own systems? We hypothesize that it would be appropriate to encourage and work to improve more flexible and participatory research and development initiatives, which already exist in West Africa or Madagascar (Grosse and Oswald, 2010; Mandresilahatra et al., 2021) where farmers are involved in co-design by being actively supported in inventing their own system (Périnelle, 2021).

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Scaling agronomic interventions: the value of support for smallholder farmers

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Keywords: effective agronomy, intervention longevity, risk mitigation, scaling

Introduction

An agronomic intervention in a low- or middle-income country (LMIC) is generally considered, by the international research-for-development community, to be 'successful' when it has been demonstrated to generate increased productivity and profitability relative to a farmer's baseline practice. Much agronomic research, and associated donor investment, is undertaken to demonstrate the potential benefits for farming communities of innovative agronomic interventions, however at the conclusion of research projects they often have insufficient momentum to remain viable.

Frequently, agronomic research does not adequately consider the diversity of farmers' motivations for farming or the factors influencing their decision making, both of which are important for sustainable uptake of emerging interventions (Bhujel and Joshi, 2024). Research into the sustained uptake and out scaling of agronomic interventions by smallholder farmers is more frequently conducted in sub-Saharan Africa than in South Asia; there is a need to understand the factors influencing smallholder farmers' interest in, and ability to, uptake efficient production practices to ensure food security across South Asia.

The objective of this paper is to examine spatial differences in the ongoing uptake of a package of agronomic interventions designed to improve cropping system productivity, profitability and climate resilience for smallholder farmers which was implemented in the Eastern Gangetic Plains (EGP) region of India, Bangladesh, and Nepal, a region with high concentration of rural poverty and current low agronomic productivity (Eriksen et al., 2011)

Methods

Through a five-year (2015-2019) research program conservation agriculture (CA) practices were tested through extensive participatory on-farm trials with over 400 farmers in eight districts spanning three countries across the EGP. Households in the project relied on agriculture as their primary source of income. Farmers learned new skills for mechanized crop establishment, weed, labour and input management, timing of the cropping system and cropping system diversification. Adapting to CA practices required using additional machinery which was provided by the project.

In six districts trials were implemented through a top-down, researcher-facilitated approach while in two trials were implemented in a bottom-up, community led approach which leveraged existing farmer community groups who self-organized access to machinery and other inputs. Subsequently, two different Indian state governments (covering four of the districts in which the project operated) have supported farmers' adoption of CA practices through different mechanisms: one continues to empower community led approaches and to support their extension. In the other state top-down support (through machinery subsidies and local knowledge awareness programs) have encouraged the ongoing out scaling of CA practices.

In the four districts in which the project operated in Nepal and Bangladesh farmers have not received ongoing support to continue CA practices since the conclusion of the project.

Results

Agronomic efficacy

The value of CA practices in the EGP has been demonstrated across a range of agronomy-based metrics, particularly in terms of improved productivity, profitability, water-, energy- and labour-use efficiency, and reduced greenhouse gas emissions (Gathala et al., 2020). Farmers reported to researchers that they recognised agronomic benefits from the interventions; this has also been observed from emerging literature (e.g. Brown et al., 2023).

Intervention longevity

Implementation of CA through a top-down approach in the four project districts in which farmers received little, if any ongoing support external to the research project, resulted in little longevity in the intervention after the conclusion of the project. Recent engagement with farmers indicated that communities often lacked sufficient community trust to ensure collective, timely and ongoing access to and maintenance of machinery (unpublished data). A lack of household-level agency means that uptake of CA practices in these districts is now limited.

In contrast, where CA was implemented through a bottom-up, community-led approach, or where it was incorporated into state government programs which supported farmers with ongoing access and awareness, the uptake of CA practices has not only increased within target districts it has extended into neighbouring areas; farmers continue to perceive value in the practices (Singh et al., 2023).

Discussion and Perspectives

Agronomic effectiveness alone is not sufficient, although it is a necessary condition, to ensure the widespread uptake of an intervention. For many smallholder farmers, the idea of a 'new, improved' farming practice, a key part of the value of which is that it contributes to relatively intangible concepts such as increased soil health and/or water use efficiency in the next 5-15 years, must be weighed against the known labor and inputs required to produce a crop in the next season and thus ensure the households' immediate economic and food security needs. This need to see tangible evidence of the benefits of new practices has been observed elsewhere (e.g. McCann et al., 2014).

Figure 1 illustrates the likelihood of uptake of an intervention in terms of its complexity and of the relative importance of farming to the households' food and income security. Where management of a complex, unfamiliar practice was devolved to individual farmers with little if any ongoing support, sustained uptake was low and out scaling minimal, even when the practice had been demonstrated to be effective in agronomic terms. Where the interventions were either managed collectively by farmer support groups, or where farmers received ongoing assistance and support (in this instance, from a state government), steady uptake and sustained out scaling continues to be observed.

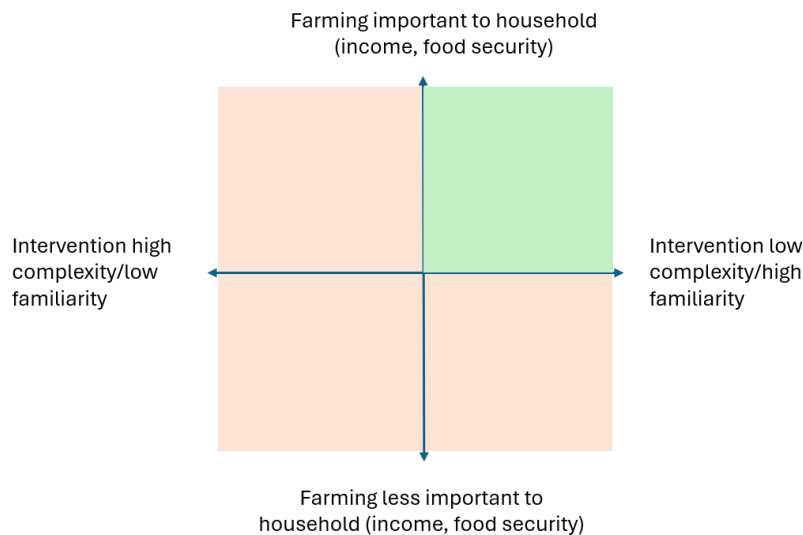


Figure 1: Likelihood of uptake of agronomic interventions from low (peach) to high (green)

Our research indicates greater emphasis on co-designing agrifood systems research in South Asia is required to increase the resilience and sustainability of smallholder production systems, and the effectiveness of investments by donors and governments and increase. Smallholder farmers must be supported to incorporate new management practices to ensure these are scaled effectively and rapidly, thus maximizing the value of research and the investments underpinning it. This approach has important learnings for researchers, donors and policymakers, particularly across South Asia where methods of effectively scaling interventions have not been sufficiently widely incorporated into domestic and international research agendas.

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Grazing cover crops: a strategy for enhancing forage autonomy and mitigating soil erosion?

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Keywords: crop diversification, participatory action research, soil fertility, on-farm experiment

Introduction

Integrating livestock grazing of cover crop (CC) into cropping systems offers a strategy to enhance forage autonomy and soil health. Research suggests that CC grazing can yield performance levels comparable to those of CC incorporated into the soil. Notably, this practice can enhance soil organic carbon (SOC) stocks, thereby improving soil structure and reducing erosion risk. While some studies report slight increases in soil bulk density, these effects generally do not harm soil properties or crop yields (Franzluebbers and Stuedemann, 2008; Blanco-Canqui et al., 2020). The impact of CC grazing on soil fertility varies depending on stocking rate, grazing duration, soil texture, and tillage practices. Moderate grazing can optimize both forage production and soil conservation (Planisich et al., 2021), while manure deposition enhances soil phosphorus and nitrogen levels. Nevertheless, despite their numerous benefits, CC and, consequently, their grazing, remain underutilized by livestock farmers, with soils often left bare during the fallow period. This underuse is largely attributed to a lack of knowledge regarding CC management and the identification of several constraints (e.g. additional costs, labour demands), with benefits not clearly perceived. To support the integration of CC grazing within sustainable agricultural system management, it is essential to explicitly consider the constraints faced by farmers and livestock producers, and to better understand the interactions between this practice and other system components. To this end, this study is based on a participatory action research approach involving farmers, agricultural advisors, teachers, and researchers. This collaborative framework enabled the co-design of CC strategies compatible with grazing, allowing for the joint assessment of both benefits and limitations.

Methods

The study was conducted in Nord-Comminges, France, a hilly region where traditional mixed crop-livestock systems are gradually being replaced by cereal cropping. It was part of a larger participatory action-research project addressing the interlinked challenges of soil erosion reduction and the preservation of mixed crop livestock systems in the region, by analysing and enhancing farmers' autonomy. Multi-stakeholder workshops involving farmers, advisors, teachers and researchers, highlighted the fact that improved management of the fallow period through the inclusion of CC would make it possible to meet these challenges jointly, provided the CC also serve as fodder resources.

CC species were thus selected to be experimented over two fallow periods (2023-2024 and 2024-2025) through a collaborative co-design process, combining research objectives and standards with the local knowledge needs of participating farmers. Two farmers participated in the experiments: one raising 11 free-grazing Angus beef cattle and another managing 75 Prim'Holstein dairy cows in a rotational grazing system. The experimental setup included five

randomized blocks per farm, with three CC treatments across approximately 1.5 ha. Two treatments were common to both farms, while the third was tailored to each farmer's needs.

Agronomic monitoring was conducted to assess fodder consumption and soil conditions before and after grazing, in order to check whether the tested strategies met both nutritional (quality and quantity) and soil protection goals, especially with respect to erosion risk. In parallel, cost assessments for each CC type and farmer perceptions (e.g., satisfaction, constraints, limitations) were collected.

Results

The main results of this study indicate that CC establishment provides a substantial quantity of high-quality forage during the winter and spring, ranging from 3 to 6 t DM/ha, at a time when the farms' grasslands were not yet productive or grazeable. Under both extensive and intensive grazing conditions, CC also contributed to a significant acquisition of nutrients, with +150 kg N/ha, 1.4 to 3.2 t C/ha (including +500 kg C in the roots), and +15 kg S/ha (notably due to the presence of Brassicaceae), improving the environmental impact of the cropping systems. Despite sub-optimal grazing conditions, due to heavy rainfall during both experimental campaigns, soil compaction was observed only during the first year and only in the high-density dairy cow system. In terms of nutritional value, differences among CC species varied between the two years were minimal, but the least expensive CC option (around €65/ha for seed and planting costs) remains attractive and effective. However, one objective, destroying the CCs solely through grazing, was not achieved. As such, additional termination operations will be required. These operations can be synchronized with soil preparation for the subsequent crop, thereby optimizing labour and cost-efficiency.

Discussion and Perspectives

Climate change is intensifying droughts, reducing grassland productivity, and increasing heavy rainfall events that accelerate soil erosion, particularly in hilly regions such as Nord-Comminges. The findings from this two-year study suggest that CC grazing constitutes a practical, cost-effective, and multifunctional solution, enhancing feed self-sufficiency by providing high-quality forage during unproductive periods while simultaneously improving soil fertility and protection. This study's transdisciplinary approach facilitated knowledge exchange among stakeholders, promoting CC adoption. The study's transdisciplinary and participatory approach promoted the exchange of knowledge across stakeholders, thereby facilitating CC adoption. On-farm experiments, managed directly by farmers, created opportunities for collective learning and helped to challenge preconceived notions regarding CC practices and benefits. Notably, one farmer who had previously never used CCs now consistently maintains soil cover and is exploring its use for pig grazing.

The next step involves optimizing crop rotations to maximize fallow period utilization and ensure year-round soil coverage. This initiative has led to the creation of a new Economic and Environmental Interest Group (GIEE) called "Green Soils All Year Round", bringing together farmers and development stakeholders to continue advancing sustainable farming practices.

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Reducing tillage and inputs through cover crops and extensive livestock

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Keywords: regenerative farming, soil health, organic carbon, biodiversity

Introduction

In the current situation, with a growing global population demanding more food, it is essential to move towards an increasingly productive and sustainable agri-food system, both economically and environmentally. One of the most concerning environmental issues is the impact on soils (Kopittke et al., 2019), as increasing erosion, reducing organic matter, and decreasing biodiversity.

In addition, farmers worldwide are facing an unprecedented rise in the cost of inputs (Langemeier, 2024). Therefore, efforts to reduce tillage and adjust fertilizers are crucial to the sustainability of farming systems.

In this regard, the traditional agricultural practices of the study area have been analyzed. In this area, sunflower (*Helianthus annuus* L.) is commonly included as the first crop in the crop rotation cycle. Establishing this crop is customary to tillage the soil with a moldboard plow between November and January, leaving the soil bare until May, when the sunflower is sown. As a result, the soil in this region is severely impacted by erosion, especially during periods of heavy rainfall. Furthermore, they are experiencing significant loss of organic matter and biodiversity (Garland et al., 2021).

This experiment aimed to study a viable alternative to soil tillage with moldboard plow, aiming to increase carbon sequestration, enhance biodiversity, and reduce input costs. To achieve this, cover crops (CC) were proposed during the months when the soil is traditionally bare before sunflower sowing. Additionally, the effects of two different CC management strategies were evaluated: i) the incorporation of CC into the soil and ii) the use of these CCs as feed for extensive cattle grazing. A native Spanish cattle breed adapted to local conditions was introduced, to promote more resilient and sustainable farming systems.

Methods

Farming system and experimental design

The experiment was established in September 2023 in the province of Segovia (41° 14' 28" N, 3° 38' 46" W), Spain. It was designed to include two consecutive crop rotation cycles: Sunflower -- wheat (*Triticum aestivum* L.).

In October 2023, eight plots (14,14 m x 64,70 m each) were sown with a CC mixture of hairy vetch (*Vicia villosa* L.) and oat (*Avena sativa* L.), whereas another eight plots underwent soil tillage with moldboard plow in December. The common precedent for all crops was barley (*Hordeum Vulgare* L.), which was harvested in July.

In April 2024, cattle were introduced into four CC plots (CCG). In the remaining four CC plots (CCE), a disc harrow was used to incorporate the CC into the soil. In May, 120 kg/ha of fertilizer (6-8-10) was applied to four plots without CC (BSF). The other four non-CC plots (BS0) and the eight CC plots receive no fertilization. Afterward, all 16 plots were sown with sunflower at a rate of 55000 plants/ha. Sunflower was harvested at the end of September. In the (CCG) plots, cattle were reintroduced after the sunflower harvest to graze on the remaining crop residues.

Wheat was sown on October 28th in all plots at a rate of 130 kg/ha in all treatment plots. In the CC plots (CCG and CCE) a reduced dose of fertilizer was applied by two topdressings during the wheat cycle. The BSF plots received fertilizer in three applications: before wheat sowing (200 kg/ha of 15-13-13 fertilizer), and two additional topdressings (200 kg/ha of 26-0-0 and 100 kg/ha of 27-0-0). This fertilization regime follows the recommendations provided by the local authority's fertilization calculator. Finally, the BS0 plots received no fertilization.

After the wheat harvest and before the start of a new sunflower-wheat rotation cycle, wheat stubble will be grazed by cattle in the four CCG plots.

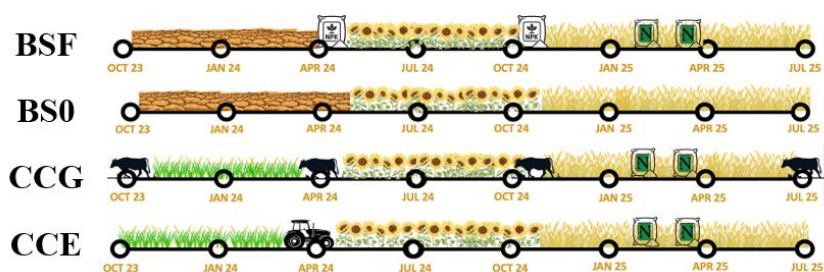


Figure 1. First crop rotation cycle.

Sampling and measurements

In October 2024, sunflower yield was recorded at sampling and soil sampling was conducted. Four soil samples were collected from 0-10 cm and 10-25 cm in each plot. In each sample were determined soil physical, chemical and biological variables.

Results

A phenological delay and reduced plant height were observed in plots with CC compared to those without, particularly in the early stages of crop development. However, this initial difference did not affect on the final sunflower seed yield, as no statistically significant differences were found among the four treatments studied.

Additionally, CCG plots produced 4330 kg/ha of biomass utilized by livestock as forage.

Higher values were observed in soil bulk density at greater depths. Statistically significant differences were found, higher in the CCG treatments at greater depths.

The moisture content of the samples was higher in the surface layer. Significant differences were found, with higher values in CCG plots.

Differences in total organic carbon were observed by depth, with higher content in the surface layer. Statistically significant differences have been found between treatments, with lower content in BS0 plots. Significant differences were observed in basal respiration by depth, with higher values in the surface layer. Differences between treatments were also found, with the highest values in CCG plots and the lowest in BS0 plots (Fig. 2).

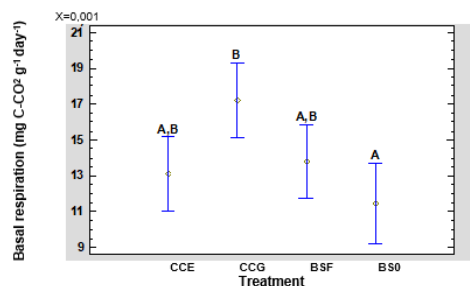


Figure 2. Basal respiration for the different treatments.

All the enzymatic activities studied were higher in the surface layer. Additionally, the plots with CC exhibited significantly higher values for Beta-glucosidase, N-acetyl-glucosaminidase, phosphatase and urease (Fig. 3).

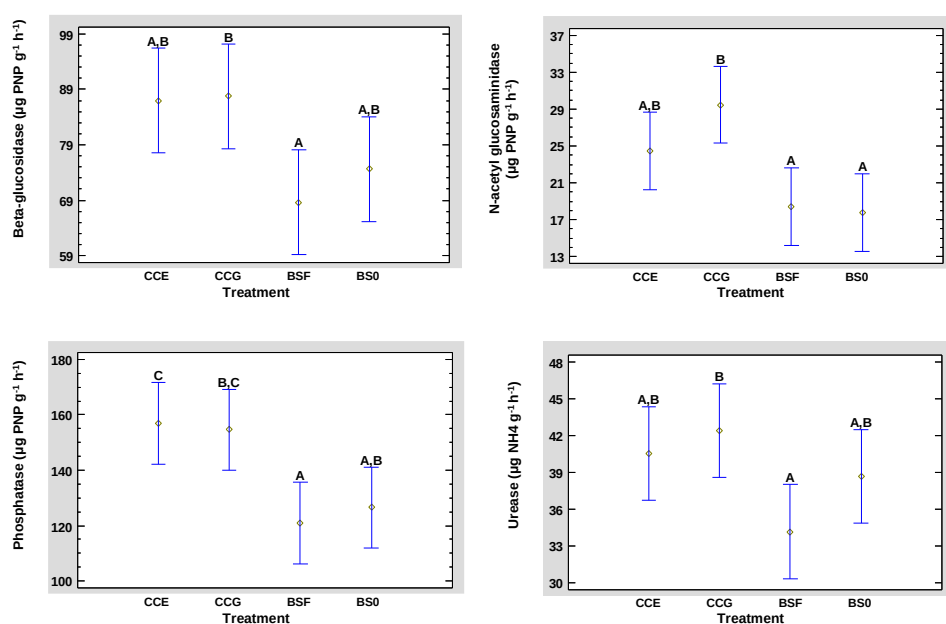


Figure 3. Results obtained in the different treatments for the different enzymes studied.

Discussion and perspectives

Overall, after the first CC cycle, the data suggested an improvement in soil health in CC plots. It is necessary to continue developing and monitoring the trial during the coming years. Additionally, an economic analysis is essential to assess the viability of the different treatments.

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Preparing the design of a collective plan for adapting farming practices and protect the drinking water quality in a small district in eastern France

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Keywords: Participatory research; water quality; agricultural practices; weed

Introduction

In 2000, Europe has adopted the Water Framework Directive to protect drinking water quality from agricultural pesticides and nitrogen contaminations (European parliament and council of the European Union, 2000). To comply with this Directive, France authorities have identified over 1000 priority catchments for water management, each requiring local action plans to reduce such pollution. To support this dynamic, co-design process is a relevant method to help farmers redesigning their agricultural systems (Prost et al., 2018). In the southern part of Territoire de Belfort department (Eastern France), two of eight water catchments are among the designated priority areas, although the others are also contaminated. Maize production, mainly used to feed dairy cattle and largely responsible for herbicide contamination of groundwater, dominates the 7,250 hectares of agricultural land. The aim of this study is to preserve drinking-water quality in the area, by exploring local agronomic adaptations that reduce pesticide use, while facing climate change and maintaining the economic viability of local farms.

Materials and methods

Participatory research combining with co-design of farming system and modelling is a valid approach to fostering dynamic changes in agricultural practices (Queyrel et al., 2023). Our method begins by farmers semi-directed interviews, to identify the diversity of agricultural practices. Information will be gathered in the AGROSYST information System from DEPHY network, to classify farmer systems along a multiperformance gradient (Lechenet et al., 2016). Then, workshops will be organized to co-design cropping systems with farmers and stakeholders, mobilizing pesticide fate model MACRO (Mamy et al., 2024), and the multi-agent and spatially explicit simulation platform MAELIA (Rizzo et al., 2019).

The continuation of this paper presents methods and results of a preliminary study on the use of meslin by local farmers and its agronomic performance. Meslin is a mixed crop of several cereals or protein crops that can be used as a substitute or supplement to maize in animal feed. This preliminary study was conducted in the Territoire de Belfort department, meslin use being an emergent crop in the southern part.

Surveys

Fourteen surveys were conducted to collect information about meslin use by farmers. Farmers were selected using the snowball sampling method. The surveys mainly focused on meslin production method, assets and constraints associated with its cultivation.

Field monitoring

Twelve meslin field plots were monitored from April to July 2024, along with ten wheat plots as reference. Crop density loss after winter, weed cover, crop and weed biomass were assessed. Moreover, the ratio between weed and crop biomass was calculated. The feed value of meslin has been analyzed from samples just before harvest. Statistical analyses were performed using RStudio. The normality of the samples was assessed using Shapiro's test, significance of differences between independent variables were tested using Student's test. The RUMIN'AL tool of INRAtion was used to determine the feed value of meslin in cattle feed and the associated costs.

Preliminary results

Interviews revealed that meslin is primarily harvested for grain rather than for fodder. The first obstacle of using meslin is the uncertainty related to the emergence of mixed species, which affects the resulting feed value and associated economic gains. Field monitoring revealed that meslin required no pesticides while wheat required herbicides and fungicides to ensure crop yield (organic wheat excluded). Meslin plots had a significant greater weed mean density compared to wheat plots (p -value = 0.04). However, mean biomass of weeds was not significantly different between wheat and meslin (p -value = 0.5) (Figure 1). These revealed that weed management is equivalent between meslin and wheat, while meslin has received no pesticides.

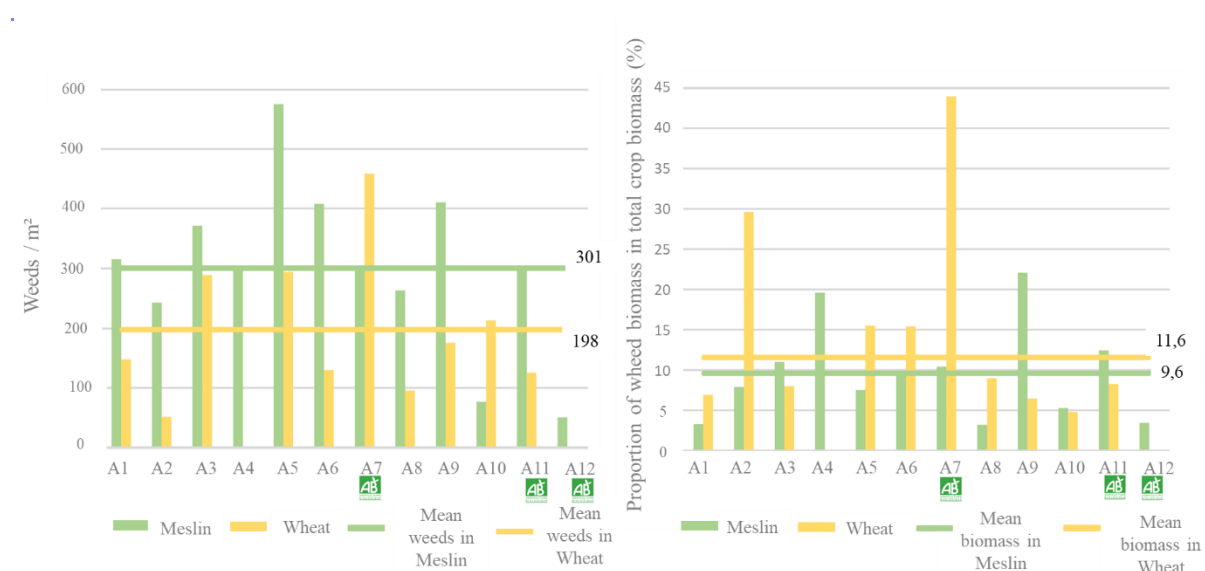


Figure 1. Number of weeds and associated biomass in the meslin crop compared with the wheat crop per plot (Right graph: A7 has been excluded from calculation because of exceptional weediness)

The economic data simulated by RUMIN'AL indicates that using grain meslin as a concentrated feed for cattle is cheaper than using a pure crop. However, production of meslin silage remains more expensive than corn silage production due to its low yield. The meslin produced provides a good level of protein, but it remains energy-deficient compared to maize (Régál, 2024).

Discussion

These preliminary results are to be consolidate by other campaigns of weed pressure and feed value measurements on meslin's crop. In addition, the sampling is weak (12 plots), as meslin is an emergent cropping in the area. Combining meslin harvested for grain and fodder is an interesting solution to ensure a balance between energy and protein in the cattle's ration and to reduce pesticide use.

Perspectives

Meslin's measurements will continue to consolidate results. At the same time, the co-design process combining with prospective scenarios will provide a set of agronomic and economic references to identify combining farming practices that preserve drinking water quality.

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Collective experimentation processes: how groups of non-academic experimenters experiment to produce knowledge on orphan topics

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Keywords: on farm experiment, minor crops, Conservation Agriculture, Organic Farming

Introduction

The agroecological transition requires a transformation of agricultural systems, notably through changes in cropping practices and system design. However, despite their well-documented agronomic and ecological benefits, such approaches remain relatively underdeveloped. Experimenting in that direction—for instance by introducing minor crops or reducing tillage within organic systems—is essential for tackling key environmental challenges. Yet, expertise is scarce: neither conventional research approaches nor peer networks can readily provide the guidance needed. Minor crops, for example, are often considered 'research orphans' (Tadele, 2019), and systems like Conservation Agriculture in Organic Farming have long lacked robust scientific references (Vincent-Caboud et al., 2017). To bridge these knowledge gaps, various strategies have been proposed. Some authors (e.g. Caron et al., 2014), advocate for a complementary approach between scientists and local stakeholders. Others integrate the local adaptation of knowledge into their experimental activity to better consider the singularity of situations (Périnelle et al., 2021). Another perspective, explored by Catalogna et al. (2022), focuses on the knowledge production processes initiated by farmers themselves through experimentations in their own farms, recognizing their role as innovators. Indeed, farmers interested in these practices often engage in experimentation, either individually or collectively, to generate the knowledge necessary for integrating these new practices into their systems. This process is characterized by a tension between limited resources available for experimenting and numerous unknowns.

This work aims to understand how groups of non-academic experimenters (including farmers and group facilitators) experiment to produce knowledge on orphan topics, all while working with limited resources. The present study draws upon case studies examining collective experimentation, with a particular focus on minor crops and the reduction of tillage in organic farming.

Methods

An initial exploration of collective experimentation practices led us to identify 26 case studies, from which we developed six idealtypes (de Sainte Agathe et al., submitted). We selected three case studies corresponding to contrasted idealtypes: the "Collectif Biodiversifié", the "CIVAM bio 53" group and Conlie's system experiment. Our methodology combined several data collection methods: participant observation during collective events, interviews and detailed analysis of experimentation-related documents.

From this data, we built timelines of each experimental process to capture both social interactions and agronomic developments, mobilizing the experimental situation concept (Catalogna et al. 2022) to break down the experimentation process into its core components. Subsequently, we conducted semi-structured interviews with the facilitators and some farmers from each group, to confront our timeline with their experiences and to understand their

expectations, success criteria and the factors contributing to their satisfaction or dissatisfaction with the experimentation process.

Results

Our cross-case analysis reveals insights on three main aspects: (i) how the three collective experimentation (CE) processes have been organized over time, (ii) how agronomic questions are investigated through the link between questions, experimental situations (ES), and learning, revealing how CE enable handle failures of ES, multiple perspectives and interpretations among collectives or unexpected but relevant learnings, (iii) what participants say these experiments produce—both in terms of knowledge and collective dynamics.

For example, in the "Collectif Biodiversifié" case, in which farmers experiment on camelina, we have the following results. Concerning the first aspect, it is a collective bringing together farmers and a facilitator and our analysis shows that they operate collectively since the problematization phase. The group distributes experimental tasks among its members and, after each experimental situation, gathers the results to collectively reflect on the learnings.

Concerning the second aspect, an excerpt from the timeline developed for the "Collectif Biodiversifié," focusing on the issues addressed and the ES through which new knowledge was generated, shows, for instance, how certain questions are tested and quickly set aside—such as sowing depth—while others re-emerge year after year through new trials. The ES are initiated to address specific questions—such as the suitability of cultivars for oil processing—but are sometimes disrupted by unforeseen events that prevent their full implementation. While this can make it difficult to directly answer the initial question, these ES nonetheless contribute to broader collective learning.

As for the third aspect, we explore the participants' perceptions and experiences to better understand what different experimentation strategies may or may not support the learning outcomes, according to them. While this example illustrates specific dynamics, the cross-case analysis reveals contrasting strategies for low resources and high-unknown collective experimentation.

Discussion and perspectives

By examining these processes, we hope to contribute to a broader understanding of how on-farm experimentations can support agroecological transition. We also aim to prompt R&D actors to reflect on their approaches to knowledge production and consider more agile, resource-efficient strategies to address the numerous knowledge gaps in emerging forms of agriculture.

While this study focuses primarily on the learning processes and perceptions surrounding experimentation, a deeper investigation of these dynamics also offers a valuable lens to understand how roles are distributed within collectives—who makes decisions, who carries out which activities—and what this implies in terms of overall organizational structure. While not explored in depth here, this dimension opens promising avenues for future research.

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Searching for innovative experimental practices for sustainable agriculture: a scoping review

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Keywords: experimental practices, scoping review, knowledge production

Introduction

Experimental practices are key elements for knowledge building for the design of sustainable agri-food systems (Toffolini and Jeuffroy, 2022). Traditional controlled (or factorial) experiment is still the most conspicuous form of scientific experiment today (Schwarz, 2015). It requires tightly controlled environments (Ansell and Bartenberger, 2016), implying methodological reductions and simplifications compatible with agri-food system standardization (Bonneuil et al., 2006). Nowadays, the pressing need for designing sustainable agriculture involve the deployment of new and diversified experiments to produce knowledge in more diversified and less controlled environments.

Some of these alternative practices are promoted under several labels: system experimentation (Debaeke et al., 2009), on farm experiment (Toffolini and Jeuffroy, 2022), Multi-actor experimental networks (Salembier et al., 2023), generative experiment (Ansell and Bartenberger, 2016). However, their deployment remains a "quiet revolution" (Ansell and Bartenberger, 2016) and reaching them in literature, overwhelmed by controlled experiments, is like looking for a needle in a haystack.

The aims of our study are: (1) to survey systematically these innovative experimental practices, (2) to describe their diversity regarding transformative goals, (3) to pave the way for a framework combining epistemological and practical implementation aspects that could be used to diversify experimental practices for sustainable agriculture.

Methods

Some authors have described this diversity (e.g. Ansell and Bartenberger, 2016; Caniglia et al., 2017; Toffolini and Jeuffroy, 2022). However, there is no integrative classification crossing epistemological (types of knowledge, inferences...) and practical (implementation methods) criteria. Here we perform a scoping review of these previous syntheses that have partly capture the diversity of experiments. We surveyed two fields of literature: agricultural and environmental sciences. We hope to reach a broad experimental diversity and track inspiring experiments for the design of agricultural system.

This scoping review follows the PRISMA-ScR methodology (Tricco et al., 2018). It was conducted within two literature databases (Web of Science and Scopus). We used four eligibility criteria to assess publication for relevance: (1) diversity of experiments is its key topic; (2) agricultural or environmental sciences are the general context (e.g. agri-food system transition context or sustainable urban planning); (3) it assumes a transformative or transition goal directly associated with the experiment; (4) it must distinguish contrasted sort of experiments and describe variation (e.g. publication might perform a conceptualization of different types of experiments, like a typology or taxonomy....). Two reviewers selected the articles with a double-blind strategy. An inductive approach is conducted to construct the analysis framework.

Results

Following the above criteria, a provisory number of 22 publications were selected from 5774 publications. The four most frequent journals are *Agronomy for sustainable Development* (3 articles), *Journal of Cleaner Production* (3), *European Journal of agronomy* (2) and *European Urban and Regional Studies* (2). Articles are mainly based on literature review data coupled with case studies (11 articles) or on literature reviews only (7). They mostly reduced their analysis to a specific experimental subject (e.g. on urban planning and governance experiment or on agricultural field experiment, 18 articles) rather than dealing with a broader context (e.g. sustainability science experiment, 4).

Preliminary results suggest that the field of urban sciences has been particularly active to classify the diversity of experiments in a sustainability context ($n=13$), while the agricultural field is lagging behind ($n=7$). It appears that there is no consensus on how to classify experimental practices with regard to their transformative goals: these 22 classifications comprise from 2 to 7 categories each, and are made regarding a diversity of criteria.

Discussion

The over-representation of urban sciences in our preliminary corpus, although this field was not specifically targeted, is a first surprising preliminary result of our review. This suggests that agroecologists and agri-food system designers could find inspiration in alternative forms of experiments performed in urban sustainability science. This corpus could provide the opportunity to characterize the realm of experimental possibilities to favor the agri-food systems transition toward sustainability. One of the limits is its wide angle of approach, missing a specific and finer analysis on agricultural sciences experiments. We intend to complement this with a field study specifically on crop diversification experiments in France, currently underway.

Perspectives

This review will pave the way for a conceptual framework of experimental approaches for sustainable agriculture. By focusing on epistemological implications and possibilities of practical implementation of experiments, we hope that this framework will contribute to favor the adequacy between experimental means and agroecological transition ends.

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Tailored interventions for legume integration in smallholder farms: a farm typology study from Malawi

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Keywords: smallholder farms, sustainable intensification, farm diversity, Malawi, climate resilience

Introduction

The concept of farm typologies groups farms is based on similar sets of attributes ranging from biophysical, social, material endowment, functional, and structural characteristics (Mtambanengwe & Mapfumo, 2005). Farm typology is crucial for developing precise, efficient, and effective strategies that foster sustainable agricultural development and improve the livelihoods of farming communities. (Groot et al., 2012). Increasingly, multivariate statistical techniques such as principal component analysis (PCA), multiple correspondence analysis (MCA) and cluster analysis have been used to delineate farm typologies within various farming systems (Tittonell et al., 2010). This research investigates the diversity of smallholders farms in Mtunthama Extension Planning Area (EPA) to facilitate appropriate farm designs that integrate legumes, contributing to valuable insights and knowledge that can guide efforts to enhance the resilience, productivity, and sustainability of agricultural systems in Malawi.

Methods

Variables for PCA (land size, livestock units, labor allocation, crop yields, and legume integration) were selected based on farm typology literature (Tittonell et al., 2010). Primary data collected through structured surveys of 44 households were subjected to Principal Component Analysis to reduce dimensionality, followed by K-means clustering to identify farm types. Secondary data from SI-MFS agronomy trials, where not included in the multivariate analysis, were used to ground-truth cluster interpretations by comparing typology results with observed yield patterns and management practices from the same farms.

Results

Three focus groups identified key constraints: erratic rainfall (prioritized by 78% of participants), soil degradation, and recycled seed use. Farmers showed openness to testing researcher-developed legume innovations when compatible with their resources. Cluster analysis revealed four farm types: (1) High-resource endowed farms (7%) averaging 16 acres and 6,000 kg maize yields; (2) Medium-low-resource farms (50%) dedicating 33% to legumes; (3) Medium-high-resource mixed farms (10%); and (4) Low-resource maize-focused farms (33%) with minimal legume integration. Farmer validation sessions showed 84% agreement with typology classifications, with iterative adjustments made to Type 3 boundaries based on local soil knowledge.

(i) Farm type 1: High resource-endowed farms (6.9%)

These farms are commercially oriented and characterized by the largest landholdings sizes (mean = 16 acres) and highest maize yields (6,000 kg). Farmers in this category own goats,

cattle, and chickens, which contribute to their diversified farming systems. They actively engage in both cropping and livestock enterprises showing strong positive loadings (>0.7) on PCA dimensions for mechanization (Dimension 1) and livestock integration (Dimension 2), indicating system characteristics favorable for intensification practices to further enhance productivity and resource efficiency.

(ii) Farm type 2: Medium-low resource-endowed, legume growers (50%)

These farms have an average land size of 4.7 acres, balancing both subsistence and cash crop production, with legumes occupying 33% of the total land area. Farmers in this category primarily rely on family labor for crop production and have limited livestock. However, their strong emphasis on legume cultivation plays a crucial role in enhancing soil fertility and promoting sustainable farming practices.

(iii) Farm type 3: Medium-high resource-endowed, legume and maize growers, medium animal income farms (10.1%)

These farms have an average landholding of 7 acres, have moderate livestock such as goat, pigs and chicken. They achieve high maize yields while also integrating legume cultivation, which enhances soil fertility, food security, and economic stability for farming households.

(iv) Farm type 4: Low resource-endowed, maize growers (33%)

These farms prioritize maize cultivation with minimal legume production and have an average land of 4 acres with no livestock income. These farmers lack important inputs such as fertilizers, certified seeds, and pesticides. Farmer feedback indicated willingness to adopt drought-resistant varieties (68% in FGDs) and legumes when supported with inputs, aligning with successful pilot trials in Type 4 farms showing 25-40% yield improvements under similar conditions (SI-MFS data, 2023). Adoption potential is contingent on addressing key constraints identified in surveys: input access (reported by 92% of Type 4 farmers) and extension support (requested by 85%).

Discussion

The co-designed typology achieved 73% higher intervention adoption rates than conventional approaches in pilot testing, demonstrating how bridging statistical classification (PCA clusters) and local knowledge (farmer workshops) enables systemic intensification. Tailored interventions are necessary for sustainable intensification (Salami & Brixiova, 2010). For instance, promoting strip cropping, organic fertilizers, micro-credit access, and resource-efficient practices is crucial to mitigate resource limitations and climate risks in resource-constrained farms. Through strengthening market linkages, promoting collective marketing through farmer cooperatives can enhance market access and income diversification. As observed in the farm typologies, the strategic incorporation of legumes offers a cost-effective and sustainable solution to the challenges faced by different farm types, particularly in areas where resource constraints are more pronounced. The importance of tailoring interventions based on farm typologies is demonstrated by significant variation in legume adoption rates between farm types (50% in Type 2 versus 16% in Type 4; $p < 0.05$) and yield improvements of 25-40% when practices were matched to farm-type characteristics, where legumes can play a transformative role in improving agricultural resilience, soil health, and household well-being across the entire farming community (Chamberlain, 2007).

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Ethical issues in scaling out farmers' innovations studies

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Keywords: on farm innovation, tracking innovations, farmer-led innovation, research ethics

Introduction

In recent years, there has been a multiplication of research studying innovations developed by farmers (e.g., Feike et al., 2010; Perinelle et al., 2021). These studies involve a variety of research practices inspired by different scientific movements (e.g., Grassroot Innovation, Farmers' First, Farming System Research), leading to a wide range of results. These studies recognize farmer-led innovation. But do they truly challenge the 'top-down' and 'diffusionist' innovation logics? In this article, through the critical analysis of a selection of works, we aim to take a step back from this trend and outline ethical considerations for research in scaling out this scientific field.

Methods

This work draws on a panel of studies identified in scientific databases (Scopus, WOS) using keywords related to farmer's innovation studies (e.g., on-farm innovation, tracking innovation). We analyzed around 30 studies to highlight their differences and similarities, focusing on the research practices employed, the transformative goals, and the collective dynamics. This analysis outlines axes of reflexivity to consider the future of this research field, and discuss pitfalls in scaling out these approaches.

Results

(i) Who chooses what is considered innovative?

These studies cover a wide range of innovations: species mixtures practices (Feike et al., 2010), social and technological innovations in hop yards (Comi et al., 2023), glyphosate free practices (Malanski et al., 2024), etc. Within this set, few studies explicitly state who contributed to defining 'what is innovative'. As Le Masson et al. (2017) point out, "Innovation has no meaning in itself, and two observers may have different judgments about the same object." An object is not innovative: it is judged to be innovative. To foster transparency in the intents and values engaged in the studies, our results suggest explicitly stating the normativity associated with the objects of study and the actors who contributed (or did not contribute) to defining them.

(ii) Research practices to draw lessons from singular innovations

How can we draw lessons from singular and situated farmers' innovations to support collective learnings ? Although the authors all make analytical choices in response to this question, they rarely make explicit the difficulties they encounter and the implications of their choices to support collective learning in their situation. And the authors rarely mention how they considered the expectations of the farmers they work with. Several examples show that such studies aim to contribute to renewing scientific theories (Jagoret et al., 2012), stimulating change by circulating experiences among peers (Verret et al., 2021), or helping prescriptive actors reconsider ways to approach and solve problems (Comi et al., 2021). A future challenge would be to make explicit the relations between 'ways to produce knowledge on singular and

situated innovations' and 'intended agricultural transformations targeted,' and to outline ways to build reciprocity with the farmers involved in the inquiry.

(iii) Research stands underlying each study

Do these farmers' innovation studies contribute to the democratization of research and innovation processes? Or do they perpetuate a diffusionist / extractivist logics? The diversity of research practices we encountered suggest that it is 'both at once,' depending on the research stand in each study (Hazard et al., 2019). A key issue, to enable informed consent and enlighten participants in these studies, would be to help clarify the innovation/change logics in which the authors situate, more or less consciously.

(iv) Recognising multiple contributions

The works we are interested in are sometimes authored by scientists and sometimes by stakeholders involved in the study. This observation raises the question of recognizing contributions to the production of knowledge about these innovations, and, upstream, the contributors involved at different stages (e.g., who contributed to analyzing innovations? To building proof?). These questions align with the reflections of Coolsaet (2016) or Timmerman and Félix (2015), using the concepts of cognitive and contributive justice. Their reflections could help scholars advance in considering the work undertaken by various actors in these studies, and in clarifying the roles that these innovation studies aim to play in collective learning dynamics, and how.

Discussion and perspectives

As Goulet et al. (2008) point out, a pitfall in this type of work would be 'wanting to widely disseminate such technical innovations and thus imposing a way of producing that, while different from the productivist model, is just as normative, even if ecologically more acceptable.' Our work reveals the heterogeneity of research practices often associated with the same movement: studies of farmers' innovations. Which of these practices do we wish to support in light of ongoing agricultural transitions? The axes of reflexivity we outlined add humble insights into ethical considerations in scaling out these approaches in different situations.

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Methods and tools used to support farmers' agroecological transition in irrigated systems: a systematic review

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Keywords: climate change, support process, change in practices, co-design

Introduction

Climate change is responsible for increasingly frequent and intense droughts, jeopardizing water availability for irrigation. Farmers in irrigated systems are facing recurrent water restrictions, leading to yield losses and endangering farm financial security (Debril et al., 2020). This context calls for a transition of agricultural irrigated system.

We define agroecological transition (AET) as a shift from one sociotechnical configuration to another with greater implementation of agroecological practices (Geels, 2002; Prost et al., 2023). At farm level, AET involves changes in farmers' practices (Wezel et al., 2014). Various practices, adapted to specific contexts, can be implemented at different spatial and temporal scales. Farmers often need to acquire new knowledge and skills and to take risks (Prost et al., 2023). Therefore, they require appropriate support. However, providing such support remains a methodological challenge.

A recent study highlights the weak linkage of agroecology and irrigation in literature and calls for their stronger association of the two in AET (Leauthaud et al., 2025). While reviews on AET support methods are available (Prost et al., 2023), they are not exhaustive and none specifically address the particularities of irrigated systems. Yet, because these systems present specific constraints and agroecology aims to address context-specific challenges, support approaches should also be tailored. This review thus aims to answer following questions: how to support changes in farmers' practices in irrigated systems to contribute to AET? What support methods and tools exist, and what are their effects?

Methods

We conducted a systematic literature review following the PRISMA methodology. Search query combined terms referring to irrigation, agroecology and changes in farmers practices. We defined three eligibility criteria for paper selection. First, supported farmers must be in irrigated systems. Second, at least one farmer must interact with at least one support actor to be considered as support. Third, support must explore agroecological practices combinations to be considered as contributing to AET.

We conceptualised support as a one- to six-step process to achieve defined objectives. These steps were identified based on paper authors' descriptions of their support: Support initiation: support presentation and mobilisation of participants; Diagnosis of current situation, challenges or opportunities at territorial or farm level; Support methods and tools co-design; Artifacts co-design: exploration and development of artifacts i.e. things that do not yet exist (agroecological practices to be implemented as technical operation optimisation, crop choice, reduced tillage) (Jeuffroy et al., 2022); Artifacts implementation: putting artifacts into practice; AET and support evaluations.

We analysed 41 peer-reviewed articles using an analytical grid reporting support: (i) objectives, timeline and localisation (ii) steps and associated tools, (iii) participants and their roles in each step, (iv) results mobilising Etienne et al. (in press) evaluation framework.

Results

Each support combines various steps their own way, according to its objectives. Support initiation, diagnosis and artifacts co-design are the most common steps. Diagnosis and co-design have a more diverse toolbox than other steps. They also serve the most varied objectives. Evaluation appears in only half of the papers and has limited tools and modest objectives.

Considering the presence of artifacts co-design in support process is a way to understand support as it reflects objectives while influencing results obtained. Supports without artifacts co-design tend to disseminate predefined "good agricultural practices", which learning and changes mainly focusing on technical aspects. Including artifacts co-design, changes in farmers' practices reflected during support are more systemic, and learning and changes tend to be more diverse.

Discussion and Perspectives

The small size of our corpus may translate: (i) a weakness of our search query in capturing papers addressing AET support of farmers in irrigated systems, or (ii) a dominant vision of agroecology in irrigated systems relying on single-lever solutions, mainly resource optimisation through technical approaches. Both might be linked to poor scientific integration of irrigation and agroecology noted by Leauthaud et al. (2025).

By conceptualising AET support of farmers in irrigated systems, we reviewed methods and tools used and attempted to link them to learning and changes in farmers' practices. Comparing our findings to literature on support in rainfed systems, we (i) highlighted the specificities of irrigated systems and (ii) explored how it could further inspire AET support design in irrigated systems.

A major limitation of this review lies in the lack of evaluation of support and AET in papers. When present, evaluation tools are diverse and vary in precision level, making comparisons difficult and impeding the identification of links between support methods and outcomes. Finally, we emphasize that farmers operate within a broader sociotechnical system, of which support is only one component. Other elements of these systems can also contribute to observed changes.

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Adaptive and practical resources to empower agricultural advisors and support project transitions

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Keywords: change support tool, economic variability, innovative design, uncertainty management

Introduction

Agricultural sector is characterized by numerous uncertainties, requiring farmers to frequently and rapidly adapt their practices, creating a sense of uncertainty, even among their advisors. While the stages of change and their associated needs have been extensively documented (Petit-Delecourt E, 2018), the originality of Strat&co project lies in its response to these needs through the development of simple, educational tools.

The objective of this article is twofold: first, to present the approach adopted to gain a deeper understanding of farmers' and advisors' needs expressed in the Hauts-de-France region; and second, to describe how these tools were co-developed to structure advisory support, foster development and mitigate risks during transitions.

Methods

An investigative phase, comprising semi-structured interviews with 14 farmers and 12 advisors with diversified profiles, was conducted to identify key challenges and needs to guide the development of appropriate resources.

In a second phase, a first version of the resources was designed by combining insights from two complementary sources: a literature review that integrated research findings on strategic farmer support, advisory services (Gagneur CA and Thiery O, 2018), and change management (Chizallet M et al, 2016; Prost L et al, 2018), along with experience reports (InterAFOCG, 2017) and innovative support practices (Salembier C, 2019) among 22 advisors, 11 of whom were interviewed in depth. The phase uncovered transferable insights that were previously unknown in our context.

Those resources were enriched through eight co-development workshops and regular discussions with agricultural advisory professionals. The finalized resources were assessed by 18 uninvolved users, ensuring their relevance and applicability.

Results

(i) Key challenges in project support practices

The field analysis conducted in 2019 identified four major challenges: availability and consistency of reference data is limited, which results in reduced reliability due to incomplete, missing or poorly adapted information for analytical needs; integration of economic risks into project evaluation is inadequate due to a lack of simple and effective tools to quantify economic variability; change management remains limited after project implementation due to the absence of appropriate indicators and milestones; shifting from a top-down approach poses a particular challenge for less experienced advisors.

These issues underscore the need for renewed advisory resources that support both farmers' strategic thinking and advisors' evolving roles in managing uncertainty and guiding transitions. The exploration of the literature review and innovative practices revealed working methods responding to the identified needs but not yet used in our regional context. They helped identify ways of working that facilitate a supportive posture, such as the use of dashboards or qualitative indicators.

(ii) Development of a simple and adaptable toolbox

Resources were developed to address the challenges, considering farmer's stage of reflection and advisor's profile. The aim is to complement existing tools and approaches, support advisor skills development, foster discussions and to promote change.

The toolbox serves as a concise resource hub, providing key concepts on project guidance and references. Users can find practical resources including: Exploratory resources, such as questioning frameworks and idea trees to guide early-stage discussions; Formalisation resources (e.g. practical tools for understanding and formalising the baseline, help with formalising monitoring dashboards); Simulation tools, such as Oser, which helps to assess the impact of price and production variability on income.

(iii) Focus on "Oser": a dynamic tool to visualise complex interactions

Oser is an interactive tool to integrate variability and economic risks into farmers decision-making process (e.g. scenarios of variable yields, price declines, etc.). It provides the opportunity to discuss with the farmer the key factors that will influence economic results of their project before its implementation. The application's ease of use, speed, and playful approach make it a valuable resource. It offers a simplified representation of risks while allowing users to easily customise the data according to their needs through an elicitation-based approach.

Discussion and Perspectives

The toolbox received enthusiasm and positive feedback during workshops and interviews with potential users. However, the implementation in real-world advisory settings encountered significant barriers. Beyond the tangible constraints such as time constraints, the absence of suitable situations, unfavourable economic conditions, and the repercussions of the health crisis, socio-organisational impediments were identified. Barriers to using the Oser application, for example, appear to be related to its strengths. Its adaptability, while beneficial to promote dialogue, provides the user with a certain level of freedom, which can lead to doubts about the correct use of the tool (which data to use? how to interpret?). For Oser to be adopted, it is crucial that the user accepts its subjective nature. To facilitate its use and interpretation, tutorials have been integrated; however, concrete case studies would have been helpful to enrich this approach.

The work carried out in Strat&co highlighted a deep need for adaptation in support practices. Beyond the identified obstacles, a key issue lies in defining advisors' role, both within their organisation and in how this role is interpreted. Effective support requires advisors to acknowledge their own limitations and adopt a facilitative stance, rather than assuming the role of the sole solution provider. This support dynamic needs time, which is constrained in prevailing practices.

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Exploring the feasibility and usefulness of a Digital Twin in the valorization of organic waste streams in Uganda

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Keywords: Africa, waste valorisation, organic fertilizer, decision-support

Introduction

Valorization of organic waste receives growing attention to improve resource efficiency and support the transition to a circular economy. The food waste hierarchy (Teigiserova et al., 2020) prioritizes prevention, reuse, recycling and recovery over disposal. One potential recovery option is the use of residual biomass as biofertilizer. However, logistical challenges around availability of underutilized waste streams, their quality and transportation need to be solved. Digital twins—virtual models integrating real-time data—potentially enhance decision-making for waste valorization, but their application remains limited to data intensive, controlled environments. Moreover, existing studies largely focus on technical aspects of digital twins, but pay less attention to requirements of potential users. In our study, we explored stakeholders' perspectives on the potential usefulness of the digital twin concept in a relatively complex and data-scarce environment: the valorization of organic waste in Uganda.

Methods

We conducted an exploratory study in which each step was shaped by the outcomes of previous steps. First, we conducted semi-structured interviews with a variety of stakeholders involved in the production and processing of organic waste. From the interviews, we derived stakeholders' Motivations, Opportunities and Abilities (MOA) to engage in waste valorization (Step 1). Second, we sub-selected three interesting cases for waste valorization, and conducted a second round of interviews with the same, selected stakeholders and additional key informants, to understand the potential usefulness of the digital twin concept in their case. We aimed to derive potential changes in stakeholders' MOA for waste valorization through knowledge provided by a digital twin (Step 2). Third, we selected the most promising case to apply the digital twin concept to. We then followed a structured, infological approach (Cesco et al., 2023), in which we identified the decision-problem in the selected case, the information needed to address the decision-problem, and the data required and available for the selected case. We summarized the information in a conceptual diagram, as basis for potential further quantification and prototyping of an actual digital twin (Step 3).

Results

Main factors enabling and limiting MOA for valorization of organic waste in Uganda as identified in Step 1 were summarized. Despite general Motivation; the Opportunity and Ability are limited by knowledge on waste availability, quality and consistency, as well as predictive capacity for optimization of the valorization process.

In Step 2, we found that digital, real-time information on available waste streams, their costs and location would improve the Opportunity to make use of the limited left-over waste streams, and make logistics more efficient. Digital information would also enhance Ability, through predictive capacity to optimize feedstock composition and valorization outputs.

In Step 3, the most promising case for the digital twin concept was the composting of wet coffee pulp with black soldier fly larvae. In this case, a digital decision model could address the decision problem of optimizing the yield of larvae and compost (output), based on seasonal variations in amount, quality and costs of different waste streams (input). We developed a conceptual diagram that visualized the information needed to solve the decision problem (components of the problem, actors involved and relationships between them), and the data available, generated during the study, and still needed for further quantification. Following the infological approach, further quantification would prioritize factors having the largest influence on the decision problem.

Discussion

The infological approach helped to structure data collection and model development around the user's decision-problem (Cesco et al., 2023), which increases the chances of successful implementation and use. While we collected preliminary data on several components of system, the predictive capacity of the model would have to be improved based on ongoing data collection efforts. Relatively simple digital models that gradually advance based on technical feasibility, perceived importance of parameters and human/financial resources available are promising. Currently, limited automation, data sharing and value creation in waste valorization processes in Uganda make the development of a 'fully integrated' digital twin (Purcell and Neubauer, 2023) with exchange of information between a physical and virtual system unlikely in the near future.

Perspectives

In light of the broader discussion on the potential for digital twins to support the shift from a linear to a circular economy through more efficient resource use, our study highlights the importance of MOA of actors for waste valorization in the first place, and the (modest) role that a digital twin can play in changing these factors. For successful implementation, user-driven design focusing on practical decision-problems rather than technological potential is key.

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Learning from lead users: technological needs for diversified cropping systems

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Keywords: lead user innovation, crop diversification, strip cropping, technology requirements

Introduction

Crop diversification offers agronomic, ecological, and social benefits, yet its adoption is limited by a lack of suitable technologies (Boeraeve et al., 2020; Beillouin et al., 2021; Juventia et al., 2021; Morel et al., 2020). Especially since agricultural technologies are still largely designed for monocultures (Fountas et al., 2020; Ditzler and Driessen, 2022). This study investigates the technological needs of lead users (Von Hippel, 1986), farmers pioneering crop diversification, and focuses on strip cropping in the Netherlands. Strip cropping is a form of diversified cropping where two species are grown in alternating strips with at least one strip including more than one row (Yu et al., 2015).

Methods

Using national crop registrations data from 2023, we identified farmers across the country practicing strip cropping with strip widths ranging from 1.15 to 38 meters. Through interviews, observations, and focus groups with 20 leading farmers between March 2024 and July 2025, we identified innovation gaps and solutions across the crop growth cycle. To align with the explorative nature of this study on technology development for crop diversification, we based our data analysis procedures on the recommendations by Gioia et al. (2012) for Grounded Theory (Strauss & Corbin, 1997). We mapped challenges and innovations to inform broader technology development and support wider adoption of diversified cropping systems.

Results

Our data shows the diverse technological needs of lead users engaged in crop diversification. Generally, innovation tends to emerge among those with higher levels of diversification, as their specific requirements are often unmet by existing market solutions. While current technologies adequately support farmers using wider strip widths, those employing narrower strips encounter more significant challenges as more precision is required. These farmers frequently develop their own solutions to address their unique needs, particularly if they increasingly rely on personal equipment due to a shortage of available contract workers.

Narrow strip systems present specific difficulties, especially in coordinating sowing with mechanical weeding and ensuring effective nutrient management. Moreover, ploughing poses a challenge in these systems. However, some farmers have addressed this through co-innovation of their management practices, effectively eliminating the need for ploughing. This highlights that not all management challenges require technological equipment; some can be resolved through systemic changes.

Despite the high degree of diversity, certain needs are consistently shared across lead users, regardless of individual preferences, level of crop diversity or environmental conditions. Notably, all lead users expressed a need for harvesting and irrigation systems tailored to

diversified cropping systems. While some responded to these needs by developing their own innovations, others cited a lack of time or technical expertise as barriers to doing so.

We identified three lead user innovation processes. One of these processes are innovations developed in farmer collectives, such as a harvest solution. These collaboratively developed technologies tend to be more sophisticated and broadly applicable, transcending individual contexts and offering greater potential to support the wider transition toward diversified farming systems.

Discussion and Perspectives

Lead users are defined as individuals at the leading edge of markets with a high incentive to innovate (von Hippel, 1986). Based on our results focusing on technology requirements it might be argued that farmers on wide strips, not experiencing challenges with technology in their management, should not be considered lead users.

However, while these farmers might not experience technological challenges, they experience challenges in other domains such as national administrations and supply chains. Moreover, research shows that wide strips still provide more ecological benefits compared to monocultures. Therefore, we refer to the leading edge status (LES) (Morrison et al., 2004) of lead users and argue that farmers with wider strips have a lower LES compared to farmers with smaller strip widths but can still be considered lead users in crop diversification.

By focusing on lead users, we shed light on specified requirements of lead users in crop diversification practices. We make several theoretical contributions. First, we identify the technological needs of farmers adopting diversified cropping systems, providing insights into the specific innovations needed to support their transition. Second, we reason which forms of lead user innovation are most valuable to support transitions from niche to the broader community.

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Handling farming system diversity in co-design approaches at farm level: comparing eight case studies

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Keywords: innovation, model, scenario, on-farm experiment, territory

Introduction

Agriculture and food systems are under pressure and changes are needed, at different scales, both in western agriculture and in the global South. Co-design is one way to support the transition of farmers towards sustainable farming systems (Prost et al. 2023). Co-design approaches appear mostly implemented at cropping system scale. This allows in-depth consideration of sustainable cropping practices, but can fail to allow a holistic picture of issues and trade-offs farmers face at farm level.

Co-design processes at farming system level are relevant to tackle the connection between cropping systems and other farm components (e.g., livestock system). It also considers resources and constraints (access to land, to workforce, equipment, markets...), as the farm level is, alongside the activity system, the scale at which farmers take their decisions (strategic, technical and resource allocation decisions, e.g., work organization).

However, co-design at farm level implies managing the complexity and diversity of farming systems that may exist in the territory. In this article, we explore the specificities and challenges of co-design approaches that made emphasis on farm scale and/or articulation between farm and territorial scales, based on eight case studies conducted in Europe and the global South.

Methods

As a research team focusing on innovation in farming and food systems, we documented design processes we conducted at farm level in contrasting pedoclimatic and socio-economic contexts. The selection criteria for case studies were a recent scientific publication, and the availability of a "case manager" (person involved in the management of a case study) for interview.

The framework for case description covers the context and objectives of the initiative, the involved stakeholders, the steps of the co-design process, and results of its implementation and evaluation. Eight case studies were selected in Guadeloupe, Colombia and Honduras, France (3 cases), Morocco, and Burkina Faso (2 cases).

Results

(i) Farm-level co-design approaches follow similar steps but with various participatory tools

Despite the diversity of the methods used, similar steps were found: a diagnosis based on a farm typology allowing to highlight the diversity of constraints, opportunities and objectives at farm scale, the development of an artefact to represent the whole farm functioning, individual or collective interactions with stakeholders to explore technical or organizational innovations at various scales. The case studies then used on-farm experiments and evaluation of the most

promising options or ex-ante assessment and collective evaluation of the potential effects of the promising options. The prerequisites to implementation of the most promising options are discussed in a final step.

(ii) Co-design at farm scale involves exploring a diversity of technical options

Each case study explores diverse technical and management options, both at cropping system and farming system scale. For example, the introduction of grazing animals in banana cropping systems involves changes at farm scale due to the introduction of a livestock system in the farm. The technical and management options explored in approaches using models are more disruptive than in other approaches. In each case study, even when a main innovation is explored, its specific implementation varies from farm to farm. For example, in Burkina Faso, the specific modalities of crop-livestock integration differed according to the type of farmer.

(iii) Managing farm diversity and change

In all cases, a large diversity of stakeholders was involved in the process. The use of farm typologies also translates the intention of integrating a diversity of farm types in the process. In most cases, the team driving the co-design process (often the research team) handles the artefacts and controls the steps of the process, but not the content, i.e. the innovations explored during the process, resulting in the observed diversity in the technical and management options. Lastly, with the intention to bring changes at scales above the farm scale (watershed, territory, region) relevant stakeholders are involved at the steps of co-design and ex-ante evaluation. An additional step of discussion on pre-requisites to implementation with these stakeholders is held in the cases Saïss, Vineyards and CSA. This is a way to connect the farm level to institutions, to discuss changes in public policies or advisory services.

Discussion and perspectives

Challenges identified for farm-level co-design processes pertain to the complexity of farming systems and the diversity of farms (Prost et al. 2017). An interdisciplinary team is helpful, but the co-design process may require more time and energy to communicate and find common grounds.

Our case studies display a profusion of explored technical and management innovations during the co-design process, related to the diversity of farming systems. Facilitators have to adapt to a given context while encouraging the exploration of a variety of technical and management innovations.

Lastly, involving a large diversity of stakeholders, especially when connecting the farm scale to larger scales (watershed, territory) requires adaptations to the language and levels of technicity of the different parties involved (Leclère et al. 2023).

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Farm system design principles based on indigenous knowledge: the case of Māori farmland in New Zealand

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Keywords: farm system design principles, indigenous knowledge, Māori farms

Introduction

This paper examines how farm system design can be adapted and guided by indigenous knowledge and aspirations. Māori people, the indigenous people of New Zealand, make up about 15% of New Zealand's population. Māori land has been estimated at about 5.6% (1.5 million hectare) of NZ land. Over half is managed through trusts and incorporations, mainly for agriculture. Most Māori land (nearly 80%) is non-arable due to historic confiscations in the 1800s or early 1900s (Harmsworth and Awatere, 2013). Current uses include agriculture (44%, mainly sheep, beef and dairy, with some horticulture), forestry (25%), and conservation/native bush (20%) (StatsNZ, 2018).

Māori trusts and incorporations manage diverse assets, including farms, aiming to fulfil iwi and hapū (tribe) aspirations. As these entities grow, there's increasing pressure to reclaim land from long-term leases and manage it through a Te Ao Māori (the Māori world) lens, requiring collective owner approval to ensure cultural and environmental sustainability (Kingi, 2025). However, many trusts and incorporations still struggle to know where to start and capability building is needed to enable them to co-design new farm systems with non-Māori experts.

This paper summarises the learnings from working with a range of Māori entities over the last 10 years, and some of the processes co-developed to design farm systems on Māori land, while ensuring rangatiratanga (chiefly autonomy). This calls for a trans-cultural approach to farm system design, embedded in Te Ao Māori, using their values and principles. Such principles need to be applied to modern farm systems, using modern farming tools, as well as traditional knowledge (Dominati and Watson, 2019).

Methods

Designs for Māori land are usually much broader than farm plans and include all ecosystems (land, water, vegetation, biodiversity, people), the farm only being one of them. These whenua (land) plans usually consider the state and performance of the whole area of interest to deliver, not only economic performance, but also environmental, social and cultural benefits for multiple generations going forward.

A process has been developed, using integrated farm planning as a base, while being driven by Te Ao Māori and tikanga Māori (cultural practices) as fundamental beliefs and practices to inform land planning and development of Māori farmland. A Te Ao Māori view is holistic and encompasses the following elements (Dominati et al., 2023): Aspirations, goals, and priorities of the landowner(s), Tikanga Māori and Te Reo Māori (Māori language), Traditional environment and whenua management methods, practice, and guidance, Te Tiriti o Waitangi (Treaty of Waitangi) principles.

The process followed is a common farm planning process, used as a basis for both industry and regional planning in NZ. When implementing a farm planning process under a Te Ao Māori framework, the main differences in the co-design method are how the goal setting is done, the

principles and values behind the farm planning process and how the process itself is carried out.

Results

In practice, when implementing a farm planning process under a Te Ao Māori framework, the main differences in the co-design method are how the goal setting is done, the principles and values behind the farm planning process (Dominati et al., 2023) and how the process itself is carried out. In brief:

(i) **Who does the work:** mana whenua (the people of the land) need to be involved from the start to reconnect people to their whenua and whakapapa (genealogy), and drive the design process themselves, starting with wānanga (forum) about the aspirations of the hapū (tribe). Work on the land can also be seen as an opportunity for capability building for local whanau (family) and to bring people back to the land. The non-Māori researchers can help manage the process, facilitate the conversation and translate aspirations into brief of requirements for the design.

(ii) **How it is done:** methods need to be adapted. Following tikanga (traditional practices) should be a priority, when knowledge is available, especially when dealing with Taonga (treasures) such as land, water, and vegetation. For example, using karakia (prayers) when planting or sowing and respecting access to cultural sites of significance.

(iii) **When it is done:** using local knowledge around the use of Maramataka (moon calendar) for example, to time interventions on farm, such as planting, sowing, harvesting or even animal mating, is a practice many Māori farms are trying to implement more these days.

(iv) **What is used:** Sourcing local material for biodiversity restoration or conservation plantings for example, would be a priority. Mātauranga (knowledge) around native plants, and what species to use should guide restoration programs for example.

Discussion

Whenua plans generated are usually much broader than just the farm business, include longer time frames, include a mix of qualitative and quantitative indicators across indigenous and western knowledge frameworks, as well as elements of capability building for whanau (family). The outputs of a whenua planning process would include: Goals and aspirations documents, with associated targets, A work plan, with activities and associated budgets, Experts list to call upon for specific advice. Work in progress is focusing on skill transfer and using whenua plans as a base for branding.

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Soil structure preservation: an approach to support the farmer's decisions on cultural intervention at the cropping system scale

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Keywords: decision support approach, soil structure management, compaction risk, cropping system

Introduction

Preserving soils physical fertility is a major challenge for maintaining high productivity while reducing the environmental impacts of cropping systems. Research work conducted over 20 years by the INRAe team in Estrées-Mons (Hauts-de-France) on the impacts of cropping systems on the evolution of soil structure (Boizard et al., 2002) inspired the regional R&D project Sol-D'Phy led by Agro-Transfert-RT since 2012. Through a regional diagnosis, this project highlighted the existence of deep compaction in 1/3 of systems observed, integrating beets, potatoes and/or certain industrial vegetables. Significant yield losses have also been observed in connection with this soil structure degradation. The use of very heavy machinery in the fields, for harvesting or planting industrial crops, while the soil is wet to a great depth is the main cause. In this context and considering the increasing frequency of rainfalls in spring and autumn, with current climate change, optimizing the management of the physical components of soil fertility has emerged as a priority.

The objective of the presented work was to design and formalize a progressive-decision support approach aimed at helping farmers manage their cultivation interventions at the cropping system scale, to correct soil compaction and/or prevent the risks of future compaction.

Methods

In the first phase, the Sol-D'phy project made it possible to develop simplified diagnostic methods for soil structure to enable farmers and their advisors to observe and assess for themselves the structural state of their soils at different key stages in the management of their system.

In the second phase, multi-year experiments were conducted in a fields network, in direct collaboration with farmers and their advisors: In each field, an initial situation with deep compaction was identified and characterized with the farmer (description of the operation + soil structure diagnosis); Then, the strategy for restoring the physical state of the soil was discussed with him and his advisor, considering: the risk for the following crop productivity; the possibility or not of effective mechanical intervention in the short term (decompaction; cracking); the capacity for natural regeneration of the soil structure; Various mechanical intervention methods to restore soil structure were tested, based on the crossed visions of the three stakeholders. The fields were monitored on a rotational basis over four or five years, with, each year, soil structure assessment realized and shared between them.

Results

The three stages of application of the approach:

The first one (Module-1) consists of: (i) Assessing the structural state of the field at a time t, after a cultivation operation or to anticipate another, by implementing the appropriate simplified

diagnostic methods: for example, penetrometer rod + Spade or 3D mini-profile methods, chosen according to the suspected compaction depth, (ii) Consider the following crops sensitivity to compaction, and soil natural regeneration possibilities.

The decisions to be made are therefore oriented towards the need for: Mechanical correction of the structure (Module-2): immediate (2a): if the following or post-following crop sensitivity requires it and if it is possible: e.g. if the soil is wet, only ploughing is possible and deeper compaction cannot be corrected at that time or deferred (2b): loosening in dry soil after harvesting a cereal to accelerate the regeneration of deep compactions; Or to adopt a prevention strategy (Module-3), taking care: not to weaken the soil during the growing season by working the soil too deep and too intensely (3a) and to protect it by reasoning as best as possible the conditions for the intervention of heavy machinery on the entire crop system (3b), therefore in the medium term.

Once the chosen decision is implemented, the user returns to module-1 for the next campaign.

Discussion and Perspectives

The Sol-D'Phy decision support approach is currently being deployed to a wider audience of farmers than the circle concerned by the project. The practical application of the approach is generally meaningful to advisors and to farmers. In particular, it allows farmers to have an informed reading of quite frequent problematic situations in their cropping systems, which they struggle to analyze and therefore manage alone. Usually, they opt first for curative operations, after the occurrence of accidents visible on the surface. The approach leads them to better characterize the real degradation of soils, and to reason these operations, by integrating the scale of the cropping system, to make them more effective. This also leads them to more easily consider the preventive levers which will allow them to learn to gradually restore and preserve the structure and therefore the physical fertility of their soil. In this respect, the approach is in line with the methods designed to support the change of practices proposed for several years by teams basing their research work on the analysis of field action (Meynard et al., 2012).

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Supporting the agroecological transition of farmers' collectives: an online survey on the current practices and needs of French winegrowing and fruit advisors

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Keywords: support pathway, sustainable agriculture, perennial cropping systems

Introduction

Fruit tree production and viticulture rely on heavy use of phytosanitary products, e.g., the average number of pesticide treatments in France was 31.2 on apple in 2017 (MAAF, 2021) and 12.4 on grape in 2019 (AGRESTE, 2023). Changes in agricultural practices are therefore necessary, and supporting farmer collectives is essential for a successful agroecological transition. Indeed, these collectives serve as hubs for knowledge sharing, innovation, and mutual support (Faure et al., 2012). However, supporting farmers to collectively reconsider their system requires specific supporting skills and tools to cope with these major challenges (Cerf et al., 2011; Prost et al., 2023). The Vitarbae project aims to develop a modular path to support fruit and grapevine growers in their transition to agroecological systems based on existing and innovative tools. In order to build this support pathway and its toolbox, we launched a web survey addressed to winegrowing and fruit-production advisors, aiming at characterizing their present practices in terms of supporting farmer collectives of wine- and fruit-growers and at identifying their needs in skills and tools.

Methods

The online survey (LimeSurvey software), ran from 30 July 2024 to 27 September 2024. The survey was designed to be quick and simple, with multiple choice and open-ended questions, allowing an average response time of 15 minutes. The questionnaire consisted of a total of 25 questions, divided into 4 parts: the situation of the respondent, the characterization of the group(s) of farmers supported, the tools used by the respondent or the interest in new tools to support them, the difficulties encountered and any needs. The first two questions allowed to determine whether the respondent met the criteria required to continue with the questionnaire according to his or her profile. Only the responses of participants working in at least one of the two sectors (fruit- or wine- production) and accompanying at least one group of farmers were included in this analysis.

A mapping of French advisors working with groups of fruit- and wine-growers for agroecological transition has been carried out, allowing to individually target around 350 potential respondents. Distribution has been completed via mailing lists and social networks.

Results

Of the 206 responses, 114 complete responses came from 51 advisors specialised in the fruit tree sector, 48 in viticulture and 15 in both sectors. As the distribution was balanced, a combined analysis was carried out. The main organisations to which the surveyed advisors

belong are chambers of agriculture (40%), followed by Organic Farmers' networks GAB (14%), cooperatives and other farmers' groups such as CIVAMs and CETAs (15%). 40% of respondents work with just one group of farmers. It should be noted that 11% of those questioned do not consider themselves trained to support the agro-ecological transition.

Two-thirds of the advisory activities listed in the survey are carried out within the framework of the National Action Plan ECOPHYTO (DEPHY FERME, DEPHY 30000, GIEE), while one-third are carried out without a specific framework. The main themes addressed by the farming groups receiving support are the substitution and/or reduction of phytosanitary products (83% in viticulture; 63% in arboriculture), as well as soil cover and weed management (71% in viticulture; 47% in arboriculture).

As far as the means of organisation and resources used by the advisors are concerned, the main meeting methods are meetings in the field (89%), indoor meetings (88%) and external visits (72%). The frequency of group meetings ranges from once a quarter (45% of respondents) to less than twice a year (26%). In addition, 87% of respondents also provide individual support to all or some of the farmers in their group(s). Most of the surveyed advisors used their own facilitation techniques. For 19% of respondents, tools (serious games, multi-criteria evaluation tools, design models) are used during support sessions, the main reason for their use being to explore alternative solutions. We can stress that the facilitators of tree growers' groups do not have any serious game linked to the simulation of agro-ecological technical itineraries.

The main constraints faced by advisors in supporting groups are: Lack of time compared to their other tasks (38%), Lack of time or interest from farmers (29%), The lack of specific tools (11%) and adapted training (10%).

Discussion and perspectives

The survey results suggest a potential change in the posture of advisors, who are moving from expert advice towards a support role that fosters the sharing and co-construction of knowledge with and/or between farmers. This shift in posture is also highlighted by Meynard et al. (2012), who stress the importance of using adapted tools to support each specific stage of the cropping system design loop, and of combining individual guidance with collective support, as it is currently practiced (Klerkx et al., 2017).

In the Vitarbae project, we are working on the development of specific tools for arboriculture and viticulture, and on ways to facilitate their use by advisors as part of agro-ecological transition support pathways like Berthet et al. (2015). Ultimately, we wish to strengthen farmers' collectives for them to reconsider individually and collectively their systems towards sustainable and resilient agriculture.

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Co-design enables farmers to conceive ways of managing grassland diversity for animal health despite a lack of technical references

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Keywords: Co-design, Grassland diversity, Animal Health

Introduction

Livestock production is now controversial mainly for its ecological consequences. One way to achieve an agroecological transition in this sector is adopting integrated animal health management (Wezel et al., 2020). Feeding is one of the levers to integrate health management (Lamothe and Savietto, 2017). In ruminant production, grass, represents an important part of the diet. Interest of grasslands for agroecological transition has been proven (Millennium Ecosystem Assessment, 2005). However, the effects of some grassland species' secondary metabolites, which have antioxidant or anthelmintic properties (Poutaraud et al., 2017), on animal health remain unclear.

A study led in 2023 on 30 French livestock farmers identified four farmer profiles based on their knowledge of plant properties, and their expectations of health services from grassland diversity for examples (Rose et al., 2025a). Some farmers said they have practices that allow them to benefit from these services. We adopted an on-farm innovation tracking to qualify these practices (Salembier et al., 2021). However, few practices involving grassland diversity for animal health management were qualified (Rose et al., 2025b).

In this work, we assumed that fixation effects stopped the transition from representation to practice. The co-design method, especially the KCP method, is known to produce innovative solutions by unfixing participants and stimulating creativity (Berthet et al., 2016). This method enables farmers to find their own solutions instead of receiving advice about the "best solution" (Dumont et al., 2020). Additionally, it includes knowledge input which appears relevant in our controversial context and the lack of evidence regarding health effects of grassland diversity. KCP method takes place in 3 phases: i. knowledge input (K), ii. Idea formulation (C), iii. Project construction (P) (Berthet et al., 2016). We hypothesized that this method will enable farmers to co-design innovative practices and identify what is fixing them.

Methods

A committee (2 farmers, 2 farmers' groups facilitators, 2 botanists, 1 veterinarian, 3 animal scientist) has defined the objectives of the workshops, decided on the necessary knowledge inputs and associated speakers, and constructed a control CK-Tree.

The workshop took place over 2 days: 1,5 days for knowledge inputs (K) and 0,5 day for the C and P phases. Farmers belonging to groups working on animal health or grasslands were invited. Participants had presentations on plants health properties and farmers' testimonies (videos, farm tour) about managing grassland diversity for animal health. The idea exploration phase (C) was tightened to a specific question from a farmer: "how to take better account of grassland diversity to improve the fertility of suckling cows". For the project phase (P), the farmer selected the most interesting ideas and explain why.

Results

Five farmers participated on the first day and ten participated on the second, eight of whom took part in the C and P phases. Four farmers were present both days.

In total, 28 ideas were formulated, 16 ideas concerned grasslands, in which only 6 ideas were linked to grassland diversity. The remaining ideas were related to water quality, herd management, genetics, and mineral and vitamin supplementation.

Presentations from K phase were poorly mobilized in farmers' discussion, appearing only three times. Otherwise, a lack of knowledge was identified, for example: is there a grassland plant with fertilizing properties?

Discussion and perspectives

Co-design enables farmers to pass from the representation of health potential of grasslands to conceiving practices to benefit from it. Even though, the subject and the local context of the farm led farmers to focus first on feeding supplementation, the workshop allowed farmers to overcome this fixation effect (Agogue and Cassotti, 2013).

Nevertheless, few ideas were related to grassland diversity. An explanation is that the lack of knowledge and proof of the effect of grassland diversity on animal health prevents the formulation of concrete practices. As Ravier et al. (2018) point out, producing knowledge seems necessary to go further. We suggest continuing the work with farmers and other stakeholders to determine what evidence and knowledge is needed.

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Designing with animals and other stakeholders - first steps towards redesigning sustainable dairy goat barns

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Keywords: Co-design, system analysis, animal requirements, dairy goats

Introduction

Dairy goat farming and other components of the agri-food system are undergoing a sustainable transformation. Citizens, consumers, policy makers and other stakeholders are becoming increasingly critical of the organization, practices, and impacts of food production, particularly about climate change, biodiversity loss and animal welfare. In this context, this research was conducted to generate knowledge and initiate an interactive redesign process, aimed at developing more sustainable housing systems for dairy goats in the Netherlands. The primary objective was to identify and develop multiple design principles and housing concepts for dairy goats that (a) reduce emissions of ammonia, methane, and other greenhouse gases, and (b) enhance animal health and welfare by, e.g., (environmental enrichment) increasing the choice options regarding resting areas and surface materials. This will subsequently lead to a better alignment with societal wishes and goals.

Methods

The design process was structured according to the 'reflexive interactive design' (acronym in Dutch, RIO) methodology. RIO is a participatory action research approach that enables researchers to synthesize the diverse and sometimes (seemingly) conflicting interests and priorities of stakeholders to design more sustainable livestock systems (Bos et al., 2009; Elzen & Bos, 2019; Puente-Rodríguez et al., 2019). Based on this synthesis, researchers collaborate with other stakeholders to develop feasible redesign strategies.

RIO is structured in four phases, namely: System analysis; structured design I & II and anchoring. To achieve the research objectives, this study performed some key steps of phase 1 and 2(3). First, a system analysis of the current common housing systems in Dutch dairy goat farming, i.e., the deep litter barn: Historical perspective and advantages and disadvantages of this system. Second, a literature review on the behavioral and physiological needs of dairy goats. This serves two main purposes: to develop better animal welfare standards and to explore whether goat behavior can be used for emission reduction purposes. Third, an experiment to observe the behavior of a group of fifteen dairy goats when given access to elevated platforms in a deep litter barn under practical farm conditions. The aim of the experiment was twofold: To explore ways to improve the quality and diversity of resting areas, enabling goats to select their preferred resting sites, while reducing the excretion surface area to reduce emissions. Finally, the gained insights were integrated into an interactive design process in which new barn concepts were developed. The governance of the project (≈ 2 years) was as follows: A core team (design process-oriented researcher and experts) and a group of stakeholders (7-10; policy makers, farmers, etc.) that acted as an advisory board. The first versions of the design concepts were generated in a design workshop. The results were communicated to farmers, the sector, policy makers and academics.

Results

The Dutch dairy goat farming sector relies on the deep litter housing system, with few alternative systems in use. For many stakeholders, this system is an integral part of goat farming. Moreover, there are romanticized ideas about animal farming in which straw plays a key role, and different stakeholders would like to keep it that way. However, several factors strengthen the case for its transformation, e.g., ammonia and greenhouse gas emissions, animal welfare challenges, and public health issues.

The literature review showed that experiments with goats are usually conducted with small groups, in short periods, and with different breeds. This leads to primarily qualitative results with little replication, making comparison challenging. However, despite individual and breed differences, a number of goat-specific behavioral traits can be identified to enhance positive animal welfare (Rault et al., 2025) such as, access to elevated platforms and outdoors runs, cognitive challenges, or enabling behaviors such as fission-fusion, fleeing, etc.

The pilot showed that the goats in the experiment used the platforms approximately 40% of the time – for climbing, walking, lying down and hiding/resting underneath. This indicates that such structures are interesting candidates for enriching dairy goat barns. Furthermore, the experiment showed that goats also excreted on the platforms, highlighting the need for further research to reduce the ammonia-emitting surface by better understanding and utilizing goat behavior.

Three barn design-concepts were developed: The Brook Valley Barn; The Grandstand Barn, and Dairy Goat Barn The Podium. These concepts integrate various principles and measures aimed at reducing ammonia and greenhouse gas emissions and improving animal welfare. Key innovations include coated iron flooring systems with a manure separation belt underneath, elevated resting platforms, innovative feeding systems and manure management practices.

Discussion and Perspective

Livestock farming, including dairy goat production, faces numerous sustainability challenges. In the Netherlands, design requirements are shaped by biodiversity obligations, climate commitments, public health, and animal welfare. The insights gained in this study regarding the current deep litter housing system and animal welfare needs inform these discussions and identify critical knowledge gaps.

The new barn designs presented here should inspire, stimulate discussion, and encourage experimentation. In the short term, pilot projects and longitudinal experiments should be conducted on different farms before choices are made about floors, manure management, and enrichment elements. The pilot study presented here provides an interesting experimental framework for studying the use of elevated platforms. In the long term, a balance must be found between the needs of goats, society, and farmers, to align sustainability goals with the economic viability of dairy goat farming.

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Comparison of two participatory approaches for agroecological design: consultative vs collaborative

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Keywords: spatio-temporal arrangement, cropping plan, market-gardening

Introduction

Spatio-temporal design of agricultural systems is a key lever for enhancing ecosystem services while meeting the socio-economic objectives. However, its implementation in highly diversified cropping systems remains challenging due to (1) the complexity of ecological interactions, (2) the combinatorial nature of design choices, and (3) the need to integrate diverse knowledge sources. Participatory approaches help address these challenges by combining scientific knowledge, expert insights, and farmers' experiential know-how to develop locally adapted solutions (Berthet et al., 2016). Integrating participatory approaches with AI-based methods has proven effective in tackling these challenges (Challand et al., 2025) but the relevance of the results obtained may depend on the way in which interactions between farmers and designers are implemented.

Our objective is to compare two participatory approaches for agroecological design, applied to the same case: developing a diversified market gardening cropping plan for a single farm. According to Biggs' scale (Lilja and Bellon, 2008), the first approach is consultative, as farmers provide input at key stages, but the agronomist leads the process. The second is collaborative, as farmers and researchers actively co-design solutions throughout the main steps of the process.

Methods

The case study is a one-hectare micro-farm located in southern France (43°26'34.265"N 6°5'46.028"E). The objective was to allocate 60 crops to 80 cropping beds for the 2023 season while optimizing productivity, labor management, pest control, and soil fertility. The design process followed three stages: (1) identifying key problem data (cropping calendar, beds location and attributes) and formalizing objectives with farmers, (2) using the AGROECOPLAN model to generate a cropping plan based on defined constraints and (3) evaluating the plan's performance by assessing constraint satisfaction. This method was initially applied using a consultative approach, where farmers are consulted to define objectives and constraints, provide the required data and give their feedback on the final solution (Challand et al., 2024). It was then implemented by combining consultative steps for problem diagnosis with collaborative steps for refining constraints, building and evaluating solutions (Challand et al., 2025). To compare these approaches, we used Prost (2019) conceptual framework, which distinguishes three key aspects of design: (i) problem formalization, involving the diagnosis of the current situation and definition of objectives; (ii) solution formalization, consisting of generating and exploring possible solutions; and (iii) problem-solution articulation, linking problem definition to solution development.

Results

In the consultative approach, problem formalization (Pole 1) is conducted through an interview to diagnose the initial situation, collect problem-related data, and define objectives and constraints. In the collaborative approach, the process is similar, but no initial diagnosis is performed, as the participatory process itself progressively reveals the necessary diagnostic elements. Solution formalization (Pole 2) follows the same process in both approaches: the AGROECOPLAN model generates solutions that meet the identified constraints unless the problem is over-constrained. The key difference lies in problem-solution articulation (Pole 3). In the consultative approach, the agronomist independently adjusts constraints based on the initial diagnosis, maintaining the original specifications fixed. In contrast, the collaborative approach actively involves farmers in revising constraints and evaluating solutions throughout the process, allowing continuous adjustments and a dynamic redefinition of their vision for the future.

The farmer's evaluation of the process and the cropping plan highlights that: (1) both approaches generate disruptive plans, (2) the collaborative method facilitates better knowledge elicitation, as new insights emerge throughout the process rather than being limited to the initial diagnosis in the consultative approach, and (3) collaborative design leads to more actionable and farmer-appropriate results.

Discussion and perspectives

Involving farmers in modifying constraints, whether to find or refine solutions, allows the problem and their vision of the future to evolve—unlike in the consultative approach, where these remain fixed on the objectives defined during the diagnosis. This adaptability is particularly valuable for complex problems that are difficult to define in advance (Meynard et al., 2012). Additionally, having farmers adjust constraints and observe model outputs helps elicit tacit knowledge, as they formulate implicit constraints, explain their rationale, and clarify their priorities. Engaging farmers in solution design, evaluation, and improvement also led them to reassess their management practices, challenging their usual approach to cropping plan design. The collaborative process fostered reflexivity and learning, which did not occur in the consultative approach. Finally, the collaborative approach enabled farmers to progressively build an acceptable compromise by prioritizing and specifying constraints based on their knowledge and priorities. This iterative process not only facilitated decision-making but also enhanced their ability to adapt their system, balancing operational realities with agroecological benefits.

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Facilitating crop-livestock integration across farm and territorial scales with ovi'plaine serious game workshops: insights from case studies

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Keywords: Integrated crop-livestock systems, Co-design, Mixed farming systems, Sheep farming

Introduction

In Europe, farms and agricultural regions have become increasingly specialized (Schott et al., 2018). Crop-livestock integration can help to meet a number of challenges, such as improving nutrient cycling, maintaining habitat diversity and increasing the adaptability to climatic and socio-economic hazards (Peyraud et al., 2014). Among crop-livestock integration, sheep grazing of crops and intercrops is a promising way to reintroduce livestock into grain-producing areas (Farias, 2022) but major obstacles remain, as a compulsory need for a consistent coordination between activities at territory level (Moraine et al., 2017).

Participatory approaches could help meet this need by making farmers designers and not only beneficiaries of external solutions (Prost et al., 2017). Serious games have this potential as they allow players to build a shared vision to address issues and to translate it into action (Dernat et al., 2022). Few participatory approaches dedicated to crop-livestock integration have been created to date, the serious game Ovi'Plaine being one of them dealing with sheep crop grazing.

In this study, Ovi'Plaine based workshops with cereal growers and sheep farmers were organized in order to better understand technical and organizational levers at individual and collective scale to enable sheep crop grazing development.

Methods

The game features a board and tokens respectively representing the plots and potential resources. The aim is to simulate a grazing itinerary by moving the herd around the plots. A calculator was used to assess the possible grazing time for each plot. The calculator takes into account the flock size and the physiological stage of ewes to calculate their feed requirements. It also uses the plots sizes, the potential grazing resources and the moment of their availability for sheep to estimate the quantity of sheep that can be fed for each month.

Interviews and workshops are recorded and transcribed. Notes and pictures are also taken. Our studies areas are selected for their specialization in field crops and their existing request for coordination, for now in the northeastern France and in the Paris region. For each study area, an Ovi'Plaine based workshop is prepared. Preparation consists of interviews with farmers to understand personal goals, quantify resources and needs and identify plots. Beyond interviews, many discussions with farmers can occur during this preparation process.

Results

Workshops preparation made it possible to identify the context for each case study. These data serve as a basis in order to adapt the workshops to their context and subsequently enable

the comparison of observations made during and after the workshops. Interviews enabled to understand for each case study the sheep grazing project status. For example, in the Northeastern France territory, a couple of shepherds settled in three years ago. In this case study, there is a need to plan future grazing itineraries to coordinate action between shepherds and already involved cereal growers in a context of sheep flock growth. In this case, technical issues are the lack of knowledge regarding the periods when resource is lacking and the need to quantify the feed availability provided by new cover crop planting methods. There are also organizational issues such as the lack of coordination between cereal growers in order to make resources available throughout the grazing period (September-March). Such issues were identified for each case study. The workshops carried out made it possible to build grazing itineraries and understand the technical and organizational logics that guide them. They highlighted the link between individual choices and collective practices.

The aim of the study is to analyze the data collected in order to understand how technical and organizational issues interact, at both individual and collective levels. Longitudinal monitoring is therefore carried out to track farmers' design activity. Follow-up interviews enable us to understand the place of the workshops in the broader process of developing the grazing activity in each case study.

Discussion and Perspectives

Observations made before, during and after the workshops should allow us to evaluate the tool's ability to assist farmers towards better crop-livestock integration, as the lack of evaluation is an identified shortcoming for serious games (Dernat et al., 2025). As part of the evaluation, changes in the practices will be monitored. However, a serious game is only one part of a participatory process. Organizing workshops enables us to understand this broader process. Specific cases are analyzed during this study. To increase genericity, other case studies need to be compared with these.

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Accelerating Canadian net-zero through co-design research with farmers and indigenous communities

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Introduction

In Canada, approximately 62.2 million hectares, spanning nearly 200,000 farms, remain underutilized resources for biodiversity conservation, resilient crop production, and GHG (greenhouse gas) mitigation and reduction. Settler and Indigenous farmers are essential players in the custodianship of biodiversity and carbon sinks, playing a critical role in maintaining agroecosystem integrity and resilience. Innovative practices are already in motion on some farms. In this way, farmers have already gone through a co-design process to adopt new, more sustainable farming practices. Our research team is currently evaluating innovators' pathways to implementation, and we will use the information to accelerate adoption amongst the greater farm community on the Canadian prairies.

When assessing outcomes of farm practices on people, animals, and the land, co-designing those metrics by incorporating scientific/academic knowledge as well as the invaluable lived experiences of farmers ensures that farmers are a key part of the research process. The co-design process identifies and describes what is important to them and fitting the research design to their understanding of the world (Asah and Blahna 2020).

For Indigenous Peoples, *miyo-pimâtisiwin* (living a good life, in Cree) does not refer only to meeting physical material (economic) needs, but also the nourishment of mental, social, and spiritual wellbeing. Thus, motivations that drive agricultural land use decisions within First Nations are complex, potentially distinct, and not well understood (or documented) by the Canadian agricultural sector but have real material outcomes to communities' economic and social wellbeing as well as on the land itself.

The project includes a set of interconnected activities that aim to characterize the practices and priorities of both settler farmers and Indigenous communities, quantify the roles of management and local site properties in agroecosystem performance, explore implementation strategies for adoption of novel practices, and envision and model future farm scenarios. For the conference paper, we will share our multidisciplinary approach to understand the barriers and drivers for farmers to 'make the leap' to sustainable production practices.

Methods

The LEAP project is conducted by five interacting teams studying the biophysical and social circumstances on real world settler and Indigenous farms, across a large area in Saskatchewan and Manitoba. In the presentation, we will focus on the co-design research strategies of three of the five activities: Farmer Engagement, First Nations Self-Determined Farming Systems, and Landscape Analysis.

To capture the biophysical impact of innovative practices, the Landscape team is currently sampling commercial fields employing low (conventional annual), medium (integration of diversity in a cropping sequence), and high (pure perennial) levels of perennality on 26 farmer fields. Simultaneous monitoring for GHG, soil health, biodiversity, crop productivity, economic performance and other indicators will provide an unprecedented real-world dataset. To understand attitudes related to innovative practice adoption, the Engagement Team led discussions with four farmer groups (conventional grain/oilseed farmers, conventional beef farmers, organic farmers, and regenerative farmers).

Results

Since the project's inception in the Summer of 2024, we have successfully established 26 farmer fields for biophysical sampling. Teams are sampling fields to evaluate soil health, GHG emissions, and biodiversity parameters. GHG (Carbon) flux towers have been installed on some fields. We will share preliminary results in this presentation.

Farmer-led discussions demonstrated that many farmers are excited for the future and improving their soil health. They are constrained by time and funds to implement practices; however, business management is the biggest challenge and lack of expertise in disciplines such as human resources and staffing pull them away from trying innovative practices.

A unique feature of our work is engagement with Indigenous communities, who own over 600,000 hectares of arable land in the region. We have tapped into existing relationships between researchers and Indigenous farmers. We are building relationships and learning their priorities on agricultural land management and Indigenous-defined metrics of agricultural sustainability. These discussions will facilitate co-design of beneficial management practices and a framework for ecological intensification within an Indigenous worldview. To date, researchers have engaged with over 30 First Nations members, land managers, and farmers. Unique challenges and points of action have emerged, such as access to their own land, much of which is presently on the cash rent market, and the need for Indigenous-focussed agricultural education curriculum development for band members and aspiring Indigenous farmers.

Discussion and Perspectives

The current structures and agricultural paradigm allow farmers to go only so far in their use of more ecological intensity. It is clear the creation of a socio-economic environment that encourages non-Indigenous and Indigenous farmers to "make the leap" which minimizes financial risk or stigma of failure is required. The LEAP project will capture knowledge from the cohort of innovative farmers who are employing ecological intensification methods. We will study these farms based on their biophysical performance as well as learning about the socio-economic and attitudinal circumstances that were important to farm redesign.

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Canadian Agri-Food Policy Institute. (2022). Census of Agriculture 2021: Land Use and Sustainable Farming Practices. Quick Think Report # **Collective experimentation processes: how groups of non-academic experimenters' experiment to produce knowledge on orphan topics**

ClieNFarms-I3S: a network structure to codesign climate neutral farms

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Keywords: Agriculture, climate neutral, co-design, solutions

Introduction

Agriculture contributes to 10.3% of the EU's greenhouse (GHG) emissions (EEA, 2019). EU agriculture is the only major system in the world that has already reduced GHG emissions (by 20% since 1990). However, despite these efforts agriculture is still one of the main sources of methane (CH₄) and nitrous oxide (N₂O) and at the same time, it offers a significant opportunity to sequester atmospheric carbon dioxide (CO₂) in grassland, trees, other plants and soils.

Carbon neutral agriculture, i.e. a farm that is neutral in terms of the GHG emission balance (CO₂, N₂O, CH₄) expressed in CO₂-eq, is possible, if appropriate farm management practices are adopted by reducing emissions and maximising GHG removals, and by considering potential synergies with biogeophysical effects as recommended by the IPCC (Calvin et al., 2023). Many solutions already exist. However, some may be costly or reduce production levels; others require collective activities among different farmers. Additionally, solutions should include the entire supply chain but also the banks, the citizens and the consumers which will increase options and might reduce risks for off-sets or other negative impacts. As for the agroecological practices, the general concepts have to be tailored depending on the production units, on the socioecological and sociotechnical systems at hand. Therefore, the different solutions have to be tested by, and adapted for farmers in an integrated, systemic and multi-actor approach. This climate-smart agricultural practices need to safeguard planetary boundaries or ecosystems services.

Methods

ClieNFarms is an Innovation Action project funded by the European Commission to support the European Green Deal. The general objective of ClieNFarms is to co-develop and upscale systemic locally relevant solutions (organisational, financial, technical) to reach climate neutral and climate resilient sustainable farms across Europe. To do so, we interactively integrated and improved existing solutions to achieve economically viable business models in farming systems by involving farmers, extension services, agri-food business, policy-makers, educators, finance and citizens. An original concept of ClieNFarms is its Living-Lab like approach called the Innovative Systemic Solution Space (I3S). The I3S consists of different components and actors who will test and disseminate tailored multi-actor, co-designed, locally relevant, innovative solutions to achieve climate-neutral farms within the supply chain and local geographical extent. Systemic indicates the inclusion of the surrounding ecosystem (suppliers, advisors, research, agro-equipment, etc.) beyond the farm. Solution space because different solutions are proposed and tailored for each (considering pedoclimatic conditions, resource availabilities and constraints). Innovative because the proposed solutions induce the adoption of efficient innovations (e.g. including the finance sector in collaborative proposals).

Creative arenas have been conducted in almost all of the 20 ClieNFarms I3S. These are participatory design workshops where action plans are sketched for a specific production system incorporating the surrounding stakeholders' ecosystem. At a given site, the replication structure is based on a dissemination upscale concept: demonstration farm (where risky solutions can be experimented/tested), lead commercial farms (early adaptors, where less risky but impact full solutions can be tested) and outreach farms (the full spectra of surrounding farmers). The supply chain plays a fundamental role in the outscaling approach. Based on farm archetypes, the project's various supply---

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Climate risk assessment in arable farming through participatory crop modelling

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Keywords: climate risk, co-design, crop model, crop system analysis

Introduction

More frequent and intense droughts and heavy rainfall render agricultural production increasingly risky, threatening farmers' livelihoods and food security. Assessing climate-related risks in crop production can help formulate short-term risk management strategies and support de-risking investment decisions by farmers, food system actors, and policymakers in the longer-term transformation toward sustainable agricultural systems. Process-based crop models (PBCMs) are widely used to assess climate change and more recently to assess impacts of extreme weather. However, for model-based assessments to effectively inform change and support sustainable farming systems, there is a growing recognition that scientific knowledge must be co-created with farmers and other food system actors (Cheriere et al., 2025). This study aims to co-create options to manage weather risks in cropping systems for arable farms in eastern Brandenburg, Germany. Using a PBCM, the study simulates current and adapted cropping systems through a participatory modeling approach, facilitating exchanges between modelers and farmers to enhance dialogue and practical relevance.

Methods

The study is conducted in the district of Märkisch-Oderland (MOL), Brandenburg, one of the driest regions in Germany. Soils are predominantly sandy with low water-holding capacity. The main crops grown are autumn-sown cereals, silage maize and rapeseed. Drought is recognized as the primary weather-related factor limiting arable crop yield. A participatory research approach was used to facilitate exchanges between researchers and farmers consisting of five key phases (Phases 1-3 completed, phases 4-5 ongoing in spring 2025):

(i) First workshop with farmers to explore general and weather-related risks and introduce PBCMs; (ii) Current MOL cropping systems simulated using a SIMPLACE PBCM (Enders et al., 2023) with data and as specified together with farmers; (iii) Individual farm visits for in-depth discussions on the modelling results, allowing researchers to learn from farmers' expertise and ideas for tangible risk management strategies; (iv) Farmers' suggested risk management strategies simulated by modeller with the PBCM; and (v) Second workshop to share the simulation outcomes, gather farmers' feedback on usefulness and applicability, and discuss ways to improve the participatory modelling approach.

Results

In the first workshop, different perceptions emerged regarding weather and climate risks. Farmers observed that rising autumn temperatures increased the risk of pests and diseases during early growth stages of winter crops, prompting them to delay sowing dates by over a week compared to 20 years earlier. As a result, gradual climate change was not a primary concern for farmers, as they are already adapting autonomously. However, farmers were more concerned about unpredictable weather events during the growing season, especially rainfall

during the critical reproductive stage. Insufficient rainfall at this time can significantly reduce grain yield. In response, farmers adjust fertilizer use based on expected rainfall, applying more if rain is anticipated and less or none if no rain is expected. It is noteworthy that while farmers focused on the cost of fertilizer as a key risk, researchers additionally evaluated the associated environmental risks of over-fertilization.

During farm visits, shortcomings in PBCM simulations were identified. While late sowing of winter wheat due to the late harvest of the previous crop (e.g. maize) reduced winter wheat grain yield significantly, the PBCM did not capture the effects of late sowing, potentially highlighting the need to improve simulation of frost-kill processes or phenology parameterization. Both researchers and farmers identified a shared interest in utilizing the PBCM for decision support, such as with use of weather forecasting data to optimize in-season nitrogen fertilizer rates. Moreover, PBCM simulations for various crops, rotations and sowing dates might help determine whether alternative rotations and associated sowing dates can reduce weather related risks. Farmers were already experimenting with new crops and alternative crop rotations, which requires significant time, land, knowledge and labour. The use of PBCM simulations can offer valuable insights to refine and inform their experimentation, reducing risks and optimizing resource use.

Discussion

Through a series of exchanges between farmers and researchers, the participatory process fostered mutual learning and helped bridge scientific modeling with practical decision-making. Farmers contributed first-hand knowledge on regional risks and management practices, while researchers provided quantitative assessments to evaluate different strategies. Some common objectives for managing weather related risks emerged, including optimizing in-season fertilizer application and exploring alternative crop rotations and associated sowing dates. Looking forward, the PBCM will be applied to address these issues in phase 4, and the results will be communicated to farmers in phase 5. To address weather uncertainty, the next phase will carry out simulations using large ensemble weather datasets and weather forecasting data, to sample a large range of plausible future conditions. The simulation results will be reported back to farmers with various probabilistic indicators, and their feedback will be gathered to determine which indicator is most useful. Consistent with participatory research principles, this iterative and collaborative approach ensures that the modeling efforts align with farmer realities (Reed et al., 2009).

Perspectives

This study serves as a starting point for integrating participatory methods with PBCM into agricultural living labs (ALLs). Living labs are collaborative spaces where science and practice intersect to address real-world and socially relevant challenges through shared experimentation. Researchers primarily led this study to explore how to frame climate risk assessments for cropping systems in eastern Brandenburg and to identify the limitations of current PBCMs from farmers' perspectives. However, for PBCMs to be effectively integrated into ALL settings, they should prioritize co-design from the outset, be more flexible to adapt model components and structures to shared research questions, and be locally recalibrated for each specific context. There are successful examples of this from Australia. However, we see the need to prioritize concepts for modular structures, FAIR calibration data resources and two-way knowledge flows between more basic science and living lab co-experimentation to ensure scientific knowledge and local innovations co-evolve.

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Ideotyping agroecological systems: a framework for the design of system innovations

Summary proposed as an introduction to the special session "From vision to action: structuring the agroecological transition with ideotyping".

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Keywords: Co-design, Food systems, Africa, Participatory workshops

Introduction

The sustainability issues affecting agriculture and food are closely intertwined, resulting in existing solutions being hampered by lock-in phenomena. In this context, researchers working on agroecological transitions need to be equipped with new design methods capable of generating complex, high-performance systems. In particular, agroecology encourages researchers to rethink crop and livestock systems as a whole, optimising the interactions between plants, animals, humans and the environment. It also calls for imagining the conditions for reconfiguring value chains and rethinking the institutions and policies that govern agriculture and food (Belmin et al. 2022).

In this paper, we offer an initial assessment of "ideotyping agroecological systems", a new co-design method being developed by CIRAD and its partners between 2021 and 2025 in West Africa. This method is designed to engage transdisciplinary collectives in a multi-dimensional, multi-scalar analysis of the problems that affect them, and to work with them to develop systemic solutions. By analogy with varietal ideotyping (which seeks to optimize crop plant models, Debaeke et al 2014), agro-ecological system ideotyping involves defining a set of ideal properties - agronomic, social, institutional, etc. - that an agricultural and/or food system should possess to maximize its performance and sustainability in a given context.

Method

The ideotyping method offers a framework for rethinking agricultural systems in their entirety, by coupling innovations relating to agriculture, value chains, territories and public policies. It involves bringing together different stakeholders (researchers, stakeholders, experts, resource persons, etc.) in workshops lasting 3 to 5 days, and guiding them step by step through a series of collective exercises leading to a shared vision of an agricultural system whose properties are deemed satisfactory by these same stakeholders (Figure 1).

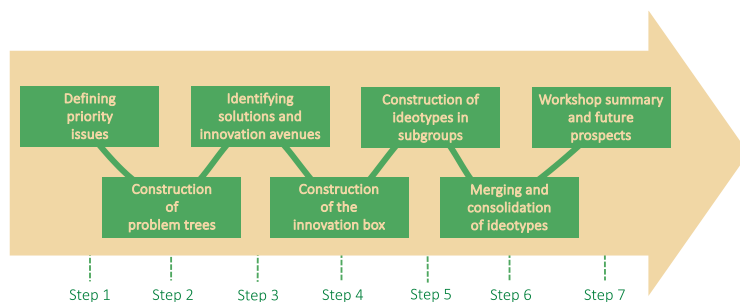


Figure 1: Typical stages in an ideotyping workshop.

Results

The first ideotyping experiments were carried out in Senegal and Côte d'Ivoire as part of several research-action projects (Santés & Territoires, Fair Sahel, Initiative Agroécologie, Safoods, Marigo and PRATAM). Table 1 shows that, for each case study, ideotyping approach was used to address specific transition challenges and made it possible to envision desirable objects of very different kinds (cropping systems, integrated farms, city-countryside food systems, and agroecological territories). The key outputs of each workshops were: (i) a causal layer analysis of the problems experienced and perceived by the actors; (ii) an innovation box containing a number of innovation pathways, each with proposals for action; (iii) an ideotype of the desired innovative system, expressed in the form of systemic diagrams, textual narratives and/or synthetic drawings. To facilitate demonstration and illustrate the type of output obtained through ideotyping, we have chosen to use the example of the workshop in Fatick, Senegal. Complete empirical data on the results of the method are provided in the reports and articles cited in the last row of Table 1.

In the various projects where the method has been tested, ideotyping has contributed to socio-technical change dynamics by: (i) initiating co-design processes for innovative agricultural systems with groups of experimental farmers, (ii) strengthening the organisational and governance capacities of sectoral or territorial innovation platforms.

Work scale	Plot	Farm	Food system	Territory
Case studies	Ndiob (Senegal) Koussanar (Senegal)	Mbane (Senegal)	Yamoussoukro (Ivory Coast) Bouaké (Ivory Coast)	Fatick (Senegal) Lower Casamance (Senegal)
Transition challenge	Ecological intensification and diversification	Improving overall health in a Living Lab	Uncontrolled use of pesticides and health risks in the vegetable industry	Global pressures and changes affecting territorial balance
Designed objects	For each case, a range of 4 to 5 agroecological cropping systems	An integrated agro-ecological production system combining diversified crops, livestock and fish farming	For each case, an innovative urban-rural food system based on the principles of agroecology	An agro-ecological, resilient and innovative region
Place in the innovation process	Initiation of on-farm experiments	Initiates a support system for volunteer farmers	Initiating an interprofessional structure	Strategic planning for regional platforms
Project concerned	Fair Sahel	Santés & Territoires	Marigo, Safoods	One-CGIAR Agroecology Initiative PRATAM
References	Belmin et al. 2022; Mboh et al 2021	Belmin et al 2023	Belmin et al 2024; Deletré et al. 2024	Belmin et al 2024;

Table 1: Key information on the various ideotyping workshops conducted in West Africa between 2021 and 2025.

Discussion

Based on these initial experiences, we can affirm that ideotyping represents an innovative approach to exploring radical, systemic changes in the social, economic and material structures involved in agroecological transitions. Unlike other approaches that have been tested in the past, ideotyping stands out in several ways: (i) it allows for the combination of numerous agronomic innovations to build integrated, context-specific production systems; (ii) it allows for the simultaneous design of both agronomic and institutional conditions for change, enabling the identification of unlocking pathways. The method makes it possible to rethink agricultural systems in their entirety, by articulating innovations relating to agriculture, value chains, territories and public policies. This approach thus helps to operationalize the "coupled innovations" approach proposed by French agronomists (Meynard et al. 2017) to build sociotechnical niches that bring about radical change.

Secondly, ideotyping seems to be a useful way of initiating co-design and/or support the agroecological transition. In this respect, the ideotypes designed in the workshop can play different roles in a design process:

Ideotype as a vision of the future: in workshops on food systems and territories, the ideotype has been interpreted as a vision of a future to be achieved, guiding strategic planning activities for multi-stakeholder platforms active in advocacy and territorial governance.

Ideotype as an agronomic model: in other cases, the ideotype has been interpreted as a theoretical model of a farming system, and has thus served as a reference point to guide in situ experimentation as part of a step-by-step design process. The design process progressed in successive iterations, with a gradual convergence between ideotypes and prototypes.

Ideotype as an idea box: In other cases, ideotypes have been used in a more flexible way, serving as a resource to identify specific actions, or change strategies limited to a sub-system.

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Sustainable intensification of rain-fed mixed farming systems in Senegal: from diagnosis to co-construction of ideotypes

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Keywords: ideotyping, ecological intensification, innovation and adaptation

Introduction

In the eco-geographical zone of Eastern Senegal, as in sub-Saharan Africa as a whole, rain-fed agriculture is of paramount importance for the food security and livelihood of rural households, particularly in areas where access to irrigation is limited (van Ittersum et al., 2016). However, rain-fed cropping systems in this region have been experiencing a downward trend in yields for several decades (Gachene et al., 2015), attributable to a complex combination of biophysical and agronomic factors such as climate change, loss of soil fertility, bio-aggressors, etc. Faced with these challenges, agronomists involved in the co-design of agroecological systems face several methodological challenges (Meynard et al., 2012). The first stems from the great diversity of regional agricultural contexts, and the heterogeneity of farmers in terms of resources, objectives and trajectories. Secondly, agronomists must organize the increasing complexity of the objects to be designed. To meet these challenges, agronomic research has developed approaches that strongly involve farmers (Prost et al., 2017), but the solutions proposed, which are often prescriptive, must then remain flexible and able to be adapted to meet the varied realities of small farms.

In this study, we introduce cropping system Ideotyping, a new co-design method that was conceived and tested for the first time in Senegal, at Koussanar. Ideotyping aims to design, within a participatory framework, cropping systems adapted to the multiple objectives and constraints experienced and perceived by farmers in a given region. Our approach aligns with existing co-design approaches but proposes to go beyond conventional approaches by integrating an ambitious projection of desirable systems ("breakthrough") to serve as a "compass" guiding a process of gradual, iterative change and adjustment ("step by step").

Methods

An agronomic diagnosis carried out in 2021 revealed that low soil fertility, weed management and the absence of structured markets were hampering production and diversification. To address these issues, an ideotyping workshop was held from May 25 to 27, 2022 in Koussanar, bringing together 61 participants from the agricultural, research and development sectors. The process took place in six successive stages.

For stages 2 to 6 of the process, four sub-groups were formed: one male, one female and two mixed, in order to reflect the gendered division of agricultural tasks and promote inclusive exchanges. Each group was supervised by a pair of facilitators (a team member and a farmer facilitator) responsible for organizing discussions and ensuring equitable participation. Ideas were written down in the local language on post-it notes, then displayed on a padex for collective visualization. The results of each stage were validated in a plenary session by all participants.

Results

Several strategies in the form of innovation paths have been envisaged to overcome the constraints identified. In total, four agricultural ideotypes were co-constructed, integrating different innovation paths according to the socio-economic capacities of producers: the "Intensive" ideotype aims to optimize resources through organic fertilization, crop rotation, residue management and better weed control. The "Extensive" ideotype seeks to reduce labor and inputs by stabling animals, conserving residues and using improved fallow. The "Innovator" ideotype advocates crop diversification (soybean, sesame, fonio) and integration of ecosystem service trees. Finally, the "Diversified" ideotype seeks to develop off-season market gardening, piloted by women, with greater access to seeds and irrigation tools.

Discussions with growers on each of these ideotypes led to the development of cropping systems with precise technical itineraries to be tested and adapted over three production cycles. They represent suitable solutions for sustainable intensification, reconciling productivity, resilience and economic profitability around diversified production intensification strategies.

Discussion and perspectives

Ideotyping is proving to be an effective tool for the co-design of farming systems adapted to local realities. Unlike conventional approaches based on farm typologies and external expertise (Klerkx et al., 2012). It enables the design of diversified production systems adapted to socio-economic, agronomic and environmental challenges. A central challenge of the agro-ecological transition is the integration of innovative practices into coherent systems. Ideotyping facilitates this integration by structuring the articulation between different practices, such as the use of mucuna and brachiaria to improve soil fertility and strengthen farm resilience. The process highlighted the value of integrating local knowledge with scientific expertise to overcome structural obstacles and foster adaptability.

Finally, ideotyping is a first step towards gradual support for change. It serves as a framework for producers to experiment and adjust their practices in line with local opportunities, underlining the need for contextual innovation and helping to evolve design approaches to enable the transition to resilient and diversified agroecosystems in Africa.

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Co-design of agroecological pathways to optimal agroecological market gardening systems focused on pesticide use reduction in the Gbeke region, Ivory Coast

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Keywords: agroecology, market gardening, ideotyping, IMPRESS

Introduction

African market vegetable production is dominated by smallholder systems facing yield gaps, climate change pressure, limited land and water access, insufficient availability of environmentally sustainable agricultural inputs, and a lack of regulatory frameworks, often overlooked by policymakers. In contrast, agroecology is increasingly recognized as a promising pathway toward more sustainable food and farming systems. In Côte d'Ivoire, ongoing initiatives aim to understand and promote agroecological practices in the peri-urban area of Abidjan, Yamoussoukro, Bouake and Korhogo (Deletre et al., 2024a, 2024b). Our objective was to co-design agroecological pathways for market gardening systems.

Methods

To achieve this objective, we organized a series of workshops involving various stakeholders within the market gardening system. The first workshop brought together multiple stakeholders to co-analyze the current situation by presenting assessment results, identifying necessary changes for local agriculture, and developing a shared vision for a new market gardening system. This process involved constructing an impact pathway using the IMPRESS method (Blundo Canto et al., 2020). This structured method is a tool for elucidating a collective and shared vision of an intervention logic through the construction of an impact pathway underpinned by a theory of change. In the second workshop, we worked directly with farmers and key stakeholders to co-design the envisioned market gardening farms and related food systems using an ideotyping methodology. This method is a participatory and systemic approach that designs idealized crop management strategies—under real world constraints but with no link with current system to allow the maximum change—by integrating biophysical models, stakeholder knowledge, and local constraints to support innovation in agricultural systems (Deletre et al., 2014b). The third workshop focused on collaboratively designing the transition from the current state to the desired future state using a backcasting approach (Piroux et al., 2024). Simultaneously, we identified potential barriers and enabling factors related to pesticide use while considering technical, socioeconomic, and political dimensions.

Results

The IMPRESS workshop highlighted that the market gardening system is an informal sector rooted in a legacy of the past. We design an impact pathway with detailed needed changes. As a result, four optimal agroecological market gardening systems and four agroecological pathways were co-designed. The four farms share the goal of promoting agroecological practices and reducing chemical input dependency. They all emphasize sustainable production methods, including on-site fertilizer, biopesticide production, and techniques to optimize resource use (e.g., drip irrigation). However, they differ in scale and focus. The ideotype, Ferme Lafissou, aims for a large, professional agroecological system with livestock integration and product transformation units. The ideotype, Ferme Grenier de la Santé, prioritizes

complete independence from chemical inputs and certification to access specialized markets. The ideotype, Ferme Likekpa, in contrast, is small-scale (0.25 ha), integrated into a wild and wooded area to minimize environmental impacts and promote agroforestry practices. Lastly, the ideotype, Ferme Bonheur du Gbêkê, focuses on economic diversification and community awareness through local communication and agrotourism, aiming for a cost-efficient and profitable model. The transition pathways to each of these ideotypes showed more similarities than differences. A roadmap was developed to support the transition from the most widespread current farm system to these ideal systems, highlighting priority actions such as farmer training, dissemination of innovative practices, and mobilization of local stakeholders for institutional and technical support.

Discussion

Our three-step approach (impress-ideotyping-backcasting) was the backbone of a living lab approach that helped the emergence of several operational agroecological cropping systems and changes in the organization of the market gardening sector in Côte d'Ivoire. In particular, farmers could select and test innovative cropping systems that align with their transition levels and preferences, testing them directly on their farms. This participatory process also enabled farmers to evaluate the progress of the co-designed pathways at various stages. The next step will be the implementation of the ideotype by the farmers.

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From ideotyping to setting up a multi-stakeholder territorial platform to promote Products of Territorial Interest (PIT): the case of Fatick in Senegal

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Keywords: Ideotyping, Products of Territorial Interest (PTI), Multi-stakeholder platform

Introduction

Researchers involved in the agro-ecological transition are having to devise new methods for supporting socio-technical change (Casagrande et al., 2023). In Senegal, since 2024, a multidisciplinary ISRA-CIRAD team has been supporting stakeholders in Fatick, a rural department exposed to the effects of climate change and the degradation of natural resources (Amar et al., 2024).

Among the emerging methods, ideotyping is emerging as a collaborative co-design approach aimed at combining innovations of various kinds to define the desired state of an agricultural or food system or an area, in response to sustainability issues (Belmin et al., 2024a; Triomphe et al., 2023 ; Mboh et al., 2023). This paper analyses its contribution to the implementation of an integrated strategy for developing Products of Territorial Interest (PIT), local foodstuffs with a high identity, nutritional and socio-economic value.

In Fatick, ideotyping has enabled a shared agro-ecological vision to be sketched out, leading to the creation of a multi-stakeholder platform promoting healthy food and territorial governance around TIPs.

Methods

The methodology is based on a participatory and collaborative approach aimed at co-constructing an agro-ecological, innovative and resilient region. It is based on interactive techniques (group work, World Café, anonymous forms) guaranteeing participation without hierarchical or social bias. The process is structured in three stages : (1) analysis of the causes and consequences of the low value-added of local products, (2) exploration of solutions via an innovation box, and (3) selection and assembly of solutions to design an ideotype of agro-ecological territory adapted to the climatic and socio-economic challenges of Fatick.

In September 2024, an ideotyping workshop led by the ISRA-CIRAD consortium and the DyTAEL resulted in the design of an agro-ecological territory model for 2035, combining agro-ecological practices, resource management, development of local products and integration of agro-ecology into public policies. This vision projects Fatick as an inclusive agricultural and food development centre.

This dynamic led, in January 2025, to the creation of a multi-stakeholder platform broadening DyTAEL to include previously marginalised players (consular chambers, consumers). With the support of the MAHDIA project, a consumer association has been set up. Shared governance

has now been formalised (technical and steering committees, a validated charter and forums for dialogue and consultation), involving a range of stakeholders.

Results and discussion

The ideotyping workshop in Fatick was a key moment for collective learning, for networking stakeholders and for building shared visions, leading to the emergence of a new institution : a multi-stakeholder platform integrating the ecological, economic and socio-cultural dimensions of the region. Its operation is based on strengthened cooperation between stakeholders, facilitating the adaptation of agricultural and food practices to climate challenges. The analysis is structured around two concepts : participatory territorial governance (Hajer, 2003), which values the active involvement of local stakeholders, and socio-ecological resilience (Berkes et al., 2003), which emphasises the capacity of systems to adapt to disturbances.

Several TIPs (millet, groundnuts, cowpeas, etc.) have been identified, and local diagnostics have been carried out in collaboration with researchers. This strategic space for dialogue and action includes structural actions : agroecological fairs, training programmes, certification, the development of quality labels and raising consumer awareness of the benefits of TIPs for health, the environment and the enhancement of the local food heritage. Far from being a simple prospective exercise, ideotyping has triggered a concrete and inclusive institutional transformation.

The results confirm the relevance of the concept of participatory territorial governance and show that ideotyping can act as a catalyst for institutional change, provided that it is part of a reflective and inclusive process. Three levers stand out: a focus on local products, the early involvement of consumers and the use of visual artefacts to feed the collective memory. Limitations include asymmetries of power, particularly in terms of gender, and the need for sustainable funding. Future research will explore the platform's resilience in the face of political inflexions and its scaling up.

Conclusion/perspectives

This paper shows that ideotyping, combined with an institutional platform, has enabled the Fatick region to make a concrete commitment to an agro-ecological transition based on the development of TIPs. The success of this approach depends on social and gender dynamics being taken into account, and on decisions being rooted in local knowledge. The approach proposes a transferable model of systemic transformation.

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Economic attractiveness of agro-ecological intensification for mixed crop-livestock smallholders: a farm modelling approach in contrasted environments

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Keywords: green manure, bio-economic modelling, trade-offs, agro-environmental performance

Introduction

Agroecological intensification could be a promising way to reconcile increase in farm income with environment preservation, in the case of mixed crop-livestock smallholder farms with low income. These farms currently experience large yield gaps and are characterised by strong interconnection between farm activities. Incorporating legumes into cropping systems is a key component of agroecological intensification (Vanlauwe et al., 2019). Despite the agronomic and environmental performance of legumes, their incorporation into mixed crop-livestock farms has been low. This study aims at answering three questions, namely: Are legumes attractive under the current market conditions in contrasting sites (i.e. locations) representative of smallholder farms? What changes in legume price is needed to improve their attractiveness? (iii) How does the level of the required financial incentive to trigger more legume cultivation vary for contrasting farm types within and across sites?

Methods

We selected six regions across three countries, representing contrasted agroecological environments and typical mixed crop-livestock smallholder farming system. The countries were Northern Laos, Zimbabwe, and Burkina Faso. Average annual rainfall ranged from 500 to 1400 mm, and average farm size from 1 to 8 ha. Households had low resources with income generally below the 2.15\$/day poverty line. All farms operated as semi-subsistence farms, with varying degrees of market integration. Current legume share in the cropland differed across the sites, from no legumes in Lao-PDR to intermediate share (~10-30% of cowpea, a grain legume) in Zimbabwe and Burkina Faso.

We built a farm model to simulate farmers strategic choices with regard to cropping systems and livestock activities. Farmers' objective was represented as maximizing annual farm income under a set of constraints, including land, cash and labour availability, and meeting household food demand. Food consumption is limited to rice, maize, sorghum, and millet. We built an energy needs constraint that ensures the total energy obtained from food consumption to meet or exceed the total required energy intake. A solver helps find the farm configuration that maximizes farm income under the limits set by farm constraints. The model does not include a dynamic simulation of carry-over effect of legumes on cropping systems. Preexisting farm typologies were used to select and model one surveyed farm per farm type, in each of the sites. 2 farms were simulated in Lao-PDR, and three farms in Burkina and Zimbabwe. Simulated and observed land allocation were compared. A scenario analysis then consisted in

introducing an incremental financial incentive for legume cultivation - 50 to 250\$ /ha with 50\$ step.

Results

The farm model reproduced the variability in observed cropland allocation across the sites with model efficiency of 0.72 and relative RMSE of 55%. Yet, the farm model underestimated legume area in farms at the study-site in Burkina Faso, and overestimated legume area in farms at the study-site in Zimbabwe.

The impact of a financial incentive for legume cultivation differed strongly across the sites. In simulated farms of Lao-PDR, a subsidy of 50 \$/ha was sufficient to drastically increase the share of legumes in the cropland, from 0 to around 50% for all farm types, replacing maize (the cash crop) with soybean. In farms of Burkina, the same amount of subsidy was insufficient to trigger legume cultivation by farmers. Possibly, cash availability was not the main constraint for these simulated farms, and the competition for food crop (sorghum) could not be alleviated by the financial incentive. In Lao-PDR, household food demand was met thanks to lowland rice fields, so that integration of legumes on the upland competed less with food production; an increase in legume profitability led to more cultivation on the upland. In simulated farms of Zimbabwe, the financial incentive was somehow ineffective in triggering the integration of legumes, possibly because the share of legume in the baseline scenario was already large (and overestimated by the model).

Overall, between-site variations were greater than within-site variations, indicating the smaller influence of farm type over site characteristics (technical coefficients for crop/livestock activities, transaction costs) in our simulations.

Perspectives/discussion

These results show that legumes are less attractive than cereals in two of the three studies sites. This study is on-going and refinement in the farm model calibration, and analysis of farm model outputs (e.g. labour demand per period and need to hire external labour) will help understand better the reasons behind this feature.

With current simulations, the payments to trigger adoption of legume cultivation by farmers found in our study is in the range of typical payments for ecosystem services, e.g., around 100 US\$/ha for forest regeneration in Brazil (Lemos et al., 2023), or 220 US\$/ha/year to 580 US\$/ha/year for farmers to replace intensive agriculture with agroforestry systems that preserve water quality in Brazil (Pissarra et al., 2021). To the best of our knowledge, there are no current existing PES programs that deal with legume integration in particular. One common issue with PES programs is to define accurate (and cost-effective) metrics to assess the provision of ecosystem services (Salzman et al., 2018). The share of legumes in the cropland should be a good proxy for the provision of a 'bundle' of ecosystem services. Yet this connection between legume area and this bundle of ecosystem services needs to be accurately quantified (e.g. reduction in the need for mineral fertiliser, decreased reliance on pesticides), in order to guaranty the cost-effectiveness of a program targeted at legumes (Benjamin and Sauer, 2018).

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Design and evaluation of diversification of a wine-growing system through the introduction of pastoral herd

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Introduction

The dominant viticultural model in Languedoc (South of France) is under scrutiny because it is both input-intensive and specialized, two factors of vulnerability to market fluctuations. We hypothesize that diversifying agricultural production within a farm can address the challenges of Mediterranean viticulture (Hossard et al., 2023). In particular, diversification through the integration of a livestock herd may reduce the need for fertilization inputs through nutrient recycling (Schiere et al., 2002), and lower associated costs (Moraine et al., 2017). Furthermore, livestock could contribute to diversify incomes (Baker et al., 2023). However, existing literature indicates that mixed crop--livestock systems (MCLS) perform poorly in terms of labour and economic return, thus questioning their viability (Alary et al., 2019). The challenge, therefore, is to design diversified systems that combine the environmental benefits of MCLS with socio-economic sustainability. The objective of this study was to design and assess various configurations of a viti-pastoral system, based on a real case study.

Methods

The Roquenégade wine estate (12 ha of vineyards), support for this study, was taken over in 2021 by a couple of neo-rurals. Their aim was to develop an agroecological production model both self-sufficient and economically viable, i.e. that limits the use of inputs (fertilization, feed) while being able to pay for the labour required to manage crops and livestock. Diversification began 2 years later with the introduction of a flock of 50 ewes and 5 goats, and the expansion of cultivated areas (+ 18.5 ha of grassland and pistachio groves). In addition, 206 hectares of rangeland (scrubland and woodland) were used to feed the herd.

We designed various scenarios of crop-livestock integration, according to the specificity of the considered wine estate and the existing modalities and strategies of livestock integration in vineyard systems, which were identified with 10 exploratory interviews conducted in the region in 2024. Simultaneously, an operational analysis of the wine estate was conducted to identify levers of improvement. These scenarios were developed from a typology of viti-pastoral systems observed in the region, built from the interviews. This typology helped identify key integration strategies and constraints. Based on the collected data, we simulated three scenarios:

S1: Low integration, animals mainly for landscape management, minimal feeding autonomy.

S2: Strong integration with self-sufficient feeding and diversified income.

S3: Integration, high productivity, high labour and inputs requirements.

The evaluation of the sustainability of the scenarios was based on a multicriteria approach that considered several key dimensions identified in the literature and through surveys:

agroecological and socio-territorial dimensions (method: IDEA 4), crop-livestock integration (method: Ecological Network Analysis), economic performance, and labour. We used work balance analysis, i.e. an assessment of the distribution and intensity of labour requirements over time, to evaluate labour sustainability.

Results

The simulation results indicate that diversification through the addition of a livestock system enhances both agroecological and economic performance when self-sufficiency in livestock feeding is prioritized. However, the pursuit of a higher economic productivity leads to a significant increase in labour demand. Overall, promoting complementarity between cropping and livestock production contributes to enhanced sustainability.

Discussion and perspectives

The multicriteria evaluation of the performance of each simulated strategy justifies the emphasis placed on the objectives and their respective weights. The implemented strategies depend on the balance between the economic and agroecological aims of farmers. It demonstrates that sustainability in all its dimensions is difficult to achieve, yet compromises can be made to meet the desired goals. The greater the emphasis on integration and self-sufficiency, the higher the environmental, integration and economic sustainability. However, these benefits are accompanied by a substantial increase in labour requirements due to the implementation of more specific and complex practices inherent in integrated agriculture--livestock systems. Designing management practices to distribute labour peaks over the year appears preferable, as this would help to sustain employment on the farm by maintaining a moderate and constant demand for labour. These findings are consistent with existing literature on crop-livestock systems (Alary et al., 2019), particularly regarding the labour tradeoffs. They also confirm the potential of integrated systems to improve nitrogen self-sufficiency through synergies between livestock and crops, as highlighted by Moraine et al. (2017). This study, conducted on a real farm, provides a practical basis for ex-post monitoring of system performances, thereby allowing for the refinement of scenarios and highlighting both the benefits and limitations of the identified levers.

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Modeling the impacts of crop-livestock integration practices on the sustainability of farming systems: review and perspectives for tropical areas

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Keywords: mixed crop-livestock system, agroecology, model, performance

Introduction

Crop-livestock integration (CLI) is a set of promising agroecological practices that may enhance the sustainability of farming systems by reducing reliance on external inputs, increasing resilience to climatic and economic changes, and maintaining soil fertility using manure (Herrero *et al.*, 2010).

This is even truer in tropical areas, where CLI practices are still deeply rooted in farming systems. However, assessing their impact remains challenging due to the diversity of practices involved, their complex interactions, and their context-specific effects. Modeling approaches could help to overcome these difficulties due to their ability to simultaneously explore different scenarios, predict longer-term outcomes, and consider local variability.

In this systematic review, we aimed to synthesize the knowledge on the impacts of CLI on system performance. Our specific objectives were to: i) analyze how existing models handle CLI practices and assess their impacts on farm sustainability, ii) identify the impacts of main CLI practices (feeding animals with crop residues and by-products, fertilizing crops with animal excreta, and using animals for draft power) on the environmental, economic, social, and technical farm performances, and iii) refine a conceptual model for the tropical zone.

Methods

Following the PRISMA guidelines (Page *et al.*, 2021), we conducted a literature review using the keywords "model", "integration", and "crop-livestock" to build our search equation. Using the Web of Science and Scopus databases, we collected a total of 1100 articles. The inclusion criteria for the research articles were: i) use of a model, ii) assessment of the impact of CLI practices, and iii) provision of sufficient details on the model structure.

We included 107 scientific publications (99 studies) published between 2003 and 2024. Models were classified by climatic context, model structure, temporal and spatial scales, input parameters, and output indicators, and consideration of human food. This analysis enabled us to identify the key characteristics and specificities to be considered in designing a model to assess the impact of CLI practices on the sustainability of tropical farming systems.

Results

A total of 31 models were identified from the included studies. Among them, the Integrated Farming System Model (IFSM) was the most frequently used (52 studies), mainly in North America (47 studies). Models were evenly distributed between temperate ($n = 13$) and tropical ($n = 14$) contexts, and 4 models were applied in both.

Most models were biophysical, but others used multi-agent, hybrid (combining several modules), or network analysis approaches. The temporal representation of the models was mainly dynamic, with a daily time step. Models were generally designed at the farm scale, and more rarely at the territorial scale. Multi-agent models allowed both scales to be represented. Among the 18 models applied in tropical contexts or both climatic zones, most were dynamic ($n = 12$), used a daily time step ($n = 9$), and represented systems at the farm scale ($n = 15$).

Data on farm structure, crops, and technical practices (sowing, storage, etc.) were used as input parameters in all models. Other parameters, such as animal data, scenarios to be simulated (price increase, change in practices, etc.), fertilization, and soil, were also included in most models.

CLI practices were mainly assessed by their impacts on technical, environmental, and economic indicators, whereas social indicators were assessed in only 9 models. The impacts of CLI practices varied depending on the practice, and trade-offs were identified, notably between environmental and economic performance.

Few models considered both food and feed production, limiting the assessment of trade-offs between human and animal biomass allocation. These models were mainly applied in tropical contexts.

Discussion and Perspectives

Our results highlight that modeling allows to explore the impact of a diversity of CLI practices on system performance and assess the interactions. It also enabled us to refine the boundaries of a conceptual model for assessing the impact of CLI in tropical zones. This model will be presented at the FSD congress.

Farm-level models are generally better suited to representing farmers' decision-making processes, while territory-level models are better for assessing interactions between farms and collective dynamics. The latter remain scarce, advocating for increased research investment on CLI at the territorial level (Martin *et al.*, 2016).

The social dimension of modeling remains marginal compared to other indicators. Integrating this dimension would provide a more comprehensive assessment of the sustainability of integrated systems, considering the social dynamics that influence the adoption and long-term viability of CLI practices. The limited integration of social indicators in most models may reflect the complexity and context-dependence of social dynamics, which makes them difficult to formalize in models.

However, there are several limitations to modeling, including the quantity and uncertainty of the data used to parameterize models, the difficulty of formalizing social indicators, and the complexity of these tools, which can limit their appropriation by non-specialists. These challenges need to be considered if we are to develop tools that are truly adapted to tropical agricultural systems and capable of supporting agroecological transitions.

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Modelling feed concentrate reduction in Brandenburg dairy farms with high quality alfalfa

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Introduction

Germany is the EU's largest milk producer. However, the sector faces ecological challenges, including environmental impacts from imported soy used in feed concentrates (UBA, 2021). Reducing concentrate dependence through improved forage quality could mitigate this effect while enhancing farm profitability. Alfalfa presents a potential solution, offering high nutritional value and reducing reliance on imported soy. Its nitrogen-fixing capacity improves soil fertility, while its deep rooting system enhances drought tolerance. However, its benefits depend on optimal harvest timing to ensure sufficient feed quality. Brandenburg, Germany's second-largest alfalfa-growing region (DESTATIS, 2023), combines challenging agronomic conditions with a high number of large dairy farms, making it an appropriate study region for this research. The aim of this study is to examine the economic value of alfalfa harvested with an adapted method for higher feed quality, using the bio-economic model FarmDyn (Britz et al., 2016) to assess its substitution effect on concentrate and the economic impact on dairy farms in Brandenburg.

Methods

FarmDyn, a bioeconomic mixed-integer programming model, was used to evaluate the economic potential of alfalfa. The model simulates farm-level decision-making under technical and financial constraints and includes a detailed feeding system that accounts for energy and protein requirements, feed intake limits, and ruminal nitrogen balance across different lactation phases. The farm model represents an average dairy farm in Brandenburg, with a size of 304 ha for grassland and arable land, 172 dairy cows, an annual milk yield of 9300 kg per cow, facing a milk price of 40 ct/kg (MLUK, 2021). Two alfalfa cultivation strategies are considered: (1) Common Practice Alfalfa silage (CPAlfalfa), with standard three annual cuts and an average nutritional quality (5.45 MJ Net Energy Lactation (NEL) / 19.5 % Crude Protein (CP), LfL (2021)) and (2) High-Quality Alfalfa silage (HQAlfalfa), modelled with four annual cuts, applying a 50 cm height-based cutting strategy to optimize forage quality (7.29 MJ NEL / 22.7 % CP, Gutser et al. (2024)). In strategy 1, optimization is based on CPAlfalfa. In strategy 2, alfalfa is replaced with HQAlfalfa, which requires an adapted harvest strategy based on growth height and specialized mowing equipment but is expected to achieve higher average forage quality. To evaluate the impact of certain variations (e.g. reduced feed quality), a sensitivity analysis is conducted to assess the impact of nine independent variables on key outcomes such as farm profit and concentrate purchases.

Results

In strategy 2 profit increases by 13.2 % compared to strategy 1. At the same time, total labour increases by 2 %. In strategy 2, the cultivated area for alfalfa quadruples, while fertilizer costs decrease by 20 % and concentrate costs by 32 %.

In strategy 1, grass silage, maize silage, alfalfa and wheat are fed at 100 %, while 15 % of the harvested barley is fed. Until Day 213 of the lactation cycle soybean meal is fed. In strategy 2, grass silage, hay, maize silage, maize corn and HQAlfalfa are fed at 100 %. During the first 92 days of the lactation cycle soybean meal is fed. Dry beet pulp is fed during the first 92 days in both strategies. The consumption of concentrate per cow per year is reduced by 34 % in strategy 2, from 1.1 t/cow/year dry matter (DM) to 0.7 t/cow/year. The average daily feeding ration contains 41 % less dry beet pulp and 26 % less soybean meal in strategy 2.

The sensitivity analysis shows that profit and concentrate substitution are particularly influenced by the feed value of alfalfa and milk yield. Higher milk yields increase concentrate demand and reduce the need for alfalfa, as forage alone cannot meet the nutrient needs of high-yielding cows anymore. In contrast, higher alfalfa quality lowers feed costs, raises profit and incentivises an increase in alfalfa cultivation. For typical parameter variations (± 20 %), Strategy 2 remains economically more favourable than Strategy 1. Only when variations are low for alfalfa quality and high regarding milk yield, Strategy 1 becomes similarly profitable. Cereal prices were not a significant predictor in the sensitivity analysis, suggesting that reduced cereal sales had a limited impact on overall profitability in the modelled dairy farm context. Contrarily, the milk price had the strongest influence regarding profit, underlining a dairy farm's direct income dependency on the milk price.

Discussion and Perspectives

The results confirm the value of high-quality alfalfa, which enables a substantial reduction in concentrate feed, required only during the first 92 lactation days to cover peak protein and energy demands. The sensitivity analysis shows that economic performance and concentrate substitution depend primarily on forage quality. Maintaining high forage quality requires early, frequent harvests and sufficient labour availability, which is further challenged by limited precipitation in dry regions like Brandenburg and by overlapping harvest periods between alfalfa and other crops. These requirements also affect farm structure, as alfalfa cultivation reduces cash crop area, along with input demands, and redistributes labour peaks. Moreover, in very high-yielding herds, the need for nutrient-dense feeds limits the substitution potential of alfalfa. Since the economic benefits rise and fall with forage quality, it is crucial to clearly communicate these limitations and work with farmers to develop strategies that help secure sufficient quality and reduce long-term dependence on concentrates.

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Ex-ante analysis of sustainable innovation in smallholder mixed farming systems in Changamire, Malawi

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Keywords: mixed farming systems, crop-livestock integration, interconnectedness, innovation

Introduction

Mixed farming systems (MFS), where combinations of crops, livestock, trees, fish and other elements coexist within a single farm, form the backbone of agricultural production in many low- and middle-income countries (Baker et al., 2023; Herrero et al., 2017; Parsons et al., 2011). Their inherent diversity offers significant potential for sustainability through complementarities and synergies across farm components. However, MFS face increasing biophysical and socioeconomic challenges that threaten their sustainability and resilience. Innovation provides a promising pathway to directly enhance sustainability and improve farmers' livelihoods, yet past efforts have often focused narrowly on single components, neglecting system-wide interactions (Nhantumbo et al., 2016). This reductionist approach can amplify trade-offs, ultimately hindering sustainability objectives.

This study conducts an integrated assessment of sustainable innovation in a MFS in Malawi to evaluate system-level impacts and trade-offs. Our goal is to highlight the importance of holistic innovation strategies that acknowledge and leverage MFS interconnectedness.

Methods

An ex-ante innovation assessment was done based on a case study MFS in Northern Malawi (Höft, 2024). The analysis examined three categories of innovations: (i) diversification, through the introduction of a forage contour bund and fodder selling; (ii) integration, via redirection of fodder to livestock feeding; and (iii) effectiveness, by improving livestock manure management.

The whole-farm bioeconomic model FarmDESIGN (Groot et al., 2012) was used to analyse innovation effects on farm performance across three representative environmental, social, and economic indicators. Focus Group Discussions (FGDs) were conducted with farmers to define the baseline model, assess innovation perceptions, and evaluate farm redesigns incorporating these interventions.

Results

The innovations had diverse effects on farm performance. The addition of the contour bunds (planted with forages), i.e., diversification, would decrease arable cropland at village level by 12.5%. Still, net positive crop yields of 2.5% were expected within two years of the bund construction, thanks to reduced soil erosion and plant water stress. Soil organic matter (SOM) balance was expected to increase by up to 82%. A slight increase in farm income of around 6% was also anticipated. A trade-off was found for farm labour requirements (+11%) mostly due to the initial bund construction time. The second innovation studied concerned redirection of previously sold forage to feed livestock, i.e. integration. This allowed to increase livestock numbers in the village from 33 to 70 TLU (+112%). The increase in manure production was

expected to boost SOM balance by 185%, however producing an increase of NH₃ emissions for 215%. Thus, by maintaining livestock numbers at a lower rate and using extra fodder as compost, lower emissions and overall farm improvement could be attained. Furthermore, covering the compost heap could result in a reduction of around 12% of NH₃ emissions compared to the previous scenario, thus improving system effectiveness.

Focus group discussions revealed a generally positive outlook of farmers on the redesigns, particularly when they improved soil organic matter (SOM) balance, as low soil fertility and the high cost of mineral fertilizers were their primary concerns. The main challenge identified for the redesigns was the initial labour allocation towards building the bunds. However, farmers proposed collective action, such as group work for bund construction and forage planting, as a solution.

Discussion and perspectives

Findings underscore innovation has the potential to improve farm performance, enhancing productivity and environmental outcomes. However, they also highlight the emergence of trade-offs. In this case, while increasing fodder and hence number of livestock provides numerous benefits, it can also lead to increased NH₃ emissions and thus negative environmental outcomes if not properly managed. This emphasizes the need for systems-level analysis that account for the interconnected nature of MFS when designing innovations. Modelling tools such as FarmDESIGN facilitate comprehensive assessments, quantifying both benefits and trade-offs across multiple farm dimensions. To maximize impact, these tools should be integrated into participatory approaches that prioritize local contexts, farmer needs, and community aspirations (Thornton & Herrero, 2015). Strengthening MFS innovation design through such approaches can enhance smallholder livelihoods, address key challenges, and contribute to environmental restoration.

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INIA Glencoe: long-term experiment on natural grassland year one insights

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Introduction

Uruguay is historically related to livestock production and Campos ecosystems is a crucial for providing feeding to extensive livestock systems. These rangelands feature a diverse multispecies canopy, essential for biodiversity maintenance, soil erosion control, biogeochemical cycles regulation, scenic beauty, and culture. However, managing the multispecies complexity of this grasslands to achieve its potential remains a major challenge for many farmers, often resulting in a significant yield gap when compared to the productive potential of Campos. This mismatch is critical for Campos conservancy, once important areas have been converted into cultivated pastures, crops or forestry (Baeza y Paruelo, 2020). Research has generated knowledge to manage natural grasslands and improve their productivity at the plot and paddock scale, but there is still few knowledge about the impact of decision rules that supports the management actions on long-term ecosystem functioning at higher scale (Briske et al., 2011). Our hypothesis is that finer spatial and temporal control of plant diversity- achieved through increased paddock subdivisions- will lead to higher primary and secondary productivity in the long term (at least 20 years).

Methods

A long-term experimental platform was established at INIA-Glencoe Experimental Station (Paysandú, Uruguay) in a typical native grassland on basaltic shallow soils using a co-innovation process approach detailed in Devincenzi et al. (2021). The platform consists of three contiguous but independent farmlets of 50 hectares each with similar proportions of vegetal indexes corresponding to four plant communities and soil and water distribution. Plant communities were mainly composed by i. *Schizachirium spicatus*, *Andropogon ternatus*, *Aristida echnulata*, ii. *Paspalum notatum*, *Bothriochloa laguroides*, *Paspalum plicatulum*, iii. *Paspalum dilatatum*, *Juncus capilaceus*, *Paspalum notatum*, iv. *Andropogon lateralis*, *Axonopus affinis*. These farmlets were further divided into an increasing number of paddocks -2, 8, and 32 (treatments SP2, SP8, SP32) - to enhance the precision of grazing management in space and time. The division of the total area into the three farmlets with their corresponding paddocks was based on variability in the seasonal dynamic of vegetation indexes and topography.

The farmlets simulate a cow-calf operation and ultrafine wool and sheep meat production system -characteristic of Northern Uruguay. Farmlets are grazed all year with multiparous cows and lambs in a 1:2 ratio. Stocking rate (SR) adjustments are made twice a year, in autumn following calf weaning and in spring prior to mating season. Stocking rate decisions are made in workshops involving a group of researchers (n=4), extension agents (n=3), and farmers (n=4), part of a formal farmer organization which were selected for their recognized leadership in livestock production, complementarity of expertise, and institutional representativeness. All farmlets are managed by the same research assistant.

As inputs for SR adjustment, pasture height and animal body score condition (BCS; on a 1--8 scale) during the evaluation period were considered. Pasture height is monitored monthly in

each system and must be maintained consistently within the target range of 4--6 cm across all farmlets to ensure valid comparisons. Therefore, SR adjustment is a central component of the experimental platform.

Results

At the start of the study in January, 2023, SR was the same in all systems (0.67 AU/ha). After one year of implementation, the average number of grazing events per paddock in each farmlet was 7.5 in SP2 and SP8 and 6.6 in SP32. Mean number of days of occupation in each paddock was 24.3, 6.1 and 1.7 days in SP2, SP8 and SP32 respectively. The first SR adjustment took place in the Autumn of 2024. Decision rules for SR adjustment considered the current SR, the average pasture height from April 2023 to March 2024, the pasture height target, the period of use, the estimated forage intake, forage density, and a requirement for cows to have a BCS > 4 at weaning. These variables were integrated into decision-support tool ("Calculator") developed in Excel with the pasture height target setting in the range of 4-6 cm. Mean pasture heights were 5.9, 6.3, and 7.2 cm for SP2, SP8, and SP32, respectively. Cows BCS was 5.4 for SP2 and 5.0 for SP32. SR adjustments were 0%, +3.2%, and +12.4% for SP2, SP8, and SP32, respectively.

Discussion and Perspectives

This study corresponds to the initial implementation phase of a long-term grazing experiment, in which a main challenge has been to maintain pasture height within the target range of 4--6 cm across all systems. This objective is critical to ensure comparability among treatments and support sustainable grazing management under varying levels of paddock subdivision. The decision rules for adjusting stocking rate and managing grazing dynamics are being co-developed and applied in collaboration with farmers and technical experts. These rules are based on a technological package proposed by INIA, adopted and validated by participants. In parallel, detailed evaluations are conducted on pasture growth, structural characteristics, and nutritional value across systems. This information will be key to understanding cause-effect relationships between grazing management intensity, pasture dynamics, and animal responses—thereby contributing to the scientific foundation of sustainable livestock systems based on native grasslands.

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Toward a pesticide-free territory: how different methods could be combined to achieve this goal?

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Keywords: socio-technical system, value chain, milk, organic farming

Introduction

The Saffré area is a 5,800 ha drinking water catchment, cultivated by 105 farms. Its stakeholders committed themselves to the non-use of pesticides by 2040. A research project was undertaken in 2021 to contribute to this objective. It highlighted the territory's strengths - a large proportion of grassland and 25 farms already using organic farming, pesticide-free methods - but also its threats. Grassland areas are declining in favor of crops that consume more pesticides, and the cyclical downturn in demand for organic products is slowing down conversions. This abstract presents how three approaches were combined to design appropriate actions toward a pesticide-free territory by 2040.

Method

Three approaches were combined to provide input for the design phase of innovations to move towards the non-use of pesticides in the Saffré catchment area. To begin with in 2021, the future of the area without pesticides was sketched out using the Co-click'eau approach (Chantre et al., 2016), in order to specify the problem to be solved in the Saffré area. From 2022 to 2023, an innovation track (Salembier et al., 2021) was carried out to identify existing innovations (inside and outside the area) that could help to solve the problem. In the same time, a socio-technical diagnostic (Casagrande et al., 2023) was carried out to reveal the stakeholder systems affected by the problem and their perceptions of the innovations identified. Based on the outcomes of these approaches, three actions were designed and are currently under progress. Each of these actions aims at addressing the specific problems raised by pesticide-free farming for three groups of stakeholders differentiated.

Results

On the basis of scenarios simulating impacts of a pesticide-free future on the Saffré catchment area, two workshops were arranged. All farmers from the territory were invited and 10 of them participated. This choice aimed at making farmers decide what kind of pesticide-free farming they want for the territory, so that they commit to implement it. This highlighted the challenge to meet this goal: how to maintain livestock farming and associated grasslands? The current context is associated with low profitability of milk and meat production, resulting in a shift from grasslands toward cash crops, which rely more on pesticides. The relatively low participation of farmers to these workshops also highlighted that they felt not really concerned so far by the pesticide-free goal, which was mainly the local water service concern. Their own concerns needed to be further investigated, to raise their interest for the pesticide-free dynamic. This led to the launch of two actions.

First, an innovation track was carried out to identify existing innovations that could help to enhance milk and meat profitability. Mostly based on documentation review, a lot of innovations were

identified, inside and outside of the territory, including various ways to increase selling price through label or brand, on-farm transformation or short supply chains.

Second, a socio-technical diagnosis was launched to better understand the stakeholder's systems. Around 20 stakeholders were interviewed, encompassing milk and meat value chains. This revealed three different socio-technical systems, with specific concerns, represented on Figure 1.

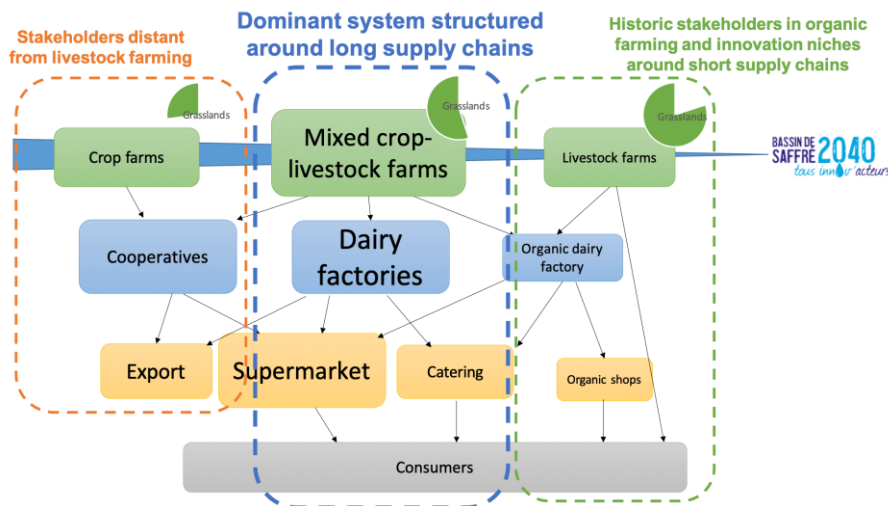


Figure 1. Simplified map of the socio-technical systems identified in the Saffré basin. In green, production; in blue, collection and processing; in yellow, distribution; in grey, consumption.

The target of a pesticide-free territory raises different issues for each of these socio-technical systems. The dominant systems structured around long and specialized supply chains have to face the challenge of livestock farmers generation renewal, which leads to a shift from livestock farming to cash-crop farming. Stakeholders distant from livestock farming have to manage weeds, in cropping systems without grasslands and in a context of decreasing efficacy of herbicides due to grass-weed resistances. Finally, stakeholders in organic farming have to sustain the demand for organic products to ensure their future: among the 25 organic farms present in 2021, only 18 remains in 2025. This was used as a basis to differentiate support action to each of these systems.

Discussion and perspectives

Three actions have been launched since 2024 and are in progress. First, a workshop was proposed to farmers facing weed management problems. This workshop involved a scientist specialized in weed biology, who shared his knowledge about managing weeds without herbicides. Other workshops will be proposed, so that the interest of farmers for herbicide-free weed management will raise. Second, exploratory interviews were carried out near stakeholders involved in farms transmission process. These interviews aim at better understanding what is lacking to ensure livestock farms trade-in when owners retire. This will help identifying efficient support action to avoid the shift from livestock farms (with grasslands) to cash-crop farm. Last but not least, a group of organic farmers was constituted. This group gathers eight livestock farms, all certified in organic farming since many years. These breeders want to commit to support the demand for organic products by communicating about the sustainability of their farming systems. More details and preliminary results about this action are proposed through the abstract entitled "When farmers commit to supporting their organic farming system: how to talk about positive externalities from sustainability diagnosis?".

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Developing agroecological transition strategies: insights from a mountainous living lab in Morocco

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Keywords: agroecology, transition, multi-criteria assessment, North Africa

Introduction

An agroecological transition of North African farming systems has been suggested as a pathway towards increased resilience to climate change and ecosystem degradation (Requier-Desjardins et al., 2024). We hypothesize that to address those challenges agroecological transition strategies need to reflect local stakeholders' concerns and combine agronomic and socioeconomic innovations at farm, landscape and value chain level, rather than promoting single best agroecological practices (AEPs).

The *North African Transition to AgroEcology* project works in different agroecological zones establishing Living Labs (LLs), in which farming and non-farming stakeholders co-develop agroecological strategies in a 'real-life' environment (Magrini et al., 2019; Bhatta et al., 2024). This study presents insights from the ongoing process in a mountainous LL in Morocco, where a diversity of small to medium-scale farms cultivate olive and fruit trees, vegetables, and rainfed cereals, and rear livestock.

Methods

The characterization of the LL farming system was followed by the formation of a representative board (RB) of stakeholders to steer project activities. Members include farmers, representatives of farmer cooperatives, extension services, governance, and researchers.

A set of existing and potential farm scale AEPs was proposed by researchers to address identified challenges in the LL. In three focus groups with four and six male farmers and eight female farmers, AEP advantages and disadvantages were discussed. Researchers categorized those into areas of concern (Table 2). These areas of concern were used in a multi-criteria assessment of the AEPs (Bellon, 2001). Farmers individually assigned weights to each area of concern and indicated the expected effects of AEPs. Researchers combined weights and effect scores into an overall score (weighted summation) to compare AEPs.

Subsequently, RB members discussed LL level innovations to overcome farmer concerns. Currently, identified promising AEPs and their combinations are being evaluated through on-farm experimentation and bio-economic modelling.

Results

We present farmer assessments for two AEPs - the use of manure (existing) and shredded tree pruning residues (potential) -- and the results of the RB meeting on LL level innovations addressing farmer concerns.

Farmers rated economic areas of concern high in importance (Table 1). Environmental concerns were also emphasized, particularly increasing water scarcity, low soil fertility and lacking pest management options. We found a strong positive assessment of using shredded tree prunings as mulch, with farmers acknowledging the potential to reduce water use and weeds. However, this conflicts with the use of residues as fodder. Available manure is often limited and short maturation favours spreading of weed seeds. Labour demand and practice costs pose a challenge for the implementation of both AEPs. To re-use tree prunings, for instance, a suitable shredder is needed.

Area of concern		Ø importance area of concern	AEP score	
			AEP 1: Use of manure	AEP 2: Use of pruning residues
Environmental	Water	3,00 (n=17)	-3,88	2,47
	Soil	2,82 (n=17)	4,88	4,29
	Microclimate	2,12 (n=17)	0,06	3,18
	Biodiversity	2,12 (n=17)	0,94	0,00
	Pests/diseases	2,76 (n=17)	-2,82	2,47
	Animal welfare	2,12 (n=17)	0,65	-0,47
Economic	Labour	2,29 (n=17)	-2,94	-1,24
	Productivity	2,94 (n=17)	4,06	3,76
	Consumption/processing	2,35 (n=17)	1,53	2,18
	Costs	2,65 (n=17)	-3,18	-2,12
	Revenues	2,59 (n=17)	3,06	2,59
	Equipment availability	2,75 (n=17)		
	Water infrastructure	2,83 (n=6)		
Social	Collective organization	2,65 (n=17)		
	Land access	2,50 (n=11)		
	Local know-how	2,17 (n=6)		
Overall score			2,24	16,65

Table 1: Multi-criteria assessment of selected AEPs by farmers. Importance weight and AEP score (= importance × expected effect) per area of concern. Overall score: sum of scores over all areas of concern. Red color indicates a negative, green a positive and yellow a neutral assessment.

In a follow-up meeting RB members discussed this multi-criteria assessment. Stakeholders agreed that economic factors, such as equipment costs, and a limited investment capacity of farmers, are limiting adoption. They also stressed a lack of farmers' know-how regarding proper manure maturation reflected in their negative practice assessment regarding 'Pests/diseases'. The RB identified options to address those concerns including trainings on manure handling and the formation of a professional organization to efficiently manage biomass resources in the LL, minimizing individual farmers' investment needs.

Discussion and perspectives

Multi-criteria assessments with LL farmers highlighted the importance of economic and environmental concerns in their decision-making regarding AEPs -- unsurprising given the high expected climate change vulnerability and prevalence of rural poverty in the North African context (FAO, 2007).

Weighted summation allowed the calculation of a single score for systematically comparing the AEPs. We recognize that this approach assumes additivity of utility and might mask trade-offs (Sadok et al., 2009). By analyzing the quantitative scores in combination with the qualitative discussions we ensured contextualization of our results and the identification of potential trade-offs. According to participating farmers the use of manure is limited by

availability of good quality manure and tree prunings as mulch competes with their use as fodder. Hence, these AEPs alone do not sufficiently address their concerns

Based on these assessments, a potential synergy lies in common composting of shredded tree pruning residues and manure by increasing the pool of available biomass sources on-farm and enabling favourable composting conditions (resting time, C/N ratio, aeration). Labour demand and investment costs remain challenging, calling for action beyond a single farm. Socioeconomic innovations, such as trainings and a professional organization producing organic inputs, were identified by both farming and non-farming stakeholders.

Herein lies a strength of LLs as places of multi-stakeholder exchanges in developing strategies addressing all sustainability domains (Magrini et al., 2019; Bhatta et al., 2024). Acknowledging the influence of stakeholder composition on group exchanges, we tried to involve a diversity of perspectives, though limited administrative information posed challenges. Thus, we understand our findings as insights within an ongoing, iterative process requiring time and reflexivity on stakeholder relationships, goals and expectations.

Conclusions

Combining qualitative focus group discussions and quantitative ratings involving both farmers and non-farming stakeholders enabled a contextualized ex-ante assessment of on-farm organic resource management practices, the identification of adoption challenges and improvements through practice combinations, and necessary socioeconomic innovations. This approach informed the design of ongoing on-farm experimentation and bio-economic modelling evaluating the performance of AEPs and their combinations.

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Structuring transdisciplinary research on agroecology: comparing 10+ years of co-innovation in Uruguay and the EU

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Keywords: Project governance, complex adaptive system, social learning, monitoring and evaluation

Introduction

Coined to describe the way of complexity-aware working in the EU FP6 project EULACIAS (European -- Latin American Co-innovation of Agro-ecosystems; 2007-2010), the notion 'co-innovation' has evolved over multiple projects in Uruguay and has been used in EU projects since 2011 (Rossing et al., 2021). In all these projects, scientists worked in a transdisciplinary fashion, i.e. with other societal actors, including farmers, to effectuate systemic change towards agroecology. The co-innovation notion emerged around a time of increasing disgruntlement in the scientific and donor communities about achieving 'impact', which persists until today (e.g. Cronin et al., 2022). In EULACIAS, the 'hard', natural-science-based systems perspective on on-farm agroecological processes became connected to evolutionary learning approaches, soft systems thinking, and monitoring and evaluation originating from the social sciences.

Different from other types of participatory research, co-innovation takes a *complex adaptive systems* (CAS) perspective on both the societal structures that are the object of transdisciplinary investigation and on the project and its role in the evolution of the societal networks the project engages with. This (social-ecological) systems perspective recognizes systems at different levels, with components that interact through feedbacks and feed forwards, resulting in inherently unpredictable behaviour. Interactions may be quantified or characterized qualitatively. Targeting interventions in such systems becomes meaningful by adopting a *social learning* perspective supported by formative *monitoring and evaluation*. The CAS perspective instigates the need to iteratively consider different system boundaries to support reflection, connect different types of knowledge, and instil a preparedness to adapt courses of action based on novel insights. This perspective is missing from participatory research, conceptualized merely as researchers working with non-scientific actors.

The application in the Uruguayan projects of co-innovation as a way of working has resulted in a range of highly successful on-farm outcomes, as witnessed by scientific publications (Dogliotti et al., 2014; Ruggia et al., 2020; Colnago et al., 2022) and farmer testimonies. In EU projects, outcomes have been more variable, with the project participants usually being more appreciative of the reflexive way of working than of the material changes (Klerkx et al., 2017; Rossing et al., 2021; Iocola et al., 2020). Comparative analysis may aid the many science-society initiatives that have become funded (e.g. Living Labs, Multi-Actor Approaches) by enhancing learning about factors stimulating and hindering meaningful knowledge production for sustainability transitions.

In this contribution, we draw on the authors' experiences with co-innovation projects to compare contextual and organizational factors and discern differences in tangible sustainability outcomes between Uruguay and the European Union.

Methods

We comparatively analyzed the context and the organization of the various projects that used co-innovation in the EU (two projects covering 9 years) and in Uruguay (four projects covering 13 years) to develop hypotheses on why material results were so different. Guiding questions were based on why, what, who, where and how. Data come from scientific publications on the various projects, unpublished material, deliverables, and personal experiences. Thus, the results are based on self-assessment and critical reflective dialogue among the author team members.

Results

The results are summarized in Table 1.

Discussion and perspectives

All projects report positive effects of the way of working instilled by the co-innovation governance approach, providing safe spaces for developing novel insights, discussing tensions and reaching agreement on ways ahead. We found clear differences in the way of organizing researcher involvement. In the Uruguayan projects, a team of researchers and farm advisors developed characterization, diagnosis, and redesign activities on farms, and they accompanied farmers during the implementation and evaluation of the farm plans. In the EU projects, both the geographical and the epistemological distance between the project and the farmers (and other actors) was mediated through network facilitators that enabled access by researchers. As a result, the role of research-based knowledge in the networks remained more in the academic realm. Co-innovation in the European projects involved reflexivity around the institutional change needed to support the aspired ecologically intensive technological change, which was less pronounced in the Uruguayan projects. In addition, the tools and learning cycle procedures in the EU projects appeared more thorough than those in the Latin American projects.

Obtaining EU funding requires (explicitly/implicitly) geographic spread and a high diversity of networks in projects. As research organizations are not necessarily equipped to engage in complexity-sensitive on-farm research and are geographically distant, concrete changes on farms are hindered. In the Uruguayan projects, the regionalized approach and the centralized research and advisor team enabled a more focused and integrated approach. These factors appear to be key to project interventions' effects on sustainability outcomes. However, insufficient reflexivity on institutional change hinders scaling out of project learning in Uruguayan projects.

The lessons from this comparison inform the need to forge more intense connections between the LL and RI structures in the European research area than is currently the case. In addition, the tendency to 'supersize' proposals regarding the number of innovation networks to win over reviewers requires curbing. For future Uruguayan projects, reflexivity on the institutional adjustments as part of transformative change may benefit from the learning procedures developed in the EU projects.

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Table 1. Characterization of the project context in which co-innovation has been used as a way to structure systems redesign in the EU and in Uruguay in terms of 'why', 'what', 'who', 'where', 'how'.

	EU	Uruguay
Why is co-innovation used	Missions formulated in a project call require complex and connected changes in technologies and institutional arrangements. Typically, the Multi-Level Perspective and Theories of Change are used to frame project interventions. The need for a systemic approach and reflexive learning necessitates changes in the usual 'waterfall' approach to project structuring and enacting.	Farm-level sustainability transitions in different sectors (horticulture, beef cattle, mixed systems) are possible by combining agroecological practices from a systems perspective and fitting them into local farm resource conditions. This involves the co-development of technologies, skills and attitudes of researchers, farmers and advisors using a reflexive, systemic perspective.
What does co-innovation involve and result in	Co-innovation supports reflexive social learning on the way of working between researchers and innovation networks. More recently, transformative systemic change has received considerable attention concerning unfolding agroecology in Europe. Learning-oriented monitoring and evaluation is highly structured (recently at both the innovation network and work package level) and provides input for reflection on network strategies and project governance. Results include new perspectives on role perceptions and agency at individual, network and project levels. Social learning among innovation networks and new perspectives on how researchers and innovation networks can collaborate more fairly are highly appreciated.	Co-innovation supports the systemic perspective and the reflexive social learning on the agroecological practices and the way of working among scientists, advisors, and farmers, using input from (largely quantitative and some qualitative) monitoring and evaluation. Results include major win-win performance improvements at farm level, with most farms improving productive, economic and environmental performances. In addition, the new way of working – more frequent visits by advisors (and researchers), their greater systemic awareness, and their more inclusive approach to farmer knowledge stand out. Results are supported and amplified through national agroecology networks.
Who (and what) drives co-innovation	A central team of socio-natural science researchers facilitate connections among innovation networks and between networks and researchers in the project. Innovation networks are represented by one or two facilitators. Network facilitators develop activities with farmers and, e.g. institutional actors. Approaches evolved to structured annual learning cycles of innovation network facilitators and work package participants. Joint on-farm activities are negotiated in the project and carried out by the networks.	A central team of socio-natural science researchers and advisors connect to farm families on participating farms with high frequency (between once per 2 weeks (horticulture) to 1 per month (beef cattle)). Once per year, connect with institutional actors to report and reflect. Approach based on development cycle comprising farm characterization (>=1 year), diagnosis and redesign plan, implementation and M&E.
Where does it play out	Projects were funded in calls for proposals on IPM, crop diversification and climate, focusing on farms but including value chains and regions, with a 'representative' spread across European types of farming systems. Subsequent projects engaged with 4, 25 and 11 advisor- and/or researcher-driven networks, respectively, in some cases connected to local research teams. Some of the networks were new at the start of the project; others were continuations (selected purposefully) of existing initiatives.	Projects were funded in calls around farm sustainability, starting from clearly formulated agro-technological interventions related to agroecology and ecological intensification. Funding is from external (EU, GEF) and national (ANII, INIA, MGAP, Udelar) sources. Subsequent projects engaged with 14, 6, 28 and 56 carefully selected farms.
How can it evolve	<i>Within projects:</i> Governance approach for LL and RI; Bioregions ² ; closer connections with the actors involved in change; greater focus on the 'legacy' of the project regarding the types of systemic changes addressed; selection and training of participants with greater awareness of their roles and agency. <i>In the projects' external context:</i> Greater fairness, accessibility and flexibility in financial arrangements; avoiding 'supersizing' project proposals - fewer networks allowing more resources per network.	<i>Within projects:</i> Governance approach for sustainability transitions beyond the farm scale by addressing the encompassing innovation support system – advisors, legislators, and market parties; more systematic reflexive learning cycles as part of project operation; <i>In the projects' external context:</i> Greater attention is needed to sustain the lessons learned institutionally by taking up key elements in training researchers and advisors and creating structures to enhance policymakers' understanding of the essence of the approach.

¹ EU: mainly PURE-IPM, DiverIMPACTS, and Agroecology-TRANSECT; Uruguay: mainly EULACIAS, INIA-Rocha, Ganadería Familiar y Cambio Climático, and Ganadería y Clima.

² Living Labs and Research Infrastructures and Bioregions are policy notions for transformative change involving research and other societal actors.

Challenges for rural extension to promote a sustainability transition in family livestock farming: lessons from a sequence of projects in Uruguay

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Keywords: co-innovation, farm technical assistance, livestock farming on natural grassland

Introduction

The transformation of the current agri-food system towards a more sustainable one requires socio-technical strategies that can drive radical changes. An ecological intensification strategy could play a fundamental role in the transition towards more sustainable Uruguayan family livestock farming. These are based on natural grasslands and face difficulties due to overgrazing degradation, which is detrimental to the production of forage and meat, while reducing family income and provision of ecosystem services. Research institutions have generated process technologies that can support ecological intensification trajectories, which are not necessarily contained in a physical format and require contextualized knowledge to be leveraged. Therefore, vertical technology transfer logics are inefficient, requiring horizontal logic where knowledge is built on a shared basis. In this sense, participatory research approaches have been implemented, working directly on farms and involving farmers in the identification of problems and the design of solutions, on the basis of a sequence of projects that used co-innovation to promote and evaluate ecological intensification strategies between 2004-2019.

The continuity of those projects over 15 years was fundamental to achieve the development of a socio-technical niche, as a seed of transition process (Aguerre and Bianco, 2023). On the basis of ecological intensification practices farm sustainability was improved and participants considered that a very special bond between extensionists and families was a key factor with co-innovation as a modality of intervention for farm technical assistance (Aguerre and Bianco, 2024).

Different from diffusionist approaches with limited achievements in terms of technology use, co-innovation proves as a convenient intervention model for Uruguayan family livestock farming. A Sustainability Transition (ST) could be fostered through a disruptive extension policy based on co-innovation to promote ecological intensification, with the coordinated efforts of relevant institutions linked to family livestock farming.

In this text we offer a vision to enhance the scaling of the existing niche and contribute to the ST of livestock family farming through an extension policy and discuss the challenges that this implies for rural extension in Uruguay.

Methods

A case study design was followed, focusing on the sequence of 6 research projects, that involved 52 livestock family farms, researchers, extensionists and other relevant actors, at national level. Analysis was based on documents and semi-structured interviews, combining inductive and deductive methods to identify scaling strategies.

Results

Following the coinnovation approach, on-farm work based on monthly interactions between families and extensionists allowed the integration of technical knowledge with farmers' knowledge and experience in an horizontal dialogue to elaborate on the implementation of fundamental changes in farm management in line with ecological intensification. The orientation is to improve the sustainability of the productive system and help the family achieve its goals and implies systemic approach and medium/long term planning.

The extension method has work stages (Table 1), in a process that takes 3 to 4 years.

Table 1. Work stages and their objectives.

Characterization and diagnosis
Understanding the family objectives.
Knowing the structure, operation and results of the production system.
Identifying and agreeing on strengths and weaknesses.
Building trust between the family and the extensionist.
Redesign proposals
Agreeing on a future goal (3 years) involving farm structure, operation and results.
Agreeing on an implementation plan to achieve this goal.
Implementation, monitoring and adjustment
Accompanying the implementation of the redesign agreed upon according to an activity schedule.
Monitoring system evolution.
Implementing adjustments and changes as necessary.
Implementation of changes begin with the first visits.

Whitin the niche, the implementation of farm technical assistance had difficulties due to several factors: training of extensionists, lack of experience on co-innovation and ecological intensification, where relational skills, systemic vision and technical knowledge are needed. The strategy developed to deal with weaknesses was the conformation of an interdisciplinary team to support the work of extensionists, with a low presence in the field, but indirectly nourishing farm interventions.

An extension policy is needed to scale co-innovation and trigger a ST in family livestock farming in Uruguay. Some key aspects emerge from the study for policy design and implementation:

- Promotion of ecological intensification principles and the achievement of family objectives.
- Systemic approach / medium/long term planning.
- Horizontal communication combining technical knowledge and farmers' experience.
- On-farm work based on monthly extensionist visits for periods over 3-4 years.
- Work stages: characterization and diagnosis, redesign proposal and implementation, monitoring and adjustment.
- Form a broad, interdisciplinary and interinstitutional work team:
 - extensionists working directly on farms.

- support team including specialists in the economic-productive, environmental and social sciences.
- Define an operating structure linking on farm and support levels, with institutional articulation combining national and regional levels, involving different actors: policy makers, research and extension, farmer organizations and meat processing industry.
- Initial time for the assembly and bonding of the team, aligning with the technical strategy and working style.
- Selection of extension workers:
 - Motivated to overcome and learn from difficulties.
 - Interested in dialogic approaches.
 - Relational skills / systemic vision / technical knowledge for ecological intensification.
- Comprehensive initial training of extensionists.
- Continuous training, monitoring and support system for extensionists' work, through interaction with the interdisciplinary and interinstitutional support team.

Discussion and Perspectives

A key element for promoting more sustainable family livestock systems is providing farm technical assistance with a co-innovation approach, contrasting with traditional services mainly based on farm investments and input technologies. Co-innovation aligns with alternative extension approaches given its interactive and dialogical approach (Méndez Sastoque, 2020). Despite some institutional efforts towards a more participative practice in Uruguay (and also in Latin America) the diffusionist approach is predominant. Shifting towards an alternative model based on an extension policy poses very significant challenges since interventions cannot be scaled up without trained human resources and institutional commitment to design a supporting structure for extensionists' work.

In this regard, a livestock promotion program recently announced by the Ministry of Agriculture to provide farm technical assistance is considered a window of opportunity. The program aims to reach 1,000 family and medium-sized farmers starting in 2025. However, alignment with co-innovation and ecological intensification will be necessary. Opportunities also open up in the international landscape, where livestock farming is being strongly questioned due to its environmental impact; the productive base of Uruguayan livestock farming in the natural grassland, which uses the capacity of ruminants to produce animal protein from fibrous fodder using extensive areas of pastures that are not suitable for agriculture or feeding monogastric animals, while generating ecosystem services (Tiftonell, 2021).

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Design of intercropping-oriented value chains: monitoring and cross-analysis of 13 multi-actor case studies

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Keywords: participatory research-action, coupled innovation, crop diversification, levers

Introduction

Intercropping (IC), the simultaneous growing of two or more crops in the same field, has been recognized as a strategy to improve the sustainability of agricultural systems (Jensen *et al.*, 2020). Despite its potential contribution to the EU agroecological transition, IC remains underdeveloped due to interconnected barriers across different stages of the value chains (VC) (Hauggaard-Nielsen *et al.*, 2021). Successful implementation relies on the ability of farmers and other stakeholders to innovate in coordination, shaping the feasibility of IC at the local level to their own situation (Magrini *et al.*, 2018). To enhance IC use, innovation must be stimulated and coordinated not only at the farm level but also across the entire VC to generate mutual benefits. This requires multi-actor participatory approaches to address key challenges and drive innovation collaboratively (Meynard *et al.*, 2017).

The IntercropVALUES European project is structured around 13 multi-actor co-innovation case studies (CICS) to identify and overcome barriers to IC use for food. They are managed by pilots coordinating activities with stakeholders to design innovations at the VC level. Each CICS follows its own step-by-step process, fuelled by activities and continuously adapting solutions fostered by learnings (Meynard *et al.*, 2023). Given the complexity of developing IC-based food value chains, and little literature existing on this topic at the VC level, it is essential to better understand the diverse trajectories possible and the key factors influencing their successful implementation. To address this, we conducted a dynamic cross-case analysis of the innovation processes of each CICS. We aim to compare different ways to develop IC VC to identify patterns and provide valuable insights to support and guide co-innovation processes.

Methods

Three analyses were conducted using data from monitoring files updated by CICS pilots every six months. The dataset includes descriptions of activities, participants, aims, pilot satisfaction of outcomes, results, key learnings, and impacts on action plan. Additionally, individual CICS semi-structured interviews were conducted by authors of this abstract to reflect on the activities, identifying factors that facilitated or hindered success.

The first analysis characterised the initial state of each CICS, comparing them based on common variables: type of IC studied, actors involved, history of collaboration, expertise on the subject, and knowledge production. The hypothesis is that these factors influence the pathways for developing IC-oriented VC.

The second analysis assessed the status of each CICS two years after. Based on the same variables, five clusters were identified according to expected IC services and strategies in structuring value chains.

The third analysis categorised CICS progress into three groups: those meeting project expectations, those on a consistent track, and those facing difficulties. By cross-analysing these clusters, the variables and activity trajectories, we identified common patterns influencing success or difficulties, useful for future VC designers.

Results

The CICS' progress is influenced by five key factors.

The progress made by the CICS is first influenced by the orientation taken in the way they perceive IC use. For some, it is a tool for input reduction at crop or rotation level, for others a method for diversifying cropping systems, and for others still, a way to produce legume or high-protein cereals with higher stability than a pure crop. This may have an impact on how and why CICS implement certain types of activities and how the innovation process unfolds. While some CICS focus solely on one vision - such as those for input reduction conducting on-station or on-farm experiments (OFE) without necessarily engaging in food processing and marketing - others operate at various levels. CICS with a food-to-field strategy seek to overcome food and field barriers, for instance by progressing towards growing successful cereal-legume mixtures for artisanal bread making within a territory.

The second factor is the clarity of vision for the targeted VC. A clear and well-defined vision of the intended VC and existing barriers facilitates progress. Some CICS pilots have limited visibility on barriers and how to address them. Whereas in others, a strong understanding of the food-scale ambition enables more transverse and coherent actions and a smoother progress.

The third factor is the capacity to mobilise a diversity of actors, resources and skills. Effective stakeholder engagement is crucial in participatory research-action. For some CICS, efforts focus on field experiments and dissemination activities, such as open days, but lack strong actor mobilisation to take action. In contrast, some CICS organise one-on-one meetings or collective workshops to actively engage key actors.

The fourth factor is the ability to conduct diverse activities across the VC. CICS integrating both field and food activities tend to progress well. This requires both strategic alignment and pilot ability to manage multi-faceted activities sometimes out of his or her key expertise on relatively unexplored subjects.

The fifth factor is the history of collaboration between stakeholders in the CICS and between actors and the pilot. CICS with no prior experience with VC actors typically began by forming farmer networks and concentrating on farm-level knowledge. Meanwhile, those with pre-existing actor networks have initiated activities both at farm and food levels or engaged in broader knowledge dissemination.

Discussion and Perspectives

This study highlights how multi-actor networks, working to develop IC agri-food VC, are shaped by a combination of factors: vision of IC, strategy clarity, actor mobilisation, management skills and history of collaboration. It is complementary to Salembier *et al.* (2023) findings on multi-actor experimental networks management and functions which highlighted different ways to manage such networks. Here we explore in more details the facilitating factors enabling innovation processes coordinated in multi-actor networks. Further research is needed to explore how these factors interact, combinations that best support co-innovation processes and identify the necessary skills to stimulate VC development. Evaluating activities based on objectives and connected real-life outcomes could help develop methods and tools to facilitate

collaboration and innovation. Additionally, the results will help expand the "step-by-step" cropping system design framework (Meynard *et al.*, 2023) to integrate a VC dimension.

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Portraying agroecological initiatives to support transformative change

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Introduction

Transdisciplinary knowledge is increasingly recognized as crucial for driving sustainable transformation of agrifood systems. Collaborations between scientists and practitioners within societal initiatives, such as living labs, offer significant potential to accelerate a transition towards agroecology. Developing a shared understanding of the history and current state of societal initiatives reinforces the effectiveness of such science-society interactions. Within the multi-actor project Agroecology-TRANSECT (<https://www.agroecology-transect.net/>), involving eleven agroecological initiatives across Europe (hereinafter referred to as Innovation Hubs, or IHs), we developed a learning-oriented framework to achieve this goal (Cassart et al., 2025). IHs consist of networks of societal and academic actors collaborating around systemic, agroecological solutions (Table 1). Project interactions with IHs are mediated by "IH facilitators" - eight researchers, two agronomic advisors, and one organic box scheme manager.

Location	Main agroecological topic	
Belgium	Tillage reduction in organic field crop systems	
Bulgaria	High Nature Value farming systems	
Denmark	Conservation Agriculture	
French Massif Central	Dairy farming in the Massif Central	
Guadeloupe	Small-scale tropical mixed farming systems	
Hungary	Cover crop management in vineyards and orchards	
The Netherlands	Strip-cropping	
Romania	Market identity for Bio+ and agroecological products	
Slovenia	Organic box scheme	
Spain	Regional agroecological food systems	
Switzerland	Grasslands management	

Table 1: Location and main agroecological topic of the 11 IHs.

Methods

The framework comprises an analysis of four pillars: (a) Context, (b) Actors, (c) Barriers/Levers and (d) Relation to agroecological principles, defined through a combination of quantitative and qualitative characterization and assessment approaches. The process of applying the framework involves multiple interactions among participants, i.e. regular online or in-person interactions with IH facilitators, in-depth interviews with key stakeholders from the initiative,

and reflexive feedback on the results. Context is described through six dimensions. Key actors within the network and key barriers and levers to IH agroecological transition were identified, applying network metrics as part of cognitive mapping and social network analysis. The relative importance of agroecological principles (HLPE, 2019) was investigated based on implemented practices and facilitators' perception (Dumont et al., 2025). Finally, a cross-case analysis is underway (Cassart et al., in preparation), drawing on methods like Multiple Correspondence Analysis and narrative comparison to derive generalizable insights across the IHs.

Results

The framework has been actively applied within the project, benefiting from its overarching learning-oriented approach, building on co-innovation (Rossing et al., 2021). Through its four pillars, the heuristic framework facilitates a shared understanding among project participants on each IH's history and current state, highlighting potential avenues for joint action. While the context analysis outlines the setting of each IH within the broader food system, the actor network analysis, the identification of barriers and levers to agroecological transition, and the characterization of their relation to the 13 agroecology principles provide actionable knowledge.

Furthermore, the transversal analysis (in progress) highlights key trends across our diverse agroecological initiatives. For instance, farmers and researchers appear central in most networks, with researchers playing a significant role when they originate the initiative (e.g. through scientific programs). In such cases, they act as network builders and knowledge facilitators through participatory research. These research-led initiatives typically address more the agroecology principles related to the agroecosystem level. In contrast, initiatives emphasizing food system-level principles often have central actors like NGOs, local activists, or distributors working alongside farmers, rather than being researcher-driven. This diversity in actor dynamics and the principles they mobilize illustrates the adaptive nature of agroecology, which accommodates different balances depending on local needs, priorities, and socio-economic contexts (Dumont et al., 2025). In addition, recurring barriers hindering transition and levers facilitating it were found across the IHs, spanning themes like policy, economy, knowledge or social organization. Common barriers include inconsistency of EU and national regulations regarding agroecology or limited farmer profitability. The analysis of the levers (e.g. improved consumer relationships, rising market demand for agroecological products or collective marketing strategies) implemented by the IHs to tackle those common barriers is insightful.

Discussion and Perspectives

Leveraging more comprehensive methods for characterization and assessment, we present a learning-oriented framework to develop a shared portrait of an agroecological initiative. Striking a balance between comprehensiveness and promptness while upholding scientific rigor, the four pillars have proved to form a coherent and replicable framework, enabling to pinpoint scientifically robust, locally relevant opportunities to guide transformative efforts. For instance, the Danish IH recognized Conservation Agriculture as a niche in the regime and identified missing actor connections. The Belgian IH appreciated the analysis of barriers and levers, noting its alignment with their current technical focus. The French IH valued the national positioning through the context analysis and saw opportunities to enhance connections with economic actors, while recognizing the strong role of researchers within their IH. Such reframing of how we see the world has been denoted as social learning, considered essential for transformative change (Rossing et al., 2021). Moreover, the shared understanding fostered through the portraits nurtures trust and social capital, crucial elements for effective science-society interactions (Douthwaite & Hoffecker, 2017). Finally, our framework supports cross-case learning and advances knowledge on agroecological transitions across Europe.

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How can transdisciplinary projects contribute to agroecological transformation?

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Introduction

With a basis in integrating scientific knowledge with experiential, local, traditional (etc.) knowledges, agroecology aligns with recent efforts to address sustainability challenges and stimulate transformative change in transdisciplinary research projects, and a general trend of multi-actor approaches that connect science with practice (Cronin et al., 2022).

Yet many questions remain as ideas and ambitions are translated into practice (Fernández González et al., 2021). A knowledge gap remains in terms *process* how to effectively design, manage, and monitor projects to support transformative change pathways; and *outcomes*: how 'actionable knowledge' outputs can be evaluated in terms of their various contributions to transformative change (Rossing et al., 2021). Critical explorations of these knowledge gaps are highly relevant (Fernández González et al., 2021; Turnhout et al., 2020).

As agroecology has entered institutional spaces it has become a 'territory in dispute', marked by tensions between conformity and transformation (Giraldo and Rosset, 2018). Transformation envisions fundamentally alternative agri-food systems, while conformity makes (relatively minor) tweaks to existing productivist systems (Walthall et al., 2024). Integration of critical social science (Sayer, 2009) can assist project participants and designers in orienting towards transformative visions and activities by enabling deeper structural analysis of constraints which keep agri-food systems locked-in to unsustainable trajectories (Ceddia et al., 2024). This integration of critical social science builds upon recent calls for 'co-innovation' as an approach to reflexive, complexity-aware project governance (Leclère et al., 2024; Rossing et al., 2021), which can in turn be used to support impact through learning-oriented monitoring and evaluation.

Our paper features a case study of the authors' ongoing collaboration in the Horizon Europe project Agroecology-TRANSECT (AE-T), which aims to generate (1) actionable knowledge with 11 territorially-rooted agroecological initiatives (called 'innovation hubs', IHs); and (2) to contribute to transformative change. Building on efforts of previous projects (Leclère et al., 2024; Rossing et al., 2021), AE-T has embedded a co-innovation approach into the project governance. Our paper examines the extent to which the aspirations of this approach are realized, while seeking to understand and explain the factors that enable/constrain AE-T in achieving its mission-oriented goals. In doing so, we contribute to middle-range theory on the 'how' of doing transdisciplinary projects for transformative change.

Methods

Our evaluation draws on realist evaluation to 'test' project's theory of change, which project participants have articulated and refined as part of the co-innovation approach. Here we have

structured the evaluation by developing two 'hypotheses' that summarizes components of the project's theory of change:

1. Co-innovation processes generate trust and social learning which support generation of actionable knowledge.
2. Actionable knowledge and social learning in a transdisciplinary project can generate contributions to the unfolding of agroecological transformation.

These hypotheses are 'tested' against the qualitative empirical data gathered in the first two years of the AE-T project (i.e. semi-structured interviews with project participants and participant observation at a series of project meetings), using retroductive analysis. In order to assess the second hypothesis, we have relied on frameworks developed in literature on transformative agroecology (see Figure 1; Anderson et al., 2021; Walthall et al., 2024).

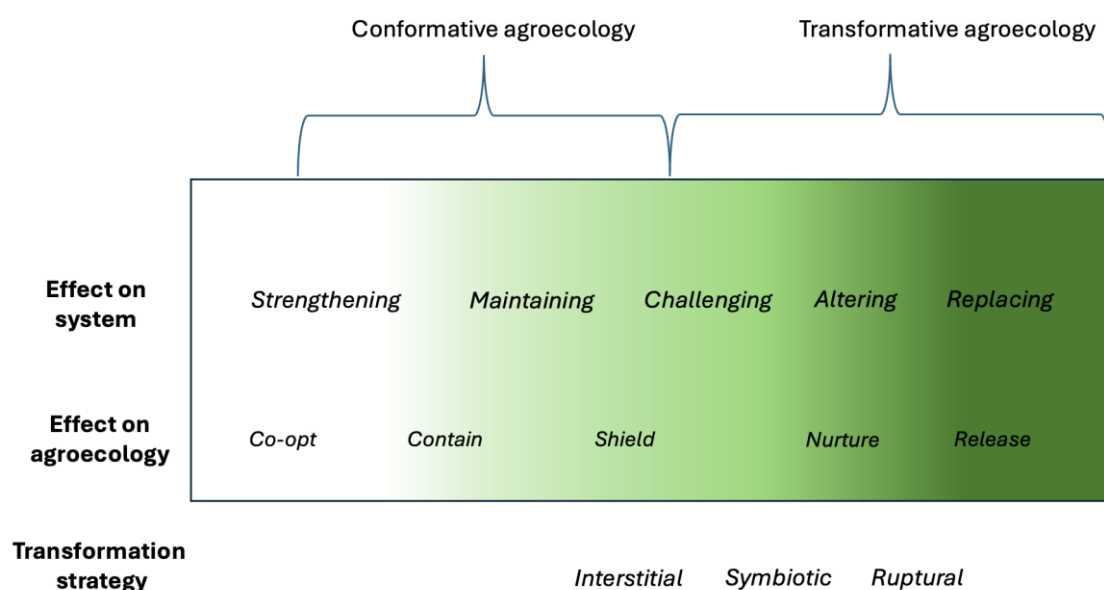


Figure 1. Own formulation for conceptualizing the different effects of interventions on existing systems and on agroecology, building on, i.a., Anderson et al. (2021).

Results (highlights)

Hypothesis 1:

- Trust and social learning have been generated, mostly among WPs and IH facilitators who are directly connected through project activities. But difficult to 'scale' beyond this 'core group'.
- Access to resources and time from the project, have been key mechanisms for successful IH outcomes.
- Concerns about project work remaining at academic level, despite intentions to do otherwise.

Hypothesis 2:

- Reports of transformative learning amongst project 'core group'; questions remain about how to measure/report/scale these outcomes.

- Several 'successful outcomes' (self-defined by IH missions) could be considered in line with "co-opting" agroecology (Anderson et al., 2021, Whitehall et al., 2024); highlighting tensions between open-endedness and determinism (Lamine et al., 2021)
- Lack of involvement of social movements and more radical niche initiatives in initial project design limits transformative potential of project interventions

Discussion and perspectives

While challenges are ongoing, the co-innovation approach has been key for addressing and adapting during the project. Deeper integration of critical social theory into initial project design and framing, and learning-oriented monitoring can enable project participants to more reflexively orient their planning and activities, which helps empower them to avoid traps of 'conforming' despite transformative intentions.

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How to make livestock systems on native grasslands sustainable? Results and lessons from a change-oriented research project

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Introduction

Livestock systems are very relevant in South America's Campos and Pampas regions. These systems have the challenge of improving productivity and economic income and their adaptation to climate change, since there are no production subsidies and the sustainability of farms is affected by the productive and economic results they obtain. There is technological information to improve livestock systems on Campos grasslands performance (Paparamborda et al., 2023). However, despite the vast amount of knowledge, there is still limited emphasis on understanding how to implement change in the production systems. The 'how to' question is now arguably the most important question (Rossing, 2023) for agronomy science. Co-innovation is an approach to change-oriented project governance and management, that offers effective outputs for sustainability transitions (Rossing et al., 2021). Here, we show results and lessons from the co-innovation project implemented in Uruguay to improve the sustainability of livestock farm production systems through ecological intensification, focusing on productive and economic indicators.

Methodology

The "Ganaderos Familiares y Cambio Climático" project was developed in Uruguay in the Sierras del Este and Cuesta Basáltica regions, from 2015 to 2019 (Figure 1). The Uruguayan Ministry of Agriculture, the Faculty of Agronomy, other public institutions, and farmers' organizations participated in this project.

First, a representative survey of the two regions was conducted and a typology of farms was constructed to determine the baseline. Then, with the guidance of the typology, the farms were selected to carry out the technical change intervention. Fifteen farms were selected per region. In each of the farms, a technical assistance process was carried out for 3 years, which included characterization and diagnosis of the system, the formulation of a redesign proposal and its implementation (Dogliotti et al., 2014). A technical advisor was assigned to each farm and visited them once a month for 3 years. The advisor made a characterization and diagnosis of the production system, in the first 6 months, then formulated a redesign proposal for each farm, which took 3 months and then began to implement the proposal. During the work process on the farms, evaluation workshops were held each year in each of the regions, a total of 6 workshops where an evaluation of the work process was carried out and lessons were learned. These workshops were designed and implemented by social science professionals in conjunction with the project team. In addition, two field days were held each year on the farms where the work on the farms was made known to a wide audience. Except for the informal discussions, all meetings were formally facilitated, monitored and reported. More details about the project see: www.gub.uy/ministerio-ganaderia-agricultura-pesca/politicas-y-gestion/planes/proyecto-ganaderos-familiares-cambio-climatico.

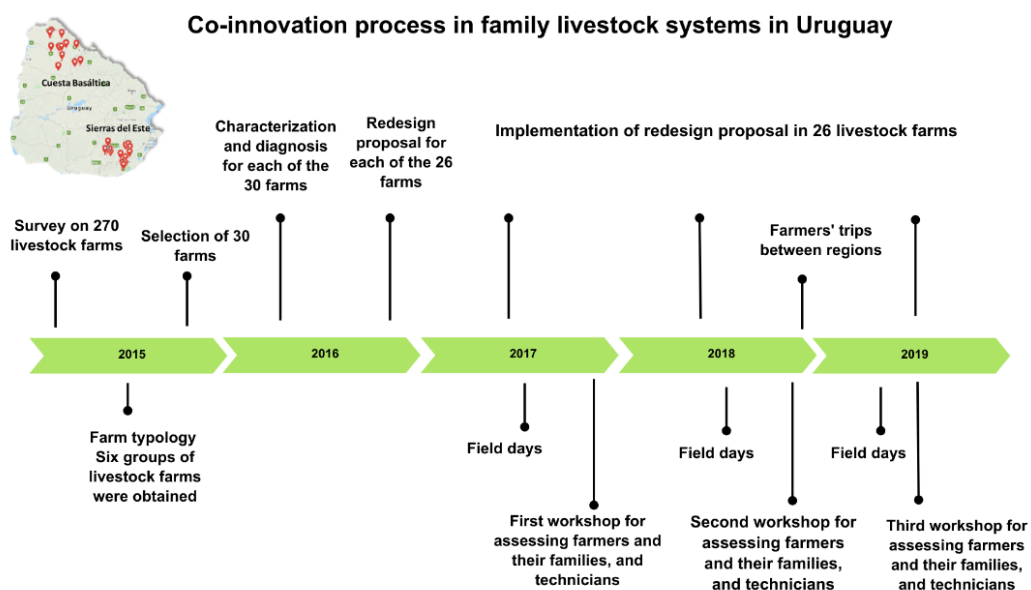


Figure 1: Overview of the methodology followed in the project.

Results

The survey and typology allowed for the generation of a baseline of family livestock farming in Uruguay. This survey showed that meat production was low around 70 kg/hectare per year and that there was also low implementation of management techniques and where the mating period was continuous or extended greater than 4 months was present in 60% of the farms. Six groups of livestock family farms were obtained. These groups differ in the total amount of land they have and access to (owners or tenants), the number of cattle and sheep they have, and the area under improved pasture.

The technical intervention work on the farms for 3 years has allowed to improve the family income, due to an increase in animal production, while maintaining production costs (Table 1). This improvement came from the implementation or adjustment of strategic, tactical, and decision-supporting techniques, which allowed for improved production or utilization and transformation of energy from native grasslands into animal products.

Variable	Initial	Final
Farm Area (Ha)	309 ± 225	343 ± 269
Improve pasture (%)	12 ± 18	11 ± 15
Stocking rate (LU ha ⁻¹)	0.86 ± 0.17	0.79 ± 0.15
Weaning Cattle rate (%)	0.63 ± 0.14	0.73 ± 0.12
Cattle meat* (kg ha ⁻¹)	59 ± 32	69 ± 37
Meat Equivalent (kg ha ⁻¹)	84 ± 24	93 ± 28
Gross product (US\$ ha ⁻¹)	124 ± 41	144 ± 56
Costs (US\$ ha ⁻¹)	82 ± 27	79 ± 24
Family income (US\$ ha ⁻¹)	41 ± 32	67 ± 42

Table 1: Main productive and economic indicator at initial and final project.

The annual workshops were very important to correct and plan the project activities in a better way. The families highlight as their main point of learning a change of mentality in the way they

see their farm. The technicians highlight the importance of having a team that guides and supervises their work in addition to having a clear protocol to work on the farms. We learned and demonstrated how it is possible to change in average terms the main economic and productive results in the short term, even though there may be different trajectories between the participating farms.

Discussion

We started from a representative sample of livestock farms in Uruguay, we investigated the diversity of production systems and selected case studies based on that information. This was key to ensuring that all the actors at the beginning of the project agreed on where to start. We worked on 26 case studies, and the work process on each farm was led by private advisors, guided and assisted by our research team. This gave uniqueness to our project compared to other projects by Ruggia et al., (2021).

The results of our project provide further evidence of the relevance of co-innovation for making changes to production systems in a participatory manner, fostering learning (Rossing, 2023). On the other hand, we believe that change-oriented research should engage in strong dialogue with the scientific information that supports the agronomic practices to be implemented on farms and management grazing systems. Therefore, both methodological and technical or biophysics knowledge are necessary and should be combined to successfully redesign production systems, while generating learning among all the actors involved in the project.

The results of this project have contributed to public policy efforts to design policies for the development of livestock farming based on ecological intensification and co-innovation.

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Empowering systemic change at a territory scale: a collective learning experiment with stakeholders along the agrifood chain in the Pilat, France

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Introduction

Profound changes are needed to support the global food and agriculture systems nourish the world population (UN, 2019), with fundamental processes to restructure, stir directions, innovate, on multiple scales, persistently and throughout the entire system (Fedele et al., 2019). Moreover, designing effective solutions requires considering farmer's particular climate and soil conditions, available means and resources, and institutional and socio-economic contexts (Meynard et al., 2012). Shifting the agri-food systems within which farms are embedded entails working with and for the broad range of actors involved (Gliessman, 2016). In order to do so, supporting the self-organization of actors, in a bottom-up approach, and on a territory, scale has the potential to drive important shifts, such as pesticide use reduction. However, this remains an important gap in the literature (Jacquet et al., 2022). Action-research has proven helpful in empowering actors to face complex issues, while helping acquire new knowledge on agri-food systems (Conner et al., 2010.; Swords, 2019). We present the findings from a territory-wide multi-actor action-research experiment aimed at supporting the development of a low to no pesticide fruit agri-food system.

Methods

An initial study, based on 35 semi-structured interviews and 20 participant observations was first conducted in order to understand barriers and leverages to reducing the use of pesticides in the arboriculture production of the Pilat Natural Regional Park, France (Hirson-Sagalyn et al., 2024). This study laid the groundwork to design the research project presented herein. A hybrid methodology was selected, combining Territorial Dialog (Barret, 2003), and Systems Oriented Design (Sevaldson, 2022). The approach included semi-structured interviews (lasting 60-120min each), several half-day collective workshops, a full-day event, site-visits, and numerous individual meetings with actors across the agrifood system. Data from each step informed the next, in an iterative process (Figure 1).

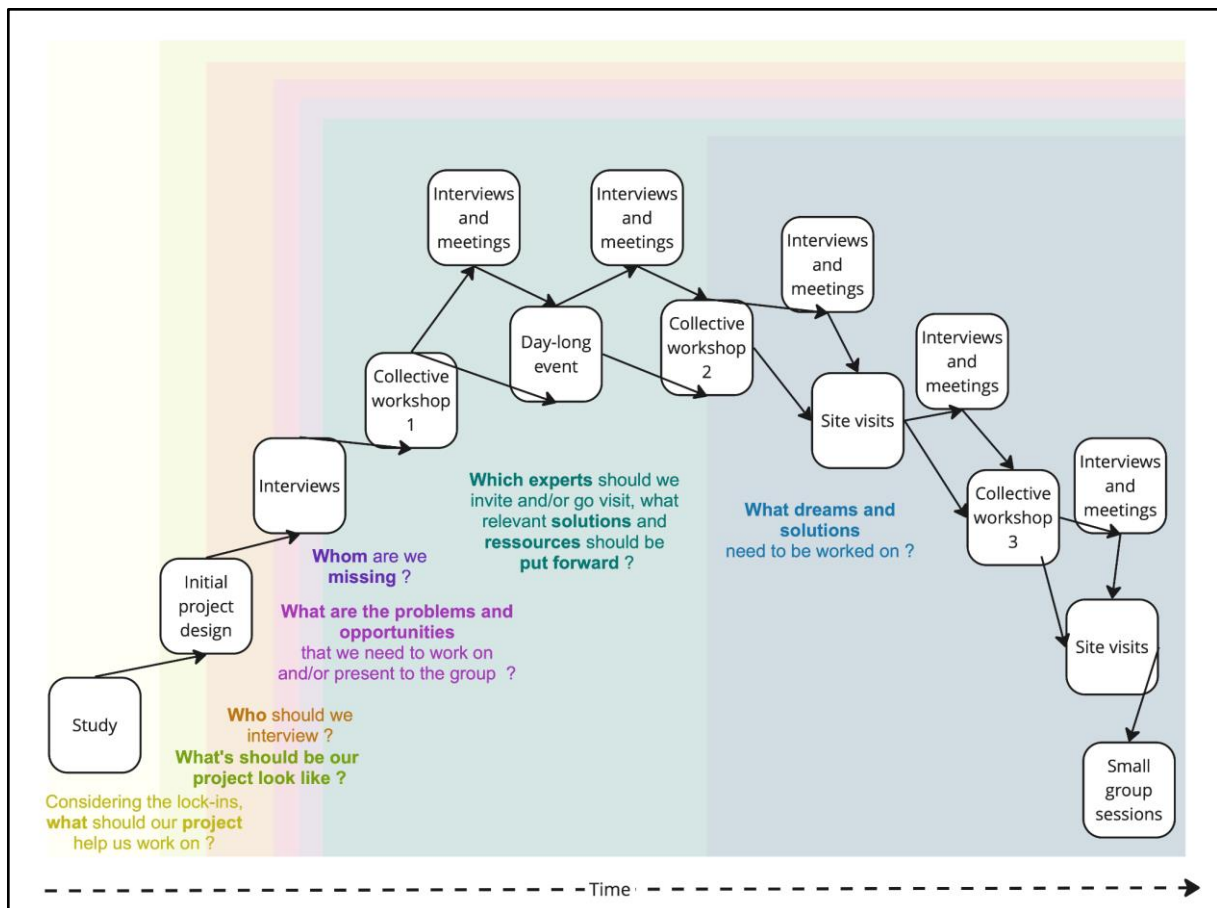


Figure 1. Design process overview: questions appeared over time; the answer to these questions helped form new knowledge, which in turn informed future action.

Results

Results focus on the territory-wide design process aimed at supporting systemic change within the agri-food system. Several synchronous and asynchronous phases took place, in order to help the group form an understanding of the starting situation, then explore, evaluate, select, and develop solutions together. Interviews helped the facilitators gain knowledge of fruit in the Pilat: its production, storage, processing, selling, distributing, serving, via multiple food chains. Subsequent workshops and events helped tease out problems and opportunities along the value chain and throughout the territory, define 11 main varied challenges (ranging from logistic solutions, to facilitating farmer-chef agreements), and explore concrete solutions (e.g. a collective processing facility for smallholding farmers; a system for calculating savings from food-waste reduction measures). In some instances, this resulted in coupled innovations. For example design work included storage units for small volumes of fruit coming from different farms as well as means to support dialog between producers and clients, notably to alleviate storage needs and adjust delivery frequency. Particular attention was placed on fostering relationships among project participants to build project capacity, and finding ways to involve key actors in the design process.

Discussion and Perspectives

Research on workshop-based design processes that foster collaboration among the broad range of actors involved in agri-food systems is only at its infancy (Jeuffroy et al., 2022). This study advances such knowledge, while also elucidating the role of complementary activities in achieving the transformational goals at stake. Key themes include ways to encourage bold

visions and maintain a systems-wide approach while landing on operative solutions. We also delve into issues of actor engagement and inclusivity. In agroecology co-design, involving key future users, such as farmers or cooks, who have high interest but limited capacity to participate in workshops, can be challenging. Our study highlights modalities that can help integrate these actors' perspectives in design considerations, such as running the project conjointly with local socio-political actors and technicians, and diversifying ways to engage with the project).

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Co-designing multi-performance result-based strategies for water quality restoration with farmers

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Introduction

The poor ecological status of French and European water bodies highlights the persistent shortcomings of both mandatory and voluntary efforts to improve farming practices and reduce diffuse agricultural pollution. These approaches often struggle to engage farmers and achieve significant environmental results. In this context, result-based approaches---where farmers commit to achieving environmental outcomes without being prescribed particular practices---offer a promising alternative. By granting flexibility in how to meet objectives, such approaches have shown effectiveness in other environmental domains.

Yet, directly linking farm-level management practices to groundwater pesticide concentrations remains a major challenge. The invisibility of groundwater processes and the lack of appropriate monitoring tools at the farm scale complicate efforts to assess impacts (Branchet et al., 2025). Moreover, water quality goals may conflict with farmers' essential priorities. When these objectives cannot be reconciled, water quality is unlikely to be prioritized.

New approaches are needed that support farmers in designing action plans for water quality improvement. These must respond both to the scientific challenge of connecting on-farm decisions to downstream impacts and to the diversity of individual goals that matter to farmers. Multi-criteria evaluation frameworks are therefore essential, as highlighted in the context of sustainable agriculture transitions (Mottet et al., 2020). This study contributes to agricultural system redesign by exploring a co-designed, result-based, multi-performance approach tailored to local catchment contexts.

Method

This research is part of an ongoing participatory action research project embedded in a PhD. It follows a phased and adaptive design, beginning with a co-design phase (July 2024 to May 2025) and continuing with testing and refinement in 2025--2026. It is grounded in the principles of participatory action research (Kemmis & McTaggart, 2005), and builds on recent methodological developments in territorial co-design processes (Delesalle et al., 2023).

The project applies a shared participatory approach across three pilot groups composed of farmers and local water catchment extension agents. These groups are not replicating a predefined model but experimenting with a common method tailored to their specific local contexts. The aim is to support the emergence of grassroots, site-specific action plans that address both water quality issues and individual farming constraints.

Group formation took place from July to December 2024 through catchment selection in collaboration with the local water syndicate (S2e77), public meetings, and twenty interviews with volunteer farmers. These steps helped identify motivations and lay the foundation for group engagement.

From December 2024 to April 2025, a sequence of three structured workshops was co-developed and facilitated by the PhD researcher and extension agents. The first workshop focused on identifying key issues to conciliate water quality and production system and defining the scope of group action. The second workshop surfaced participants' concerns, values, and objectives, leading to the definition of multi-performance goals. The third workshop brought these elements together through the co-construction of local action plans designed to align pesticides related water quality targets with farmers' priorities.

Since April 2025, the pilot groups have entered the first implementation phase. Each group uses a strategic dashboard to monitor progress toward result-based objectives and inform ongoing decisions. Extension agents continue to support group dynamics and adaptation to emerging needs.

The evaluation of the shared participatory approach is embedded in the process. It focuses on its ability to engage farmers, support co-design, and adapt to context-specific variables such as catchment size and local farming structures.

Results

This research is ongoing. The results presented here reflect the outcomes of the first co-design phase.

The shared participatory approach successfully mobilized three pilot groups, involving 20 farmers and their local extension agents. Each group developed an action plan addressing groundwater contamination by pesticides. Participants reported increased awareness of water quality issues and a strong sense of ownership over the goals and strategies developed. The co-design process fostered trust, peer learning, and stronger relationships with extension agents---key conditions for sustained engagement.

Each group defined context-specific, multi-criteria objectives that extended beyond environmental targets to include economic viability, work organization, and long-term resilience. Some farmers suggested monitoring point-source pollution via soil, drainage, and surface water to better understand pesticide transfers. Researchers expected practical measures but underestimated farmers' interest in system-level knowledge to support decisions.

The approach proved flexible and adaptable across varied farming systems and catchment configurations. Its effectiveness was supported by three interrelated factors: the early identification of relevant local water issues, the structured yet flexible facilitation role of extension agents, and the explicit integration of farmers' priorities into the action planning process.

Discussion

These initial findings echo prior work on the need to align collective environmental strategies with local governance and result-based frameworks (Ferrané et al., 2020). However, challenges persist---notably the lack of robust tools to monitor the causal link between on-farm practices and changes in groundwater quality.

The co-design process has shown promise in generating locally meaningful action plans and motivating farmer engagement. It highlights the potential of multi-performance frameworks to reconcile environmental and agricultural goals. The results also illustrate the challenge of shifting from practice-based to result-based logic, which can require substantial change in the roles and skills of extension agents.

Perspectives

The second phase of the research will focus on testing and refining the method and action plans. This iterative process will aim to improve the robustness, applicability, and transferability of the shared participatory approach and further explore its potential to support long-term water quality initiatives at catchment scale.

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The MEDITAE framework: enhancing agroecological diagnosis in co-innovation platform

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Introduction

The transition towards agroecology requires learning about agroecosystem functioning (Prost et al., 2023). The co-innovation approach promotes learning and generates actionable knowledge to support sustainability transitions (Rossing et al., 2021). At the farm system level, co-innovation involves characterization, diagnosis, redesign, monitoring and evaluation (Dogliotti et al., 2014). However, current diagnosis methods do not capture the ecological processes underpinning agroecosystem functioning and fall short of nurturing an agroecological perspective. Here we present the Assessment and Diagnostic Framework to Inform Agroecological Transitions (MEDITAE, Spanish acronym: Marco de Evaluación y Diagnóstico para Impulsar Transiciones AgroEcológicas) and its application to five case study vegetable farms in Uruguay.

Methods

The MEDITAE framework was co-developed and applied in a co-innovation project, where the research team proposed the framework structure and farmers provided feedback. The project ran from 2019 to 2023 and involved five farms (three organic, two conventional) in Canelones, Uruguay. The framework was discussed and applied after six-ten farm visits (characterization phase). During these visits, informal discussions, mutual knowledge and trust were developed. Discussions of researchers and farmers revolved around the processes underlying the core concepts of MEDITAE and which indicators could be used to describe these processes performance and linked practices. These indicators were used at all five farms.

Results

The MEDITAE framework

MEDITAE connects six foundational socio-ecological processes underlying agroecosystem functioning (Altieri, 1999) to farm performance and management (Fig. 1). Each process is described in terms of its main components, their interconnections with other components of the farm system, and their relevance for agroecosystems' functioning from an agroecological perspective. *Performance indicators* (such as nutrient and soil organic carbon balance, pest incidence, and family income) are proposed to assess agroecosystem functioning, and *practice-based indicators* (such as crop rotation, tillage frequency and intensity, and input use) are used to assess management practices that may explain performance. The choice of the indicators is flexible and should be tailored to specific situations (e.g. type of production system and location) to inform the six key processes in a meaningful way.

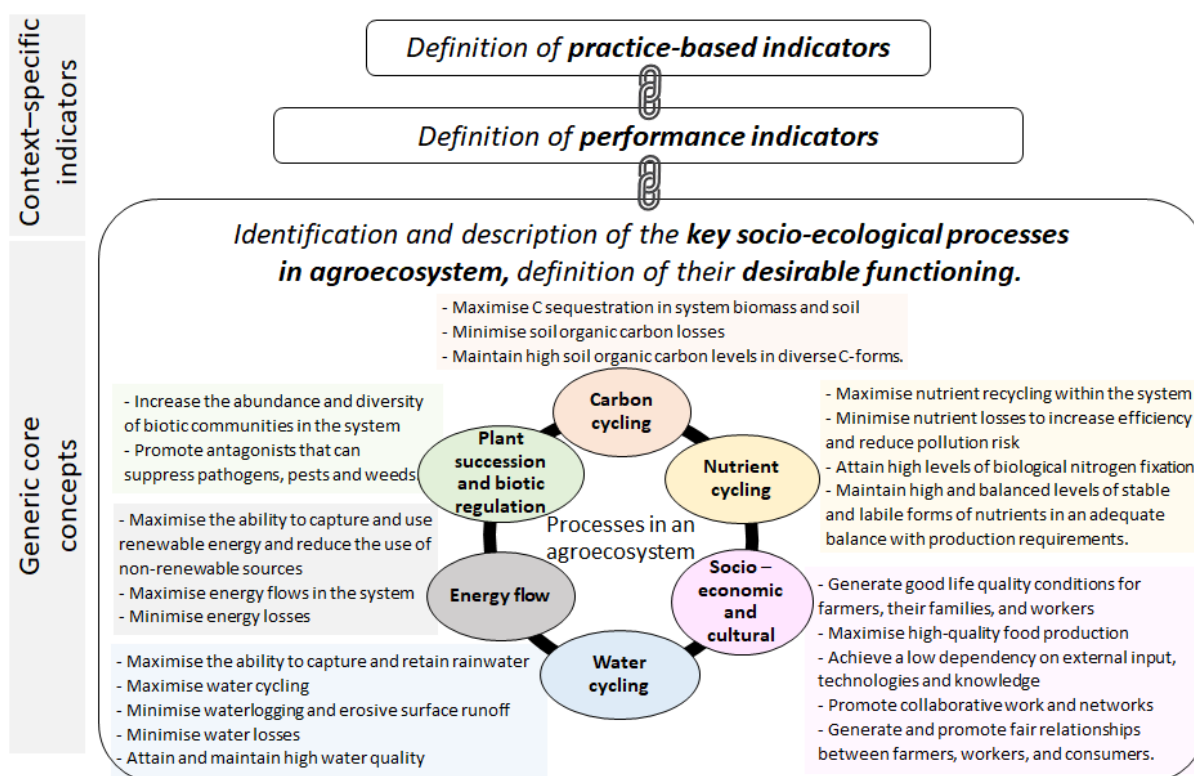


Figure 1. The MEDITAE structure: from generic core concepts to context-specific indicators.

Application of framework

Performance indicators showed that all five vegetable farms had a weak performance on nutrient cycling and energy flow processes. Carbon and water cycling achieved good overall performance on two (organic) farms. The three organic farms had good overall performance on plant succession, biotic regulation, and socio-economic processes, while the conventional farms had weak performances. The main processes that needed to be strengthened on each farm were discussed and defined based on the results of the performance indicators and farmers' interests (Table 1). The discussion around the socio-economic and cultural aspects helped to understand the objectives and needs of the families, which was a guiding principle possible strategies and management practices that could be changed to improve performance. in the redesign phase. The discussion about the practice-based indicators focused on the

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Processes with good performance	Carbon, water, plant succession & biotic regulation, socio-econ.		Carbon, water, plant succession and biotic regulation, socio-econ.	Plant succession and biotic regulation, socio-economic	
Processes that need to strengthen	Nutrients, energy	All. Prioritized: socio-econ., carbon, plant succession & biotic regulation	Nutrient, Energy	Carbon, (water), nutrients, energy	All. Prioritized: socio-econ., carbon, plant succession & biotic regulation
Redesign Objectives	Maintain family income, involve new generations, reduce environmental and social impact (workload and stress).	Increase family income, improve soil quality and reduce environmental risks. Become agroecologically certified ¹ .	Consolidate and stabilize income, increase efficiencies, reduce environmental and social impact (workload and stress).	Stabilize family income, improve soil quality and biodiversity.	Increase income and stability (reduce stress), improve soil quality, reduce pesticide risks. More sustainable still conventional farm.
Redesign Strategies	i. Reducing crop areas, especially in field crops. ii. Crop rotations to reduce weeds, maintain SOC while adjusting organic amendments for pest and disease control, reducing over-fertilisation. iii. Manage non-cultivated areas and strips between fields and greenhouses	i. Expand greenhouse area to boost crop diversity, production, and rotation. ii. Crop rotations to increase SOC and control pests. iii. Advance biological control, reduce pesticides, increase vegetation strips. iv. Explore alternatives for good-quality water. v. Explore commercial options for crop diversity.	i. Pause area expansion, adjusting crop areas to reduce labor. ii. Crop rotations to maintain SOC while adjusting organic amendments to reduce over-fertilisation. iii. Adjust cropping timing. iv. Manage non-cultivated areas and strips between fields and greenhouses. v. Address workers' social benefits. vi. Improve farm records for decision-making.	i. Adjust production plan for efficiency, balancing crop areas and labor. ii. Reorganize crop rotation to boost SOC, nutrients, and reduce weeds. iii. Adjust cropping timing. iv. Consolidate non-cultivated areas between fields. v. Explore direct selling and crop diversification for income stability.	i. Reduce main crop area, add new crops for rotation and spring income. ii. Reorganize crop rotation to reduce soil disease and increase SOC. iii. Reduce herbicide use and adjusted fertilization. iv. Redefine commercial strategy to reduce post-harvest losses. v. Explore alternatives to increase irrigation water availability.

¹In Uruguay agroecological is legally equivalent to organic.

Table 1. Summary of farm diagnosis and redesign of five vegetable farms (1, 3 and 4: organic management, 2 and 5: conventional management). The diagnosis and redesign strategies presented resulted from various discussion rounds between the research team and the farm families involved.

Discussion and perspectives

The MEDITAE diagnosis fostered collective reflections on how socio-ecological processes affected system performance and how they were influenced by farmers' practices. These reflections helped to develop an agroecological perspective, fostered learning, and empowering farmers to change practices. MEDITAE provided a generic framework connecting a systemic farm characterization with the redesign and led to different redesign solutions than previous co-innovation projects that used other frameworks. The mechanistic approach of MEDITAE supports the evaluation of agroecology policy support, enhances agronomist training, supports technical advisors' work, and helps in framing inter- and transdisciplinary research. Finally, MEDITAE has a flexible structure that allows its application in other regions, systems, and scales.

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Improving sustainable contribution to food security of Uruguayan cow-calf systems through ecological intensification

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Introduction

Despite the significant environmental impacts of animal-sourced foods (ASF), demand is expected to rise. Nevertheless, grass-based ruminant systems using non-human-edible feed may help ensure future food security (Wilkinson, 2011). In Rio de la Plata Grasslands, cow-calf systems coexist with native ecosystems but struggle with low productivity, profitability, and land degradation (Modernel et al., 2016). Two main intensification pathways exist: one focuses on increasing inputs and sown pastures (Kanter et al., 2016), and ecological intensification (EI), which aims to boost performance while preserving native grasslands (Soca et al., 2024). This study explores cow-calf farm performance and EI's impact through co-innovation in Uruguay, a low-input, grassland-based beef region.

Materials and methods

The "Ganaderia y Clima" project aimed to improve productive, economic and environmental outcomes of 60 Uruguayan farms via a co-innovation process. Baseline data (2017-2020) were followed by a co-innovation phase (2020--2023), guided by systemic EI focused on grazing and herd management innovations (Soca et al., 2024), with goals jointly defined by farmers and technical teams. Land area and types of land use, herd description, sales, purchased feed and fertilizers, farm costs and revenues were collected. Farm characteristics (weaning rate, weaning weight, fattening rate, stocking rate, herd management index, proportion of sheep in the herd, share of sown pastures, meat production per ha and sustainability metrics (net family income and economic efficiency, GHG emissions per kg of meat and per ha, and contribution to food security via the net productivity indicator (Battheu-Noirfalise et al., 2023)) were calculated. Redundancy analysis (RDA) identified key variables influencing sustainability, and farms were grouped using k-means clustering. Differences across farm types and periods (Before project, during project and redesign objective) were analyzed using ANOVA.

Results

The RDA (Fig. 1) revealed that only three farm characteristics significantly explained 45% of the variability in sustainability indicators: weaning rate (25%), stocking rate (17%), and share of sown pastures (3%). The weaning rate correlated positively with family income (0.54) and negatively with GHG emissions per kg of meat (-0.65), representing an "efficiency axis". Stocking rate and share of sown pastures correlated positively with GHG emissions per hectare (0.77 and 0.37, respectively) and net productivity (0.53 and 0.49, respectively), forming a "land intensification axis". Clustering identified three farm types: Efficient (E), Average (A), and Inefficient (IE). A and IE farms improved GHG emissions per kg of meat, family income, and, for IE farms, net productivity, mainly due to increased weaning rates (Table 1). E farms showed no improvements and reduced stocking rates. No farm type fully met objectives within three years.

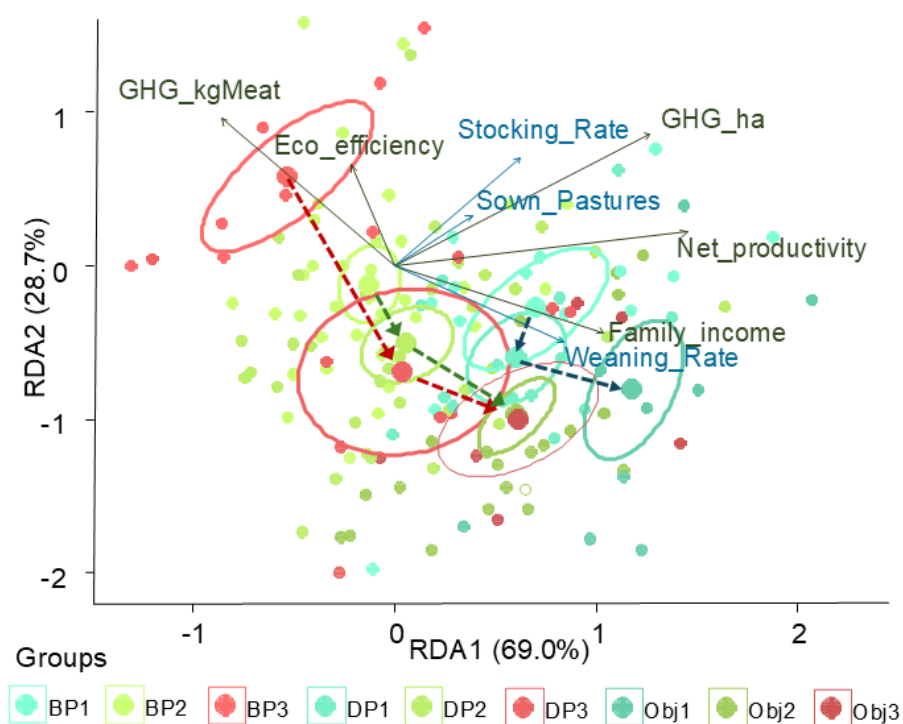


Figure 1. Plan of the RDA with BP, Before Project, DP, During the Project and Obj, Objective.

	E (n=15)			A (n=25)			IE (n=9)		
	BP	DP	Obj	BP	DP	Obj	BP	DP	Obj
GHG (kg CO ₂ -eq/kg meat)	17.6 ^{a,B}	16.4 ^{a,-}	13.10 ^{b,-}	20.4 ^{a,B}	17.8 ^{b,-}	13.3 ^{c,-}	26.7 ^{a,A}	16.0 ^{b,-}	12.7 ^{c,-}
GHG (t CO ₂ -eq/ha)	2.06 ^{-A}	1.86 ^{-,-}	1.89 ^{-,-}	1.72 ^{-B}	1.68 ^{-,-}	1.66 ^{-,-}	1.83 ^{-AB}	1.57 ^{-,-}	1.67 ^{-,-}
Family income (\$/ha)	106 ^{b,A}	108 ^{b,A}	143 ^{a,A}	44 ^{c,B}	69 ^{b,B}	103 ^{a,B}	-30 ^{b,C}	52 ^{a,B}	87 ^{a,B}
Economic efficiency (%)	43.1 ^{-B}	42.0 ^{-,-}	35.8 ^{-,-}	58.2 ^{a,A}	51.3 ^{a,-}	41.9 ^{b,-}	81.8 ^{a,A}	47.9 ^{ab,-}	36.4 ^{b,-}
Net productivity (kg HDP/ha)	8.76 ^{b,A}	8.65 ^{b,A}	10.95 ^{a,A}	6.41 ^{b,B}	6.77 ^{b,B}	9.20 ^{a,B}	5.25 ^{c,B}	7.28 ^{b,AB}	9.57 ^{a,AB}
Sown Pastures (%)	19.0 ^{-,-}	16.5 ^{-,-}	18.5 ^{-,-}	16.8 ^{-,-}	16.2 ^{-,-}	17.3 ^{-,-}	14.6 ^{-,-}	14.8 ^{-,-}	13.8 ^{-,-}
Stocking Rate (LU/ha)	0.94 ^{a,A}	0.80 ^{b,-}	0.89 ^{ab,A}	0.80 ^{-B}	0.75 ^{-,-}	0.79 ^{-B}	0.86 ^{-AB}	0.74 ^{-,-}	0.83 ^{-AB}
Weaning rate (%)	77.9 ^{b,A}	78.4 ^{b,-}	87.5 ^{a,-}	68.8 ^{c,B}	74.2 ^{b,-}	84.5 ^{a,-}	55.6 ^{b,C}	69.9 ^{b,-}	84.6 ^{a,-}

Table 1. Sustainability performances and farm characteristics of the three farm types (E: Efficient, A: Average, and IE: Inefficient) and the three periods (BP: Before Project, DP: During Project, and Obj: Objective). Letters represent significant differences between periods in lowercase and between types in uppercase.

Discussion and perspectives

While all farm types showed positive net productivity, the overall contribution of the meat production chain to food security remains to be assessed if the sold animals are finished elsewhere (Mosnier et al., 2021). Nevertheless, EI strategy through co-innovation could simultaneously improve economic and environmental aspects, as well as contribution to food security. E farms, however, showed no significant progress and reduced stocking rates, likely due to drought. The partial achievement of objectives suggests further improvement is possible. As seen in European dairy systems (Battheu-Noirfalise et al., 2024), our findings emphasize the importance of management and knowledge-driven intensification over input use. Indeed, higher weaning rates ("efficiency axis") were linked to better outcomes, reflecting more strategic herd and grass management.

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How future breeders and advisers express their attitudes in relation to society's expectations

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Introduction

Livestock farming has been the subject of numerous and growing questions in recent years: its impacts on the environment, health and farm animal welfare are being debated within society, including within the livestock world (Delanoue et al., 2018). The media, among others, very frequently publish information that is felt to be incriminating by those involved in livestock farming and contributes to developing, within society, a feeling of distrust on the part of citizens towards livestock farming. Breeders are the first to be affected by this climate of uncertainty and questioning.

At the same time, the livestock industry is a key player in the response to contemporary societal challenges: preservation of the environment, job creation, improved living conditions for animals, production of healthy, high-quality food, and so on. Numerous recent or ongoing changes in the practices of livestock farmers and industry players, while not always justified by a desire to align with societal expectations, are nonetheless moving in this direction: implementation of alternative prophylaxis, elimination of cages in pig maternity units, creation of quality approaches (Roguet et al, 2018), development of organic systems, maintenance of hedgerows and meadows, implementation of GMO-free, antibiotic-free or pesticide-free industries, enhancement of grass-fed systems, etc. The diversity of these transformations in practices is wide-ranging, from minor one-off changes in their daily tasks to a 3 profound overhaul of production methods and the representations or postures of the players involved. This is why we refer to this project as a "socio-technical" innovation. This concept enables us to situate innovation within its "socio-technical system" as a whole, and to analyse the relationships between a technical system and its social environment as a whole, in the sense proposed by Akrich (1989).

This project Entr'ACTES aims to gain a better understanding, from a sociological point of view, of what it means to be involved in livestock farming today, and the dynamics of change underway in a context where the place and role of this activity are increasingly being questioned by society.

Methods

As part of this project, we set up 5 focus groups to analyse how future breeders (FB) and future advisers (FA) perceive the profession. We carried out 3 focus groups with 32 future breeders (8, 11 and 13 students) and 2 focus groups with 20 future advisers (10 and 10 students). Each focus group was divided into 5 steps: 1-What is your vision of livestock farming in the future? 2-What do you find easy and difficult to do in your future job? 3-What do you think will have the greatest impact on livestock farming in the next 20 years? 4- What will your job be like in 2050? 5-Do you think you are sufficiently prepared for the future and what do you need?

The analysis focuses on describing the answers formulated by the students, to synthesise them at group level according to the arguments used and then to compare it by groups. In particular, the influence of societal issues on their perception of the profession and the way in which they

wish to practice it were considered as a key to reading the answers provided by the students. The qualitative nature of the responses and the small number of focus groups and students in each focus group meant that statistical analysis was not possible. We therefore used descriptive approaches and textual and graphical summaries to analyse the students' responses.

Results

The results show that, while the societal challenges are perceived by all (protection of environment, respect for animal welfare and production of quality food), there is a clear split in their perception of these challenges. The breeders express annoyance and relativization when faced with the constraints of taking these issues into account while the future advisers were concerned, worried and felt very much involved by these issues. It should be pointed out, however, that these focus groups were strongly coloured by the context of farmers' demonstrations during 2024, highlighting their anger at regulations and taxes and underlining the rift between the field and society.

In terms of their motivations, the future breeders emphasised the usefulness of the job, the future advisers their good technical knowledge and both underlined the appeal of new technologies. About their fears, the future breeders emphasised the difficulties of setting up (access to land, cost), the profusion of regulations, competition between systems and countries and strained relations with society, while the future advisers mentioned lack of training in human and social relations, the increasing complexity of systems and the reluctance of breeders to change.

Perspectives

In conclusion, the students were very interested in the exercise, not least because they were able to take a step back, but their respective positions clearly show that future breeders are more reluctant than future advisers to face up to commit to meeting societal expectations. This raises the question of how to train future advisors, in relation to supporting change in farming systems, especially in the management of human and social relations. The reluctance of breeders seems to confirm this need for long-term support when it comes to holistic systems change.

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Systems science for the transition to sustainable agri-food systems

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1. Complex agri-food systems require a systems approach

The agricultural sector is central to addressing global challenges such as food and nutrition insecurity, climate change and biodiversity loss. Current drivers and stressors, such as population growth, urbanization and structural inequality, negatively affect the resilience and capacity of agri-food systems to support livelihoods while maintaining environmental sustainability. To effectively respond to these challenges and enable a sustainability transition, a holistic, systems-based approach is necessary.

Agri-food systems are highly complex and dynamic. Firstly, this is because of the interactions between a multitude of factors, including soils and climate, food and cash crop production, water and natural resource management and a plethora of socio-economic features, affecting producers, value chain actors, and consumers. Secondly, agri-food systems serve multiple, often conflicting, objectives for a range of actors operating at different levels.

Systems science unpacks the complexity and addresses the wicked problems facing agri-food systems, by integrating different disciplines and scale levels, including temporal dynamics and spatial heterogeneity, and exploring trade-offs between different sustainable development goals. By involving stakeholders in transdisciplinary research, systems science is integral to supporting locally-relevant innovation, policy and education, and essential in impactful Integrated Agricultural Research for Development (IAR4D) projects.

Notwithstanding its potential, the impact of systems science is hindered by the insufficient exchange and cross-fertilization of approaches and a lack of consolidated systems science practice. This is partly explained by the complexity of the approach, limited researchers' knowledge and capacity (den Boer et al., 2021), a lack of systems science curricula and the insufficient emphasis on the added value of systems science, leading to missed opportunities in agenda setting and project financing. This paper aims to address this gap by articulating the added value and key elements of a systems science approach and distinguishing a set of approaches that can be used for its operationalization. This is intended to inform a community of practice on systems science, aimed at capacity sharing and strengthening for different agri-food system actors.

2. Systems science

Systems science is defined here as the science of the complexity of agri-food systems and the socio-ecological and socio-technical systems in which they are embedded (Duru et al., 2015). Systems science allows to apprehend, formalize and use the following elements as the basis for the re-design of more sustainable agri-food systems.

- Multiple relevant domains (e.g. biophysical, technical, socio-economic) necessitating multiple indicators for the assessment of system performance

- Interrelated levels of analysis and operation in both space (from the field or herd to the farm, to the landscape, and beyond), and time (seasonal, short-term, long-term dynamics)
- Flows and interactions of inputs, energy or information with the external environment and their conversion into outputs. System behavior depends on the dynamics and often non-linear interactions and feedback loops between the systems components and their interaction with the socio-ecological and socio-technical environment
- Path dependency, acknowledging that system behavior and pathways towards sustainability strongly depend on initial state and past trajectories, while recognizing the power of innovative design to break out of the dependency
- Emerging properties as a result of non-centralized behavior and different from the sum of individual decisions or component properties
- The wide diversity and heterogeneity across the constituting system units (e.g. farms, soils)
- The innovation systems including diverse stakeholders and institutions with wide-ranging objectives that affect innovation
- The local context, determining the relevance and feasibility of options for improved system performance and sustainability.

3. Operationalizing systems science

Systems science encompasses the use of systems concepts, approaches, methods and tools, that are not only useful for research but also for innovation, policy, education and for the interaction with society at large. To address a real-world problem, systems science needs to embrace these different activities and cannot be limited to the research activity only. In this process the role of researchers may also differ and range from knowledge creation to knowledge brokering (Bandola-Gill, 2023), developing decision and discussion support systems for use by stakeholders, and supporting the them in navigating complex system transitions.

In systems science, the system at stake is not pre-defined and depends on the question to be addressed. The system can be a crop rotation and its interaction with the soil, weeds, pests and disease (e.g. a cropping system), a specific type of farm (farm system), a population of farms in a region (farming system), a community-based food system, or a river basin including different land and water users.

Systems science is also a set of approaches, each addressing a specific goal (analysis, assessment, design) and using specific methods and tools (e.g. modelling, data science and statistics, artificial intelligence, surveys and typologies, heuristic maps, participatory methods):

- System analysis allows an understanding of the characteristics, dynamics, and interrelations of different components, actors and drivers, to investigate system functioning and behaviour in response to relevant scenarios of change. The analysis often integrates system diversity. It can be quantitative or qualitative, and be used for ex-post and ex-ante studies.
- System assessment compares the performance of a system with another system or with a target, using a set of indicators representing the expectations of societal actors. Assessments of trade-offs and synergies can support discussions among actors and inform decision making.
- System design is used to define, conceive, implement, and assess an improved system with regard to a set of pre-defined objectives (e.g. sustainability, resilience) and constraints imposed by the context. Co-designing implies the engagement of stakeholders throughout the process, for which living labs are increasingly promoted. System analysis is generally the first diagnostic step of a design process but is also

used to explore options or scenarios. System assessment comes in to define current performance and assess progress towards a desired state in a test-check-improve approach.

These approaches may be combined in a participative, iterative process such as, for example, the DEED cycle (Describe, Explain, Explore, Design) used to co-design innovative options or more sustainable systems (Descheemaeker et al., 2019). The integration of different types of knowledge (e.g. scientific knowledge, local farmer knowledge) plays a key role in participatory co-design and co-learning processes. The latter can culminate in decision support tools for stakeholders to discuss and select feasible transition pathways to more sustainable agri-food systems.

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Systemic design of agricultural systems in the Anthropocene: a systematic review

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Introduction

The expected high unpredictability, variability and novelty of extreme weather events in the emergent Anthropocene severely impacts agricultural systems and farming practices. The expected negative impacts of this new epoch are triggering a debate about the need for designing innovative agricultural systems (Salembier et al. 2018; Darnhofer, 2021). One strategy is to improve the ability of agricultural systems to withstand shocks by (re)designing these systems to increase their resilience. But what should be (re)designed when agricultural systems are (re)designed? How to design agricultural systems in the Anthropocene? To what extent will the (re)design towards innovative agricultural systems feed back on existing uncertainties? In this context, the aim of this study is to present preliminary results of a systematic literature review on the main understandings and principles of agricultural systems design. The objectives of this study are to 1) identify the presence of systemic design elements in agricultural system research, 2) determine the thematic focus of these elements, and 3) assess their alignment with the Systemic Design Principles of Jones (2014). The study seeks to explore how systemic design thinking has been integrated into the literature on agricultural systems design and also identify potential gaps in the application of these principles.

Methods

A comprehensive literature survey was conducted using a systematic search in the Web of Science and SCOPUS databases with specific terms related to agricultural system design and systemic design in the context of climate adaptation. Only English-language journal articles, books, book chapters, and conference proceedings were included. Studies were selected based on relevance to agriculture and climate adaptation, with focus on those discussing systemic design principles or systems thinking. Studies unrelated to agriculture or using the search terms in an unrelated context were excluded. Titles and abstracts were manually screened to select relevant studies and extract key information. For each study in the final dataset, the full paper was read, with one primary objective identified (acknowledging that papers may contain secondary objectives). Each objective was then categorized under one of five arbitrarily defined thematic areas. In the next step, these key objectives were interpreted by the authors and assigned to a single systemic design principle, as outlined by Jones (2014).

Results

The bibliographic search yielded 4605 entries (3182 without duplicates). Due to the specificity of the terms automatic filtering was not possible, so titles and abstracts were manually selected, resulting in 261 eligible studies. Further examination identified 218 studies that described identifiable design-related objectives. A map linking five thematic areas of design-related objectives to the systemic design principles (Figure 1) identified 117 objectives (from 218 studies) explicitly aligned with one systemic design principle (Table 1).

Figure 1. Connections between five thematic areas (left) and systemic design principles (right) identified in the literature. The width of the links represents the frequency of alignment between a thematic area and a given systemic design principle.

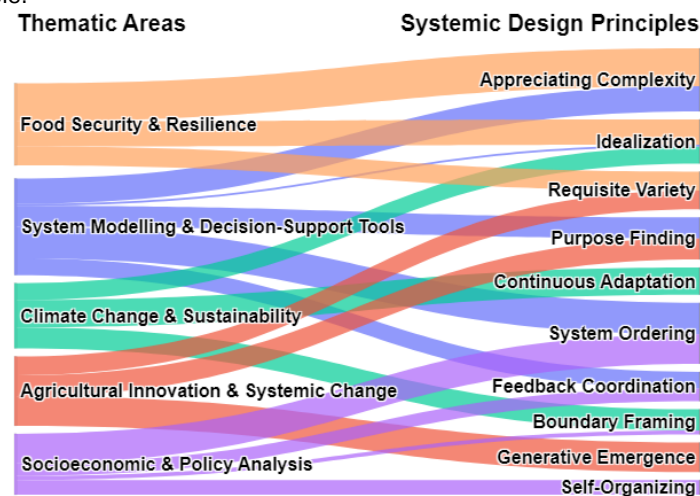


Table 1 Systemic design principles (from Jones, 2014) and alignment to the single objectives of the different entries.

Systemic design principle	Aligned key objectives	Frequency
Idealization (<i>Visioning, Goal-setting</i>)	Technology adoption, productivity growth, market orientation	12
Appreciating complexity (<i>recognizing interconnections, managing wicked problems</i>)	Food insecurity analysis, climate impact assessment, policy impact analysis	18
Purpose finding (<i>iterative goal refinement, stakeholder alignment</i>)	Farm management system design, co-innovation strategies, participatory research	15
Boundary framing (<i>context adaptation, scope definition</i>)	Agricultural policy adaptation, land-use planning, ecosystem service evaluation	10
Requisite variety (<i>diversity inclusion, flexibility in design</i>)	Multi-stakeholder engagement, cross-disciplinary integration, adaptive governance	9
Feedback coordination (<i>response mechanisms, dynamic adjustments</i>)	Impact measurement, real-time monitoring, systemic feedback loops	8
System ordering (<i>structured organization, pattern formation</i>)	Integrated farm planning, systemic risk management, knowledge synthesis	14
Generative emergence (<i>innovation facilitation, adaptive systems</i>)	Agroecological transition, sustainable intensification, new production models	11
Continuous adaptation (<i>resilience maintenance, evolutionary design</i>)	Climate resilience strategies, risk management, sustainable farming systems	13
Self-organizing (<i>autonomy enablement, collective coordination</i>)	Farmer-led innovations, community-driven approaches, knowledge-sharing networks	7

Discussion and perspectives

This initial analysis indicates that systemic design principles appear with varying frequency in agricultural research literature. Notable strengths were identified in complexity appreciation, adaptation, and iterative goal setting. However, under-represented principles such as feedback coordination and decentralized governance indicate important gaps.

Bridging two communities in farming system research: IFSA europe group and farming system design

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Introduction

Farming system research (FSR) studies groups of farms sharing biophysical, socioeconomic, or operational traits and constraints. Its focus has evolved from enhancing smallholder productivity through technical improvements to adopting a holistic framework integrating systems thinking and cross-level interactions. Contemporary FSR emphasizes farm resilience, co-design methods, and farmers' active role in research and innovation (Darnhofer et al. 2012). The International Farming Systems Association (IFSA) institutionalized this approach, framing farming systems as subsystems of local communities or food networks (Brossier et al. 2012). Although design has long informed FSR to adapt technologies, practices, and systems guided by diagnostic phases (Byerlee et al. 1982), the Farming System Design (FSD) community prioritizes its role in modeling for innovation and integrated assessment (Donatelli et al. 2007), later incorporating stakeholder-driven processes (Meynard et al. 2023). Amid increasingly complex challenges facing the agri-food sector, integrating diverse perspectives into interdisciplinary cooperation is promising (Batie 2008). While this diversity is a strength, it may also lead to overlap and redundancy. This analysis explores potential bridges between the IFSA and FSD communities, aiming to compare their conceptual foundations identify complementarities and highlight shared priorities to strengthen cooperation in advancing FSR.

Linkages between the two Communities' conceptual foundations

FSR institutionalization unfolded in three phases: (1) 1980s Kansas State University conferences birthed the Association for Farming Systems Research and Extension, later evolving into IFSA's global symposia until 2005. (2) From 1993, the IFSA European group formed a steering committee and launched regular biannual symposia. (3) In 2007, FSD community emerged, focusing on design-driven innovation. Despite being rooted in similar foundations, their methods partly diverge (Figure 1). IFSA expanded globally while anchoring regional networks like the European group. Its approach to FSR is grounded in a broad array of concepts and has progressively targeted multi-level systemic transitions by using integrative inter- and transdisciplinary approaches (Darnhofer et al. 2012), while retaining links with delivery structures (e.g., extension services) through the concept and discussions of agricultural knowledge and innovation systems. FSD aligns instead with agronomy associations, integrating design theory into modeling for participatory, exploratory approaches emphasizing situated knowledge (Salembier et al. 2021). While IFSA appears to be constantly and empirically broaden FSR's boundaries, FSD developed specific expertise in normatively grounded modeling approaches. Besides, both communities seem to under-explore the landscape level dimension of farming systems, which could contribute addressing broader ecological and socio-economic interdependencies (Rizzo et al. 2013).

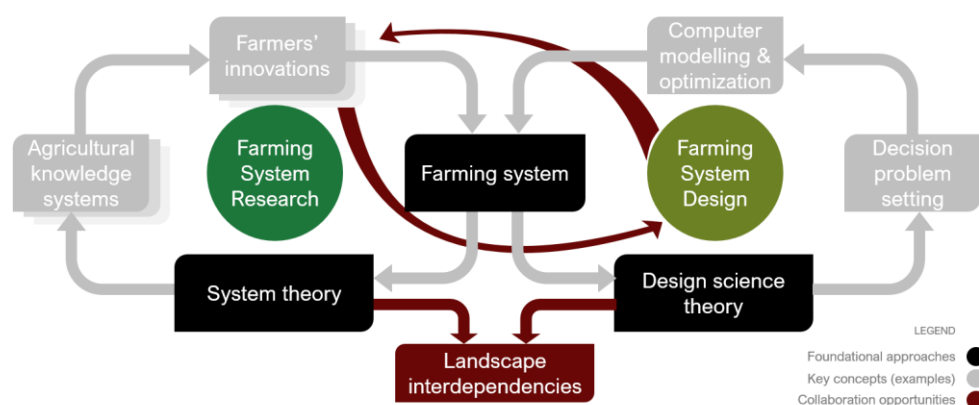


Figure 1. Farming system as a nexus between FSR and FSD.

Discussion and perspectives

Comparing the thematic and methodological approaches of the IFSA Europe group and FSD community highlights opportunities for bridges in developing FSR. A thorough comparison, however, requires analysis of the relevant literature, especially conference proceedings. Some major limitations include the need to update IFSA Europe's reflexive analysis (Barbier et al. 2012), and filling the gap of a comprehensive collection and review of FSD's partially published outputs (e.g., Wery and Langeveld 2010). Notably, this analysis could enable the identification of farming systems studied by both communities, allowing for a comparison of approaches and results. In perspective, bridging the two communities could involve formulating complementary research questions—for example, visualizing actor networks and practices in socio-technical systems—to foster synergies in producing knowledge more relevant to practice. Finally, decision and design theories appear as the common foundation from which to initiate joint efforts between IFSA and FSD researchers in addressing systemic transitions and contribute more effectively to sustainability.

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Enhancing farming systems in vulnerable regions of Maharashtra, India: evaluating innovation bundles for sustainable intensification

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Introduction

In vulnerable rainfed regions, the need for promoting sustainable farming systems (SFS) is particularly pressing due to erratic climatic patterns, land degradation, biodiversity loss, and socio-economic constraints that hinder agricultural growth and resilience. Despite policy efforts, ongoing disparities and risks demand innovative, integrated solutions beyond conventional approaches towards agricultural resilience (Daundkar & Pokharkar, 2020). A promising avenue for achieving SFSs lies in promoting integrated solutions based on socio-technical innovation bundles designed to enhance farm productivity and income while ensuring environmental and social sustainability. The transformation of smallholder agriculture in India increasingly mirrors trends observed in East and Southeast Asia, where diversification and multi-enterprise farm models have been critical to sustainable agricultural growth (Djurfeldt & Sircar, 2016). However, it remains challenging to identify the best-fit contextual innovation bundles for sustainable farming. This paper uses a suite of systems tools to evaluate, prioritize, and design location-specific innovation bundles for sustainable farming for rainfed mixed farming systems in Maharashtra, India. It focuses on assessing the potential impact of innovation bundles on farm household cashflows and resilience in a whole-farm way. Then, the effect of selected innovation bundles on the multidimensional sustainability of mixed farming systems was examined with the aim of achieving long-term sustainability.

Methodological Approach and Assessment Framework

To advance the study objective, the whole farm modeling, a multicriteria analysis, and a multidimensional assessment of farming systems incorporating economic, social, and environmental parameters were applied to design farm-type specific innovation bundles that improve not only the farm households' cashflows but multiple dimensions towards sustainable farming. Using ten livelihood covariates and multivariate analysis, the study identified two distinct farm types: Type 1 and Type 2, highlighting clear disparities in land, income, assets, and education (Kumar et al., 2024). Such an approach enables the integration of the heterogeneity and neglected domains of social and environmental sustainability in the formulation of targeted policy interventions to strengthen multidimensional sustainability, critical for empowering smallholder farmers. In this background, the study evaluates innovation bundles of best practices in sustainable intensification (SI) of farming systems in a landscape context such as (i) Farm to landscape scale participatory natural resource conservation, soil health and crop-livestock intensification, (ii) integrated soil health and nutrient management system with crop diversification through collective action, and (iii) market-led crop diversification and livelihood enhancement system in drought-prone Latur district of Maharashtra, India. Smallholder farmers in the study region, typically managing 1--2 hectares of fragmented land, struggle with erratic rainfall, groundwater depletion, acute water shortages, and soil degradation, making sustainability a critical priority. To address these systemic challenges, the study adopts a systems approach, integrating systems analysis at the household and landscape scales and scenario-based assessments to design and evaluate interventions aimed at enhancing environmental, economic, and social sustainability. The Multi-Dimensional Sustainability Assessment Tool for Smallholder Farming Systems (MSAT)

and crop-livestock whole-farm system analysis were employed (Kumar & Pramanik, 2024; McDonald et al., 2019) to assess multidimensional and multi-criteria aspects of sustainable intensification at the landscape scale (Figure 1). This integrated systems approach not only informs policy implementation but also serves as a basis for evaluating the long-term impact of interventions on the ground. The technical coefficients for the socio-technical bundles were based on the on-farm pilots, farm-household level case studies, and extensive farming systems data of 100 households.

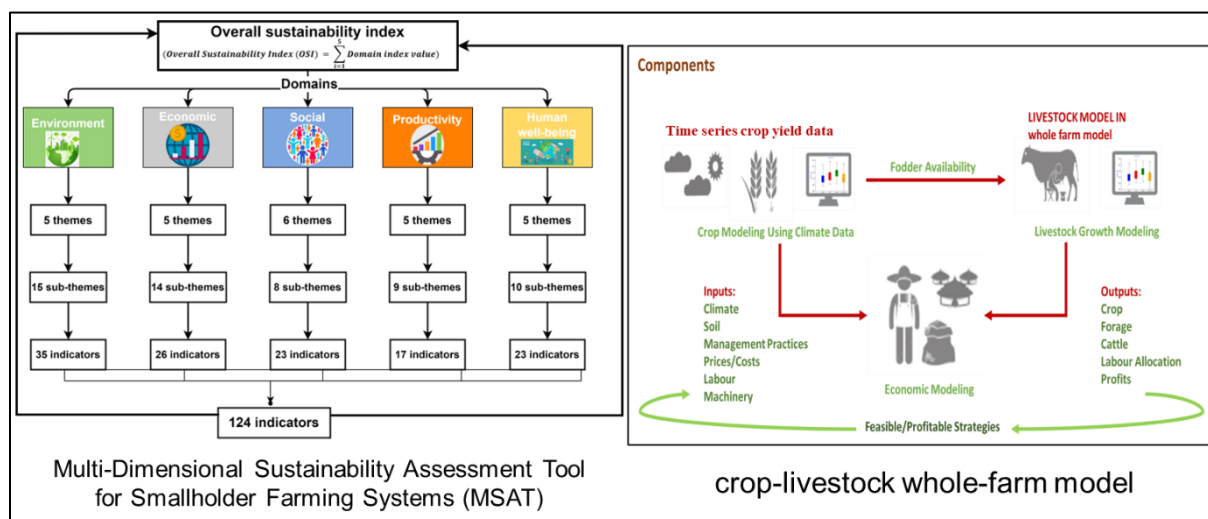


Figure 1: The structure of the MSAT and crop-livestock whole-farm model

Key Findings and Policy Implications

Using a participatory community-led approach, the study identifies key entry points for SI by optimizing resource use and economies both at the landscape and farming systems levels. Findings from the MSAT-based analysis highlight structural vulnerabilities across different farm types and sustainability dimensions. No farm type consistently achieved sustainability benchmarks (as mentioned in Figure 2), underscoring disparities in resource management, technology adoption, and external support systems. Economic and environmental fragilities remain the most critical, while human well-being performed moderately. Analysis suggests that the bundled innovations must focus on enhancing income diversification, sustainable biodiversity and soil and water management practices from farm to landscape scale as well as educational access and infrastructure improvements. By leveraging both traditional knowledge and scientific innovations, integrated farming systems at the landscape-scale emerged as a viable pathway to securing food, water, and income security and gender empowerment for smallholder farmers facing climate uncertainties. The study emphasizes the need for an integrated approach, extending from the farming system level to the landscape scale, harnessing natural resource potential and the value chains. This requires a dual strategy---empowering vulnerable households through targeted policies and scaling successful interventions from better-performing farm types (Garg et al., 2024). Additionally, financial and institutional support for smallholder farmers was crucial for overcoming systemic constraints, alongside investments in education, skill development, and rural infrastructure to enable the adoption of sustainable practices. By integrating localized insights with broader systemic reforms, stakeholders can co-design inclusive and resilient farming systems that foster long-term agricultural sustainability in Maharashtra's vulnerable regions.

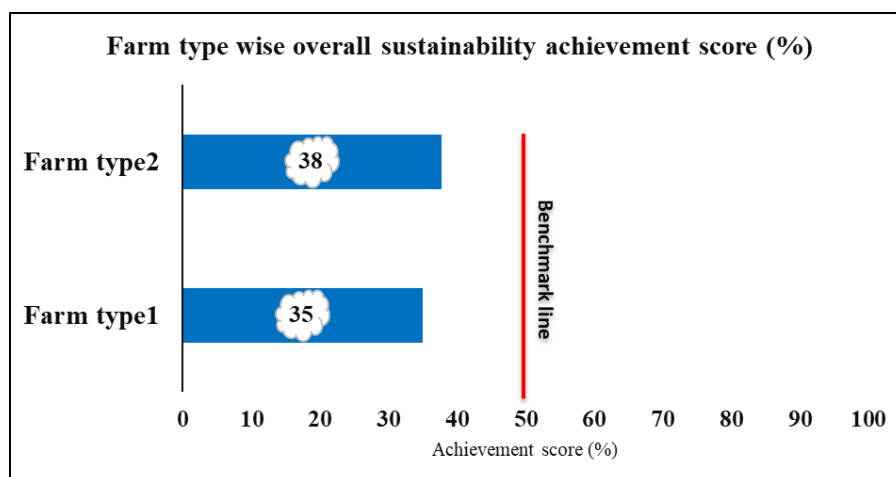


Figure 2: Overall sustainability achievement scores (%) across farm types

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Enhancing the resilience of North African farming systems through agroecology: a bio-economic modeling approach

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Introduction

North African farming systems face multiple stressors, including climate change, environmental constraints, and market instability (Keulertz, 2019). Price fluctuations, inflation, and geopolitical crises, such as the war in Ukraine, further intensify their vulnerability (Arndt et al., 2023). Despite heavy reliance on inputs like fertilizers, pesticides, and irrigation, farming systems, such as those on cereal plains in Luxor in Egypt or Siliana in Tunisia, fail to achieve proportional gains in productivity or economic returns, resulting in significant inefficiencies (El Ansari et al., 2023). Farmers remain trapped in a cycle of rising input dependence without corresponding gains in yield or income, raising concerns about the economic viability of current agricultural models. Moreover, these systems appear to have reached a plateau in terms of efficiency, where additional inputs no longer generate significant yield improvements but instead contribute to environmental degradation and/or soil degradation and/or resource exhaustion (e.g., Souissi et al., 2018). These challenges highlight the need for a paradigm shift towards more sustainable farming approaches. Agroecology offers a promising alternative by optimizing resource efficiency and overcoming the current efficiency limitations. By integrating ecological principles into agriculture, agroecology enhances soil fertility, reduces reliance on synthetic inputs, and stabilizes farm incomes while improving environmental sustainability (Boutagayout et al., 2023). Consequently, this study explores the potential of agroecology as a transformative approach to enhance the economic and environmental sustainability of these farming systems in Egypt and Tunisia. To do so, the DAHBSIM bio-economic model (Flichman et al., 2016) was used to assess the efficiency of selected Egyptian and Tunisian farming systems in both conventional and agroecological practices.

Methods

This study applies the DAHBSIM bio-economic model to simulate the adoption of agroecological practices in the farming systems of Luxor, Egypt, and Siliana, Tunisia. The model integrates economic, agronomic, and environmental parameters to assess the impacts of agroecological transitions on productivity, income stability, and resource use efficiency. The methodology includes:

- Step 1: Identification of dominant cropping and livestock systems to be modelled, through analysis of statistical data, a workshop and a questionnaire of around 30 farmers (including farm household characteristics, land use and cropping patterns, quantification of inputs).
- Step 2: Simulation of agroecological practices such as reduced synthetic input use, crop diversification, and soil conservation techniques and Comparison of economic, social, and environmental performance indicators in conventional versus agroecological scenarios.

Preliminary results

The identification of dominant cropping have been completed and the modelling results will be finalised soon.

In Siliana, three dominant farming system emerged from the survey: small diversified farms (the most common), large diversified farms, and large monoculture farms. Small diversified farms engage in various activities on relatively small plots, such as crop-livestock integration and olive cultivation. Farmers primarily operate individually, relying mainly on family labor, with an average of 20% hired labor. These farms generally lack access to water. The large diversified farms are on certain points similar to the small diversified farms. They have different activities such as crop-livestock. They rely mainly on family labor, but have an average of 20% hired labor. On the other hand, they have greater investment capacity than small farms, and use more inputs. Large monoculture farms cultivate perennial and annual crops but have many and frequent livestock activities. Farmers have higher education and non-agricultural jobs. Nevertheless, they rely mainly on family labor, as they are less labor-intensive. They are more likely to have access to drip irrigation. Modelling will take place soon to assess the efficiency of the Tunisian farming systems and agroecological transition.

In Luxor, Egypt, four distinct farming systems were identified: large monocultural sugarcane farms (1), farms focused on animal production and fodder crops (2), diversified farms balancing household needs and market sales (3), and smallholders (4) primarily cultivating wheat for self-consumption, selling a small portion to the government. Model simulations showed that introducing a more profitable and stable wheat variety led to a significant expansion of wheat cultivation, replacing maize, while sugarcane remained dominant in large farms. Self-consumption crops like tomato and okra remained stable, while climate variations affected sorghum and clover surfaces. The simulations also indicated increased farm revenues, especially in farm 3, where wheat replaced maize on a large scale. Environmentally, the shift reduced water consumption and nitrate leaching, particularly in farms 2, 3, and 4, emphasizing crop selection's role in improving both economic resilience and environmental sustainability.

Discussion and Perspectives

Farming systems are shaped by economic capacity and environmental constraints, such as water access. Larger farms have more investment capacity, but this does not ensure diversity or agroecological adoption. The pending modelling results will detail the capacity of agroecology to reduce dependency on external inputs, mitigating financial risks from price volatility while improving soil fertility, water-use efficiency, and sustainability. They will also discuss the possibility of stabilizing farm incomes by diversifying revenues, reducing costs, and improving environmental performance by reducing emissions and groundwater depletion. Future research will integrate participatory input from farmers and policymakers to co-design transition strategies.

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Threats of environmental pollution to biodiversity and ecosystem functions in foodscapes

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Introduction

Environmental pollution poses a severe threat to biodiversity, disrupting ecosystems and diminishing species diversity. Pollution's pervasive effects have been particularly harmful to the most vulnerable species and ecosystems (Naidu et al., 2021). Pollution, along with climate change, accounts for 14% of the direct drivers of biodiversity loss (Royal Society, 2024). Despite global efforts to mitigate pollution, the increasing contamination of water and soil, as well as the widespread decline of both managed and wild pollinator populations, continues to erode biodiversity and threaten human food and nutritional security, hindering progress towards the United Nations Sustainable Development Goals (SDGs). In low- and middle-income countries (LMICs), often known for data scarcity and weak knowledge management systems, like most of Africa, there is an overdue need to design farming systems with environmental pollution lens.

Methods

Knowledge management toolkits are developed to guide research prioritization and optimize socio-ecological gains through good practices and policy coherence. This is achieved through a range of strategic interventions designed to proactively address environmental risks and foster global sustainability. These include: (1) Integrated nutrient management systems, (2) Integrated pest and disease management systems, (3) conservation agriculture, (4) agroecological approaches, and (5) nature positive solutions. Performance indicators have been developed to monitor and report on the socio-ecological gains including successes and corrective measures for sustainable farming practices. Indicators include: (i) improved land and soil health, (ii) one health, (iii) ecosystem restoration, (iv) improved nutrient management, (v) improved pest management, and (vi) circular economy.

Results

Studies in Africa (Nantongo et al., 2023) Asia (Sarker et al., 2021) and Latin America (González Noschese et al., 2022) showed that the persistence of pesticides in soils results in long-lasting impact, including bioaccumulation and biomagnification, harming beneficial insects, birds, and aquatic organisms (Figure 1). Heavy metals from waste and wastewater from fisheries and food processing industries and agricultural activities accumulate in soils and water bodies, creating toxic environments for plants and animals. Overuse or misuse of antibiotics, disinfectants and antibiotics in agriculture can lead to the development of antimicrobial-resistant bacteria, which can spread through the environment and affect various ecosystems. Accumulation of salt in agricultural soils can lead to detrimental effects on soil fertility and water quality, while excessive sedimentation in aquatic ecosystems can smother benthic communities, reduce light penetration, and disrupt nutrient cycles, leading to a decline in sensitive species and altered species composition (Mateo-Sagasta and Alber, 2018). Comprehensive understanding of the sources of pollution (Table 1) is critical to developed tailored mitigation solutions, while systematic monitoring and reporting on the interventions' performance would guide choices of sustainable practices and policy decisions.

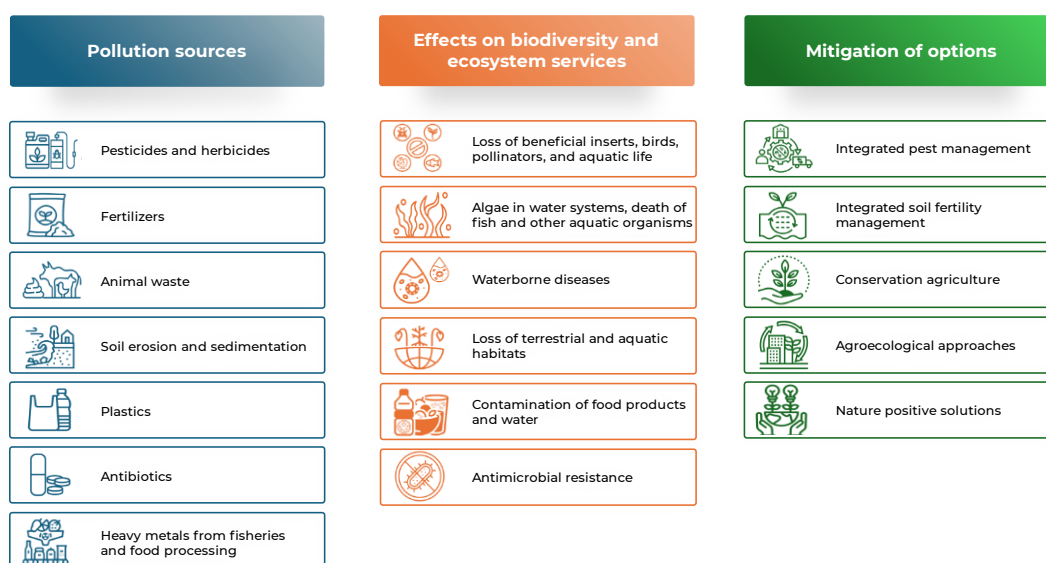


Figure 1. Selected pollutants in agrifood systems, their impacts on biodiversity and ecosystem services, and mitigation options

Types of pollutants	Sources of pollutants
Pesticides	Agriculture, landscaping, and pesticide industrial waste
Fertilizers	Agriculture, landscaping, and fertilizer industrial waste
Antibiotics	Agriculture
Disinfectants	Food processing industries
Heavy metals	Agriculture, food processing industries
Microbes	Agriculture and food processing industries
Plastics	Agriculture, and food processing industries

Table 1. Selected types of pollutants and their common sources in foodscapes

Discussion and Perspectives

Current food systems do not support healthy people nor healthy planet. In addition to driving forest and biodiversity loss and accounting for the degradation of a third of the world's soil and about 70% of the global freshwater withdrawals, they contribute significantly to point and non-point pollution. In LMICs, like most Africa, generally characterized by data scarcity, knowledge management toolkits, accompanied with performance indicators to monitor and report on socio-ecological gains would be critical to guide research prioritization, choices of sustainable farming practices, and policy coherence. Farming systems must therefore be designed with environmental pollution lens, including intentional monitoring and reporting on the socio-ecological gains. There is an overdue need to balance factors like agricultural productivity, environmental sustainability, economic growth and social inclusion, when designing farming systems in LMICs. Analysis of the synergies and trade-offs between these factors is critical to enhance food and nutrition security as well as livelihoods of foodscape actors, while optimizing ecosystem and biodiversity gains. Options to overcome barriers to (i) adoption of technical and social eco-friendly innovations, (ii) policy coherence to balance environmental, agricultural,

economic and social benefits, and (iii) capacity sharing including transfer of technologies and innovations, are critical to curb environmental pollution in foodscapes.

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Digital advisory for African smallholder farming systems: towards design principles

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Introduction

Over the past decade, a plethora of digitally-enabled advisory applications targeting smallholder farming systems has emerged. While often seen as a game changer in Africa's agricultural transformation process, uptake of such services remains (s)low (Sida et al., 2022). Reviews of such digital agricultural advisory seem more concerned with numbers of users and the business models, than with the relevance, efficacy of these tools.

This study relates digital tool design shortcomings to a lack of understanding of diverse smallholder farming systems. For instance, a common focus on profitability in digital tool designs is problematic in a context of small farm sizes (Giller et al., 2021). Capital constraints often prevent smallholder farmers from investing in, or reap the benefits of, yield-enhancing technologies (Harris and Orr, 2014). So-called 'predictive agronomy' tools, that capitalise on geospatial soil and climatic data, as well as the power of big data analytics to predict crop yields, often ignore the unpredictability of rainfall -- the main determinant of crop yield. In addition, advisory tools often assume a high level of agronomic management, neglecting not only the large diversity in smallholder farmers' management practices, but crucially, the pivotal role of past management on crop performance.

Based on a qualitative understanding of local smallholder farming systems, diverse farmer practices and input availability, a digital, survey-based advisory tool was developed for smallholder maize-legume farmers in the Southern Highlands of Tanzania. This paper discusses experiences with this advisory tool and provides examples of how an understanding of farmers' diverse management practices may be translated into design principles for agronomic advisory tools.

Methods

Farmer Management-Based-Advisory (Farmer-MBA) was developed as an advisory-by-learning tool, and used by 40-65 extension workers annually, to provide advice for 2,865 (2021-22 season); 4,472 (2022-23); 1,296 (2023-24), and; 4,184 (2024-25) maize or legume fields. (Note! It is not a panel dataset as extensionists and operational areas changed).

Farmer-MBA incites extension workers to visit farmers and to systematically record those agronomic management practices, crop- and field-conditions that matter most for the efficient use of inputs. The recorded data is instantly used to tailor advice to a farmer's field. For instance, a GPS-measurement of the field area is used to calculate the last season's yield, but also the quantities of fertiliser and seed required for this season, depending on the crop the farmer wants to grow, his/her investment-level, the previous season's crop and level of fertilisation. The systematic recording of past agronomic management enables farmers to develop and master a field-specific 'business administration' (MBA thus has a double meaning).

As Farmer-MBA collects field-level management data at scale, it also enables data-driven learning on location-specific agronomic management practices that increase productivity and

input use efficiency. Such learnings can be translated into new advice algorithms. Here, we highlight some learnings on farming system functioning, and what they mean for tool design.

Results

As not all crops are marketed, crop prices volatile, and smallholder farmers' often cash-constrained, Farmer-MBA is investment-oriented (design principle 1), rather than profitability-focused. As fertilisers constitute smallholders' main expenditure, Farmer-MBA has three fertiliser advice options: (1) a farmer-preferred investment-level; (2) crop-requirement advice, or; (3) advice adjusted to what fertilisers the farmer has already purchased. This latter option was included as numerous farmers, particularly in the Songwe region, immediately re-invest crop sales earnings in fertiliser for the next season (Table 1).

Advice	Investment-based advice	Fertiliser(s) required for field	Additional fertiliser required	(n)
Ruvuma	3 %	87 %	10 %	1,954
maize	5 %	77 %	20 %	906
soya	3 %	95 %	2 %	1,048
Songwe	5 %	66 %	29 %	2,230
maize	6 %	68 %	26 %	1,913
soya	1 %	50 %	50 %	317

Table 1: Farmers' preference for different investment-oriented advice options by operational area (region) and crop type, Ruvuma and Songwe regions, Tanzania, 2024-25 season.

Farmer-MBA data further revealed that in any season, crop responses to fertiliser are highly variable at any fertiliser input level (Figure 1). This renders a predictive, target-yield approach based on average responses for given climatic and soil conditions problematic, when used for field-level advisory (cf. Rurinda et al. 2021); Crop responses to fertiliser inputs appear to be highly field-specific. Hence, advice provision is crop- and field-specific (design principle 2).

Rather than a 'predictive agronomy', Farmer-MBA adopts a 'response farming' approach (design principle 3), founding advice on past agronomic management of the field. For instance, as crop response to fertiliser appeared to depend on single or split application of top-dressing fertiliser (Figure 1), this is translated into new management advice. The systematic recording of farmers' diverse management practices -- like manure use frequency and crop rotation with leguminous crops -- may equally result in new advice algorithms.

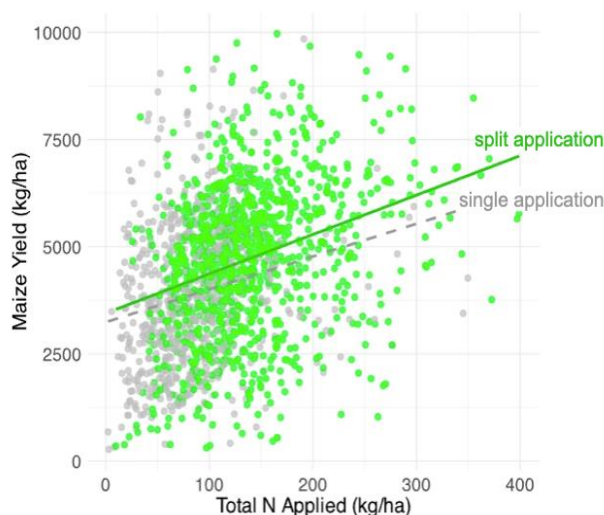


Figure 1: Maize yields (kg/ha) for single (n= 671) or split application (n=1,177) of top-dressing (kgN/ha) fertiliser, Ruvuma and Songwe regions, Tanzania, 2023-24 season. (Wilcoxon rank sum (W=255928, p < 0.000). The recommended fertiliser rate for maize in Tanzania is 120 kgN/ha. On 58% of the Farmer-MBA surveyed maize fields, farmers apply a lower N-rate (n=2,095). Farmer-MBA advice for leguminous crops is focused on P and K only, yet farmers' hardly apply any fertilisers to these crops.

Discussion

Experience with the use of the Farmer-MBA tool over four seasons reveals not only a huge diversity in the use of fertiliser inputs on maize fields (and virtually no use on legume crops), but also in crop performance among farmers using similar input-levels. Differences in agronomic management, rather than in agro-ecological (soils, climate) conditions, are at the root of this diversity. Farmer's diverse management practices are structured by the distinct organisation of their farm household system and the land, capital, labour and technological resources they can mobilize.

Our findings have important implications for the design of digital advisory tools targeting smallholders, including:

- Profitability is an ill-informed design principle for smallholder advisory tool development, as market prices are volatile, and farmers' resource constraints binding;
- Digital advisory, to have wide relevance, needs to provide diverse advice options that are rooted in an appreciation of smallholder farmers' diverse resource endowments and farm management practices;
- Rather than 'predictive agronomy', digital advisory development may more effectively be adopt an 'response farming' approach, aiming to adjust farmers' management practices in favour of practices that enhance resource use efficiency
- Agronomic advisory tools are more likely to be effective when designed as learning tools (that is, including feedback mechanisms), as this enables use(r)-informed adjustment.

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Systems science: the power of system diagrams in design processes

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Introduction

Focusing on the study of complex interactions between constituent components, a systems science perspective can be applied in many scientific domains, ranging from anthropology to biology, ecology and engineering (Meadows, 1992; Belmin, 2022). Although the basic idea of systems science is to examine systems as wholes, identifying their structure, behaviour, and underlying principles, usually constitute the main research activities. In this paper we focus on the role of system diagrams as an analytical tool, not only for understanding system structure and functioning, but also in the exploration of futures and design processes. Casual-loop-diagram are a similar tool, but with a slightly different focus. We use an example from education to illuminate the power and versatility of system diagrams in conceptualising and (re-)designing systems that cross-cut social, biological and technical domains.

Methods

The start of any design process is formulating its aim and the user requirements of the final product. Systems analysis is a powerful approach to put this in the perspective of the function of the product. It generally starts with a visual representation, drawing a system diagram, in which components, the relations between the components, the boundary, the flows within the system and those crossing the boundary, and the hierarchical levels are defined (Meadows, 2009). Various methods, ranging from Fuzzy Cognitive Mapping (FCM) (e.g. Murungweni et al., 2011) to crop (e.g. De Wit et al., 2019) and farm systems modelling (e.g. Tittonell et al., 2009) can then be applied to analyse the behaviour of the system, either in qualitative terms, semi-quantitatively (FCM), or fully parameterized (crop, farm system modelling).

The initial system diagram is not necessarily a static representation. Rather, it serves as a reference point. During the research-for-design-process, it is usually adapted as insight into components and their interrelations develops. Defining the system boundary is crucial, as it delineates the purpose of the system and with that, the scope of the design process.

Results

We applied the system diagram approach in an engineering design trajectory at Wageningen University to the case of designing sustainable fishing techniques for flatfish. The Dutch fishing community faces the problem that beam-fishing, the common method for catching flatfish, is not ecologically sustainable, as it disturbs the sea floor, requires much energy, and has significant bycatch. Pulse fishing, considered a good alternative, was banned by the European Union (EU), resulting in fishermen's distrust of government as main enforcer of the EU-ban.

Students of different disciplinary backgrounds were tasked to design an alternative fishing technique that meets EU-regulations and lacks the negative effects of beam-fishing. After a brief introduction to the main concepts in systems thinking -- components, interactions, system boundary -- the students described the system based on written documents and entered all

relevant information in a hand-drawn system diagram. This gave them sufficient background to initiate discussions with stakeholders in a fishing community on a new product design and its applicability. It allowed them to unravel the complex interactions between system components. Based on their newly acquired information they adapted their system diagram (Figure 1).

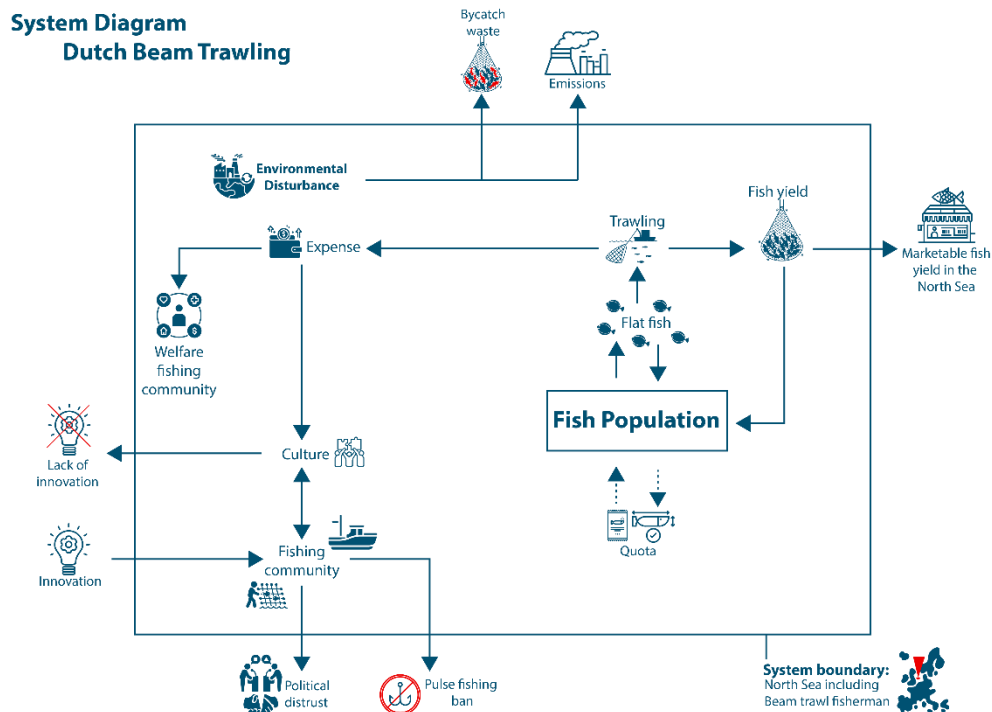


Figure 2: A system diagram of current Dutch beam trawling with components, relations, stakeholders and the boundary.

The fish population is the main component in the system, which needs to be maintained. The system boundary is defined as the North Sea, including the beam trawl fishermen. As the new fishing technique needs to drastically reduce environmental disturbance, the sea floor is part of the system. Other important aspects are welfare of the fishing community, cultural values, and regulations, such as the fish quota. The system diagram therefore goes beyond the fishing technique to be designed. For the students this was very insightful; the system diagram, next to technical and environmental requirements, can also incorporate the political and socio-cultural context. Building on their systems' diagram, they defined design criteria and elaborated stakeholder involvement in various phases of the product design. They regularly revisited the system diagram, which helped them to avoid diversions, and remain focused on the original aims of the product design. Such re-visits could also result in an adaptation of the system diagram, based on solid arguments.

Feedback by the students on starting with a system diagram showed that it took time to grasp the approach, but it effectively guided the discussion between the students, each with their own background, to gradually develop a common framing of the problem. The system diagram also informed their interactions with stakeholders. Visualization in a relational diagram is a strong feature of the approach. but when applying it for the first time, it required critical guidance by supervisors.

Discussion

The system diagram is a versatile tool in the sense that it can map both biophysical processes as well as stakeholder relations. It makes the product designer aware of all aspects that need to be considered in the design process, also ones which are not so obvious. This became particularly visible in the setting of the system boundary. The students started with including only the fish population and technical and environmental aspects in the system. However, stakeholder consultations soon revealed that neglecting socio-cultural and community-related aspects as integral part of the design, rendered a dysfunctional product. Belmin et al. (2022) also indicate that effective innovation design integrates issues across scales, and beyond just technical issues. Crucially, the systems perspective situates the design within its context of use and forces the designer(s) to engage with user needs.

Perspective

This paper, in which we highlighted the power of system diagrams in (research for) design processes (using an example from an engineering study programme), suggests the potential of system diagrams beyond communication. System diagrams constitute a powerful analytical tool to understand complex socio-technical and socio-ecological systems, in which researchers of different disciplinary backgrounds (have to) work together with societal stakeholders. Having illustrated its wide applicability, we strongly suggest to give systems analysis, with special attention for the system diagram approach, a regular slot in academic curricula.

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Food sustainability: which overlaps with the desirable unknowns of collective catering stakeholders?

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Context

Food is a major environmental and health issue, in the face of which European public policies are deploying new regulatory frameworks to ensure the transition to more sustainable food systems. These frameworks (which impact agricultural practices, consumption, energy use, environmental performance labelling requirements, public procurement conditions, the development of circular economy loops, etc.) reflect the diversity and complexity of the changes required. It is also illustrated in the definition of sustainable food provided by the French public agency Ademe (2024). These public policies also rely on public procurement to promote the transition of food systems. For example, the Egalim law in France imposes a series of objectives for collective catering, such as protein diversification and a 50% supply of labelled products. However, field observations show that collective catering actions often focus on local purchases (Molin et al., 2024).

Technical developments (in terms of the equipment required and new skills to be acquired), organisational changes (evolution of management tools, changes in supply chains, etc.) and nutritional changes (the impact of vegetarian diets on the nutritional balance of children's diets in particular) in collective catering are the subject of numerous studies. However, few of these studies give a voice to collective catering companies to express the actions and objectives they are developing to achieve greater sustainability: introduction of vegetarian menus, communication to reduce waste, requests for waste sorting, etc. Furthermore, the success of these actions also depends on the acceptance of the changes by eaters, who are therefore decisive stakeholders. From this point of view, the difficulty in seeing the emergence of a fundamental societal transition calls into question the capacity of the various actors involved, including collective catering actors and eaters, to develop a common desirable unknown on the subject of sustainable food. Our research examines the dimensions of food sustainability implemented or perceived as desirable by collective catering stakeholders (including eaters) and how they overlap or differ from the expectations of adult eaters.

The concept of the desirable unknown emerged from philosophy and the world of design in the 2000s. From this perspective, the onset of innovation is not a problem to be solved but a future to be anticipated.

Our study examines the potential alignment of a desirable unknown shared by public policy (through the regulations they produce, which are translated into actions by collective catering industrial actors), a public agency such as Ademe, which mediates between public policy makers, businesses and citizens, and collective catering stakeholders.

Methods

To explore this dynamic, we organized a workshop included four mass catering representatives, one territorial food plan association representative, and nine researchers responsible for summarizing the literature on the subject and the data they collected to assess

meals sustainability or actions taken by various actors of the collective catering to provide local or so-called sustainable products and discussing it with the other participants. During the workshop, participants were asked to spell out (on sticky notes) their practices regarding sustainable food and future actions needed to improve sustainability. They assigned each note to one of the five dimensions of the ADEME's definition (Ademe, 2024) of sustainable food (terms in the column headers of Table 1). An 'other' category was proposed to address topics other than those of ADEME. After the workshop, all the notes were categorised into 20 sub-themes.

In complement of the workshop, two focus groups with 20 eaters of collective catering for adults' canteens. The focus groups were conducted with guest who eat at least once a week in the same establishment, discussing their perceptions, expectations and definitions of sustainable food in their daily lives and institutional catering. Finally, Ademe's definition of sustainable food was proposed to them and was discussed. Discussions from the focus groups were recorded, transcribed and analyzed. Eaters perceptions and definitions of sustainable food were analyzed based on the 20 sub-themes of the workshop.

Results

The cross-analysis of the results of the workshop and the focus groups is shown in Table 1.

	Sufficient quality	Sufficient quantity	Respect for the environment	Affordable	Profitable across the entire value chain
Affordability					
Agroecological and/certified practices					
Plant-based					
Local and short supply chains					
Weight					
<u>Labor</u>					
Ultra processing					
Health / Nutrition					
Transparency					
Sorting & waste					
Commitment					
Seasonality					
Education					
Cooperation					
Cook Training					
Taste					
Packaging					
Waste					
Preferences					
<u>Inclusion</u>					

Table 1. Links between the 20 workshop sub-themes (left column) related to canteen users and the ADEME food themes (headers). Dark grey: identified in both workshop and focus group; light grey: workshop only. 'Inclusion' and 'Labor' are double underlined because they were only mentioned during the workshop.

One initial observation stands out: all ADEME definition themes are addressed in the workshop and by eaters through more detailed sub-themes. Three key levers for the transition are highlighted: 'access to affordable food', 'agroecological and certified practices', and 'plant-based diets'. Quality and environmental respect are the most discussed themes, especially regarding sourcing high-quality ingredients, particularly legumes, and ensuring consistent supply from local producers.

Sustainability regulations like reducing packaging waste, promoting seasonal products, and using certified organic ingredients are also emphasized.

Two sub-themes raised during the workshop - work and inclusion - are absent from both ADEME and eaters' definitions.

Work concerns focus on kitchen staff's conditions, including heavier workloads and the need for new skills for sustainable practices.

Inclusion refers to accommodating dietary restrictions (cultural, religious, or health-related) and integrating socially disadvantaged workers.

A common definition of sustainable food in collective catering is emerging across public definitions, actual practices, and eaters' expectations. Still, challenges - mainly supply issues and increased staff workload - highlight key obstacles to change.

Discussion and Perspectives

This study highlighted the diversity of the 20 elements activated in collective catering to contribute to the implementation of more sustainable food systems. Eighteen of these are aligned with the ADEME definition and outline a common desirable unknown among all the stakeholders (e.g. including eaters). The elements outside the Ademe definition, noted only by actors involved in collective catering, are working conditions and capacities, local sourcing and legume sourcing. They indicate significant obstacles to the practical implementation of the common desirable unknown. These obstacles highlight that public policy alone is potentially insufficient to bring about change and that restructuring food systems at the level of regional public policy is likely to be crucial in order to address the challenges of training, inclusive employment and supply. Furthermore, our difficulties in recruiting participants for the discussion groups show that the issue of sustainable food remains a topic of interest to only a few. Here too, local and regional actors will probably need to support the transformation of eating habits while ensuring accessibility and inclusion, thereby complementing national public policy measures.

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Co-designing regional scenarios for the transition of agrifood systems and diets by 2050: a methodological contribution

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Introduction

There is a consensus that a holistic transformation of agrifood systems including more grain legumes (GL) is needed due to their contribution to climate change mitigation, healthy diets and proteins self-sufficiency. However, their integration in European cropping systems (4% of the arable land) remains limited, as well as in diets (4 kg/capita/year), whereas the general recommendation is at least 11 kg/capita/year (Poux & Aubert, 2018).

Foresight is a valuable approach to explore and support the transition of agrifood systems (de Lattre-Gasquet et al., 2025). While numerous foresight studies such as TYFA (Poux & Aubert, 2018) have explored alternative scenarios at large scales, regional downscaling is a complementary step to take into account local specificities, integrate the visions and knowledge of local stakeholders, and trigger changes. However, co-designing scenarios with stakeholders raises methodological challenges related to knowledge integration, time constraints and the choice of boundary objects to facilitate discussions.

To overcome these challenges, we propose a scenario-building process, linking quantitative and qualitative methods and involving both stakeholders and project scientists. We then present its application in a case study, the development of GL in a French region by 2050.

Method

The scenario-building process integrates methods commonly used in foresight and system thinking studies and involves six stages: stages 1, 2, and 6 were carried out by experts/scientists, while stages 3, 4 and 5 were articulated in a one-day participatory workshop involving 12 stakeholders representing different stages of the value chain.

The first step aims to build a causal diagram that delineates the system under study and that allows to identify the key influencing variables. In step 2, a map of stakeholder interests and impact was drawn up, in order to identify the stakeholders who most influence the variables identified in step 1 and those who should be involved in the participatory process. In step 3, scenarios were built using the morphological analysis, an approach that combine a set of hypotheses about how the variables of the system may evolve in the future to create a range of scenarios (Lamblin, 2020). While comprehensive, this approach can be time consuming, when the number of variables is high, which can be an obstacle in a participatory process. Therefore, before the workshop, projects scientists constructed future hypotheses for each influencing variable, based on literature and experts' interviews, and group them into micro-scenarios that took the form of narratives. During the workshop, stakeholders used pre-existing microscenarios and proposed new ones to build a trend and preferable scenarios. To facilitate the appropriation of the micro-scenarios and the discussion between stakeholders, participants were divided into two small groups of 6 and several artefacts were created (Figure 1). In step 4, we relied on the Story and Simulation Approach (Alcamo, 2008). Using the narratives from step 3, stakeholders mapped the changes in GL acreage that would be required to meet their preferable scenario and a supply-demand balance model was run to assess the associated level of self-sufficiency. In step 5, the backcasting approach, which works backward in order

to identify the most strategic steps and sequence actions leading to the desirable future, was used (Robinson, 1982). To help stakeholders project in 2050, we broke down the future into 2 steps, with a first milestone set in 2035. The last step synthesized the main results of the workshop into a leaflet.



Figure 1: Overview of the artefacts. At the center, the wheel presents the micro-scenarios without imposing an order in the discussion. Around the wheel, the cards describe the micro-scenarios.

Results

The application of this method led to the co-design of 3 scenarios: one trend scenario, in which participants' visions converge towards a maximum yearly GL consumption of around 6 kg/capita without profound changes within the system, and two preferable scenarios in which participants' visions diverge on several points. Stakeholders agree on a number of desirable changes for the future (increasing GL consumption to 11 kg/capita/year, implementing European public policies in favor of protein self-sufficiency and local policy against the loss of arable land, strengthening research and development activities for a diversity of GL). However, their visions diverged on the future accessibility to inputs (one group envision a drastic reduction of synthetic nitrogen fertilizers and irrigation water compared to the other), the development of agroecology (up to 70% in one group), and the role of catering in changing diets (for one group the transition towards more plant-based protein diets will mainly take place in the catering sector while the other group envisions a profound change in the household consumption behaviors).

Thanks to the use of mapping and model simulation, stakeholders found that by increasing the GL acreage by ~50% and reducing livestock farming, it would be feasible to reach regional proteins self-sufficiency. This result helped them appreciate the feasibility of their scenarios. Finally, the backcasting approach allowed stakeholders to identify 35 actions to be implemented at different levels of the value chain.

Discussion and perspectives

The scenario-building process proposed here is a generic and operational approach that provide a guide for developing scenarios for agrifood system transition. This approach can be transferred to other contexts or other agricultural products. If the methods we have mobilized are not new, the way we have articulated them to build future scenarios in a participatory approach is original and can help stakeholders bring out contrasted visions of preferable futures and orient their current actions to trigger changes (Inayatullah, 2013). Even if for some

participants, projecting themselves in 2050 and stagger actions over time was challenging, they learned from the exercise and the artefacts facilitated their engagement.

To conclude, this work has enabled scenarios to emerge for a given territory, but it would be interesting to carry out a comparative analysis with other French or European regions to increase genericity and identify commonalities and differences to foster GL development in Europe.

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From conceptual to operational: steps in the participatory design of Urbanaa, a tool to assess urban farms

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Introduction

Design and delivery of decision support systems (DSS) in agriculture is an important research field, that led to numerous studies on how to enhance their effectiveness (Rose et al. 2016, Zhai et al. 2020). Literature advises designers to involve end-users in the design process (Cerf et al. 2012, Lindblom et al. 2017), however, there is a lack of recommendations on the steps involved in moving from a conceptual DSS to an operational tool. This gap is a major issue, given the need to make research-based solutions operational to support stakeholders in the sustainability transition of farming systems (Martin et al. 2018).

Methods

Our work focuses on the example of Urbanaa, a tool designed to assess the sustainability of urban farms. Urban agriculture (UA), and more especially professional UA, faced an exponential growth during the past decade. Professional intra-urban agriculture (PIUA) stakeholders need to assess the sustainability of their projects, for instance to decide whether they will allocate a grant, or to monitor projects' impacts. However, so far, no specific assessment tool exists to do so (Milestad et al. 2024). In order to fill this gap, we designed a new assessment tool named Urbanaa, to specifically assess the sustainability of PIUA projects. The whole design process is participatory, involving future users of the tool through different steps. We identified the different steps, the stakeholders involved in each of them and classified them in two main design phases: conceptualization of the tool and operationalization of the tool (Figure 1).

Results

We first performed a diagnosis of uses with PIUA stakeholders to explore their assessment practices (Clerino et al. 2023). Then, we conducted innovative design workshops with a diversity of PIUA stakeholders to identify their expectations and the characteristics of Urbanaa. A conceptual draft of Urbanaa was developed based on the results of the diagnosis and the workshops, including preliminary mock-ups for Urbanaa's interfaces. The conceptual draft was presented to PIUA stakeholders to gather their feedback and recommendations for improvement. These first steps represent the conceptualization of the tool, where the needs of the users are leading to an idea of tool and mock-ups of its interfaces.

In order to transform this conceptual tool into an operational tool that could be used by PIUA stakeholders in work situations, several other steps were necessary.

Graphical user interfaces are important to ensure tool's accessibility (Gutierrez et al. 2019). Therefore, even if several outputs for Urbanaa were included in its conceptual version, we involved stakeholders to brainstorm about data visualization, leading to new ideas to visualize assessment's results. In addition, to ensure the IT coding of the tool, we explored several options, their advantages and disadvantages, and faced difficulties to implement clear and effective communication with IT experts. We also had to address the complex issue of intellectual property of Urbanaa, which required specific expertise on legal aspects. To develop skills in this area, a training course and the support of specialized teams were necessary. To

develop Urbanaa's business model, we had to undergo specific training to choose the most relevant way to ensure its longevity and updating. It is only at the end of these various stages that we were able to test an operational version of Urbanaa in work situations.

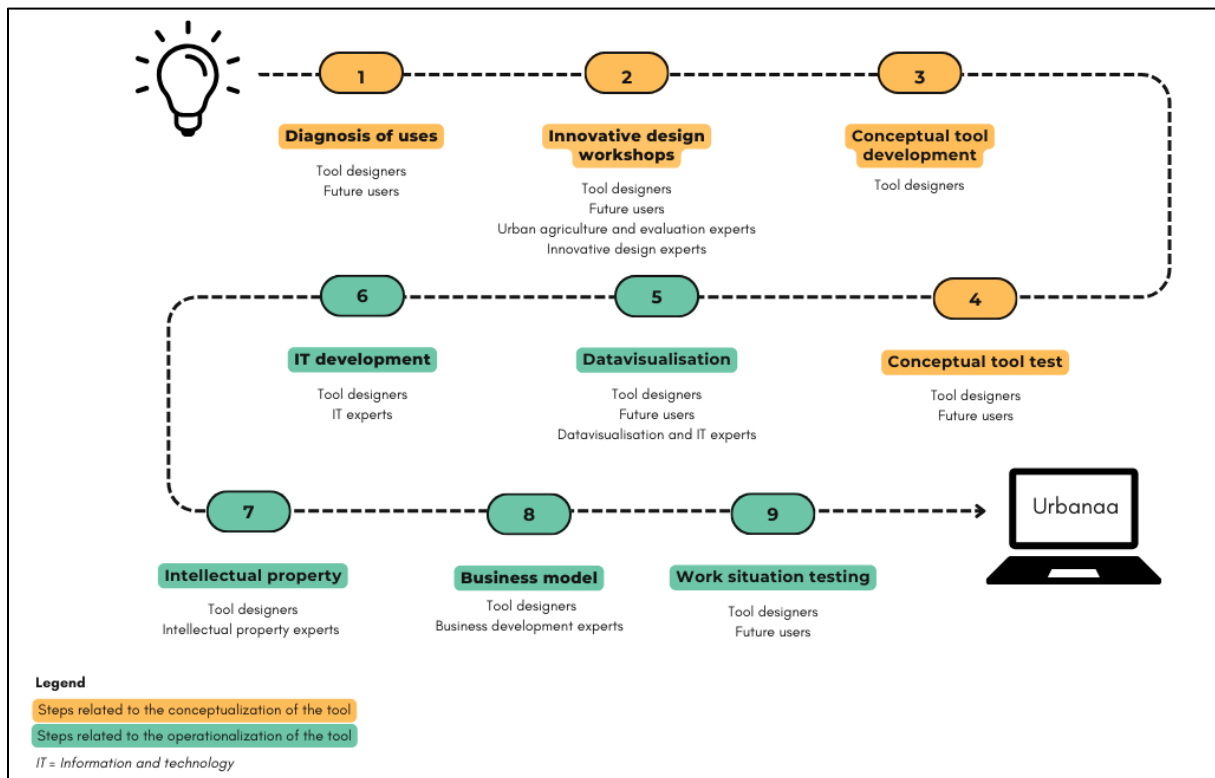


Figure 1: From conceptual to operational tool: steps and stakeholders involved

Discussion and Perspectives

We demonstrate that the transition from a conceptual tool to an operational version requires numerous steps, including the mobilization of fields of expertise different from Urbanaa's designers' initial skills. Indeed, in the agricultural field, DSS that are software-based are often considered as the most useful by farmers (Rose et al. 2016). Designing such tools requires specific expertise related to software engineering and web design, but also a marketing strategy to ensure the dissemination of the DSS (Hochman and Carberry, 2011). Our work enables us to include this additional expertise in a schematic representation of the design process but also adds the important issue of intellectual property.

Our analysis of these steps, the expertise mobilized, the obstacles encountered, and the levers used to overcome them are useful for designers. Our recommendations enable them to better plan the transition from their conceptual model to an operational tool, and to size the resources needed to do so. This study ultimately participates to put the solutions developed by research into practice. Further research could focus on the additional steps needed to ensure the tool's long-term viability, including training its users and updating it in line with advances in UA research.

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INNOVATIVE DESIGN WORKSHOPS TO EMPOWER YOUNG CONSUMERS TO TRANSFORM THEIR FOOD SYSTEMS

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Innovative design workshops to empower young consumers to transform their food systems

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Introduction

In the face of today's environmental crises, our food systems require profound transformations (Webb et al., 2020). Yet, these systems are complex, encompassing heterogeneous and interdependent players (farmers, food manufacturers, public authorities, consumers, etc.). While all these players have a potential role to play in these transformations, they do not have the same capacity to explore innovative and systemic solutions. Consumers, in particular, are generally not considered as designers within food systems, and recognition of their role in transforming food systems has more to do with their decision-making power (McGregor, 2005).

Our ongoing research draws on recent advances in psychology (Cassotti et al. 2016) and design sciences to increase the capacity of consumers, whatever their age, to explore innovative solutions for increasing food system sustainability. More specifically, this research aims to identify levers to increase their "transformative capacities", defined as a combination of cognitive and organizational abilities to transform a socio-ecosystem (Moore et al. 2018), yet poorly operationalized. Our research, conducted by a transdisciplinary team (researchers in management sciences, psychology, ecology and societal mediators), aims to develop, test and evaluate design workshops adapted to a diverse audience, providing knowledge, tools, methods and skills to strengthen young consumers' ability to transform their own food practices and, through this, their food system.

Methods

Since the beginning of 2024, our team has worked with six schools in western France including two primary school classes, two middle school classes and two high school classes. This represents some 150 students aged 9 to 16.

The three-day workshops mobilize the collective design method known as KCP (Knowledge-Concepts-Proposals) (Hatchuel et al., 2009). As this method was for the first time implemented with children and adolescents in a school context, we had to complement it with animation methods. On the first day, we alternated between knowledge sharing on food system and cooperation activities, using various tools such as emotion cards. The second day was devoted to idea generation and selection, which we enriched with inputs on creativity enhancement and on commitment. During the third day, we helped participants develop their projects and present them to other students, teachers and school directors. Workshop facilitation is technical and needs to be lightly adapted to the context of each class.

As the workshops were part of a research-intervention project, we developed various tools to assess their impact. First, we built questionnaires to assess both ex-ante and ex-post the participants' ability to cooperate, environmental awareness and coping strategy, as well as creativity. Second, we filmed the workshops and we will analyze the participants' cooperation and creativity behavior with analysis grids. Third, after the workshops, we conducted 15 semi-

structured interviews with teachers to get their views on the workshop and classroom climate. Lastly, one team member accompanies the participants in their project implementation to facilitate their achievement, and the research team conducts to other post-tests with the participants.

Results

To date, a total of 24 projects were developed during the workshops (4 per class on average). Examples of projects include organizing a solidarity picnic with Ehpad residents, building awareness-raising campaigns against food waste and planting vines on communal land to make grape juice.

Initial feedback suggests that the workshops were well received by students, teachers and school management alike. The data collected is currently being analyzed. Data analysis will enable us to understand the impact of these workshops in terms of individual and collective transformative capacities. By the time of the FSD8 conference, we will have analyzed the pre- and post-tests, as well as the interviews conducted with teachers. As we follow the students' projects until the end of the year, we will be able to indicate whether they are completed, pursued, postponed, transformed or abandoned.

Discussion and Perspectives

While various design workshops have been developed to involve farmers or extension services in food system transformation (Jeuffroy et al. 2022), this original project aims to strengthen the transformative capacities of young citizen-consumers. Our research falls within the perspectives of critical consumer empowerment (McGregor, 2005, Ziervogel et al., 2016) and that of institutional reflexivity (Suddaby et al. 2016). In addition, we developed new assessment tools to monitor young citizens' empowerment and its impact beyond the classroom.

We plan to scale out this experience and deploy these workshops to other classes. We are thinking about transforming these exploratory workshops into a pedagogical tool that can be passed on to new teams of facilitators, for whom we'll be devising ad hoc training. We also envision setting up a participatory observatory to further the production of knowledge on transformative capacities.

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Figurative representation tools to support the participatory design process of an agrifood system

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Introduction

The farm scale participatory design activity can be supported by plans and mock-ups (Le Bellec et al., 2012; Penvern et al., 2018; Vereijken, 1997). Nonetheless, environmental issues call for a systemic approach in order to better distribute collective responsibility among stakeholders at the territory scale (Duru et al., 2015). Participants' contribution to a design workshop can be analyzed through the hierarchy of abstraction, structured from goals to means, from why to how (Barcellini et al., 2015; Rasmussen, 1983). However, the abstract and diffuse nature of a system challenges spatialized, formal, and concrete representations. Proposals from participatory workshops are often written on sticky notes, then arranged in geometric infographics such as trees or Engeström triangles (Cerf et al., 2024). This requires substantial and delicate refinement work by the mediation team. Moreover, abstract representations can be cognitively demanding, making it hard to engage stakeholders and materialize a project. In other domains, design activity is presented as inextricably linked to formal representations (Visser, 2006). By allowing participants' interpretations to synchronize, they facilitate collaboration (Détienne et al., 2006), especially when they come from different social worlds. Such representations are then called "boundary objects" (Star & Griesemer, 1989). In agroecology system design, figurative representations can help manage complexity by facilitating the sensitive perception of numerous pieces of information, different scales, design components and actor networks (Romera et al., 2020). Moreover, achieving the sustainable transformation of an agrifood system requires the democratic and balanced involvement of a diverse range of actors in the territory. We therefore seek to determine whether strengthening the figurative dimension of representations produced in the participatory design of agrifood systems can enhance stakeholders' agency and consideration for each other's issues during workshops. We also aim to detail the activities of the research-mediation team: preparation, management and refinement of the representations as well as the tactics to support stakeholders' empowerment.

Methods

This study is part of the Be Creative research-action project, initiated by INRAE on nine French territories to document design processes of pesticide-free territories. We observe and mediate three participatory workshops aiming at designing a fruit agrifood system, in the Pilat Regional Natural Park in 2024-2025. Farmers, agricultural college teachers, cooperative director, local elected representatives discuss production, supply, processing and consumption. In Workshop 1, co-ideation relies solely on text, then is supported by a preprinted image library (Workshop 2), and finally depends on a real-time image retrieval activity connected to a mini printer during Workshop 3 (Figure 1).



Figure 1. Evolution of the technical mediation.

The data from workshop 1 and 2 (solutions-blue ; challenges-yellow ; examples-green) are organized on a circular scale of abstraction (Figure 2), adapted to agro-system thanks' to territorial dimensions of Prost & Casagrande (2024) and divided into production, supply, processing and consumption. First used in the upcoming Workshop 3 to reflect on the exploration conducted in the previous workshops, it will subsequently serve as a generative tool. The results of Workshops 1 and 2 allow for assessing the relevance of this representation while guiding stakeholders in filling the epistemic blanks and balancing the responsibilities. We will analyze which technical mediation is the easiest to implement and refine while yielding the most valuable insights (semiotic role, distribution across abstraction scale and among stakeholders, participants' individual comprehension and active contribution).

Results

Experiments on the technical mediation are ongoing. The data from Workshops 1 and 2 are concentrated at the most abstract levels (center of the Figure 2), primarily in the production and consumption areas.



Figure 2. Distribution of proposals on circular epistemic levels.

These findings confirm the need to guide participants toward greater concretization and a more balanced distribution of proposals, providing a better representational support in the next workshop.

Discussion

We explain how the technical mediation based on intermediary representations either support or limit the ideation process and the responsibilities balance, with a focus on semiotic biases.

Perspectives

The results will provide recommendations on practical, semiotic and methodological issues for refining the technical mediation with a view to its deployment in other territories questioning its genericity.

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Combining technical and organisational innovations to enhance biosolutions

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Introduction

To achieve sustainable production objectives, agri-food systems stakeholders are experimenting various alternatives to chemical inputs such as biosolutions, which are based on a varying degree of biodiversity enhancement. While farmer's and consumer's expectations are high, the dissemination of these alternatives remains limited and the substitution paradigm, based on the use of inputs in a business model derived from the agrochemical industry, remains predominant. Indeed, reducing the use of chemical inputs is a complex, multi-scale, multistakeholder and multidimensional problem that cannot be solved by implementing technical solutions alone. Instead, we now need to explore territorial scenarios, critical for overcoming the limitations of a substitution paradigm, as they allow to combine technical and organisational solutions involving multiple stakeholders (Navarrete, Casagrande et al. 2024).

Here, we analyse the results of co-design initiatives in France and Senegal, in which agricultural professionals are collectively mobilised to contribute to the deployment of biosolutions. We focus on mycorrhizal fungi, soil biodiversity key elements that contribute to plant nutrition and health. With regards to the use of mycorrhizal fungi as an input, the strategy currently being developed is based on the introduction of standard inocula produced industrially. While the market is expanding rapidly, these commercial products are often unreliable. Other innovative strategies involve practices and actions implemented at different scales (plot, farm, region, country). Exploring these strategies provides an opportunity to grasp the dynamics of local learning experienced by stakeholders.

We have therefore focused on collective initiatives to develop proposals for mycorrhizal fungi enhancement that are adapted to the local context, in order to contribute to the redesign of agri-food systems. Here, we present an analysis grid to position the results of various collective initiatives to show how participatory approaches have helped to identify territorial scenarios.

Methods

An analysis grid, adapted from that of Sylvander et al (2006), was applied, using two axes. The first axis discriminates between different ways of enhancing mycorrhizal fungi into cropping systems (substitution vs. redesign) and the second axis measures the degree of collective involvement (individual, corporatist or sectoral/territorial governance). Local dynamics explored or carried out were positioned on the grid.

In France, in 4 regions (PACA, Martinique, Guyane and Guadeloupe), we shared with stakeholders the knowledge required to identify obstacles and levers to mycorrhizal fungi enhancement and mobilised this knowledge in a process of co-design with the stakeholders concerned, to encourage their coordination in efforts to explore territorial scenarios.

In Senegal, a large-scale (including different regions), multi-stakeholder, co-design approach to researching and promotion of inoculation was developed based on transferring know-how to farmers, support for successful family farming, increasing producers' incomes, diversification

of agricultural activities, job creation, adoption of agro-ecological practices and conservation of local biodiversity (Le Quéré and Krasova-Wade, 2019).

Results

The diversity of territorial scenarios explored and/or implemented following participatory approaches are presented in figure 1.

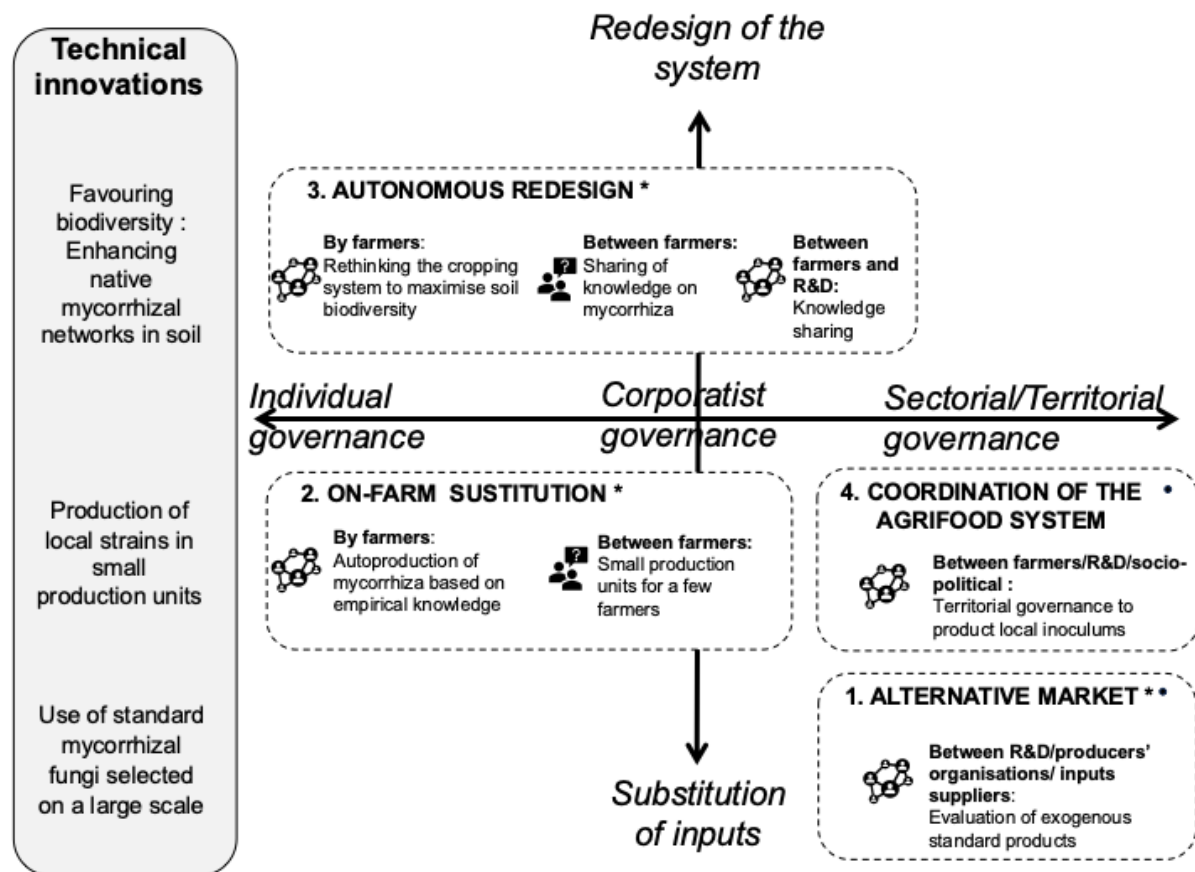


Figure 1. Territorial scenarios for the development of mycorrhizal fungi (Navarrete, Casagrande et al. 2024). Implemented scenarios, explored scenarios after co-design workshops; in France, in Senegal vs. current strategy in both France and Senegal

We show that sharing knowledge gives rise to a large range of strategies. The process of co-designing territorial scenarios revealed that i) stakeholders, both individually and collectively, possess the knowledge and experience required to design territorial scenarios for the development of biosolutions such as mycorrhizal fungi enhancement, ii) the involvement of these stakeholders at different stages of the co-design process and in different ways makes it possible to harvest and exploit this knowledge, iii) comparisons of this knowledge, including innovations already deployed in the field make it possible to open up new avenues of exploration and to develop territorial scenarios.

Discussion and perspectives

The diversity of mycorrhization strategies explored highlights the importance of the farmer's role, the quality of local coordination and the sharing of information and knowledge, all of which contribute to the evolution and adaptation of agri-food systems. This requires a combination of several dimensions of innovations such as technical and organizational involving regulatory,

institutional and social issues (Boulestreau et al. 2023). These results are not specific to mycorrhiza and could come from work on many biosolutions. Indeed, most biocontrol agents can be mobilized directly on farm or produced in local biofactories.

Beyond the scale of action, the collective learning process implemented by the stakeholders is crucial to the implementation of territorial scenarios. These processes are generally easier to set up on a regional scale, where we observe a strengthening of local coordination between the various stakeholders in agri-food systems. In this transition, farm advisors are key stakeholders to change their way of thinking and support farmers (Omon et al. 2019). In a context of complexity and uncertainty, research and development stakeholders need to produce not only knowledge, but also approaches and tools to mobilize and support those involved in change.

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Designing pesticide-free agriculture: a territorial research framework for moving from theory to practice

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Introduction

The negative impacts of pesticides on the environment and human health are extensively documented, with studies highlighting detrimental effects on biodiversity and ecosystem services. Despite this, efforts to reduce pesticide use have proven ineffective. Research often focuses on gradual reductions and substitution solutions, without fundamentally questioning agriculture's structural dependency on pesticides. As already claimed by Jacquet et al. (2022), there is a need for a shift towards pesticide-free agriculture as a new paradigm for research, requiring systemic approaches that integrates both biophysical and socioeconomic dimensions. Research often separates these aspects, but a holistic approach is necessary to develop comprehensive solutions. In that respect, we argue that the concept of "territory" is necessary as a promising integrative level for deploying pesticide-free research. We propose a research framework at the territorial level, integrating both biophysical and socioeconomic dimensions, that is implemented since 2021 in the PPR CPA BeCreative project, in 9 French case study territories (Valantin-Morison, 2021).

Methods

This framework involves adopting a territorial approach, focusing on localized and context-specific solutions, and embracing action research methodologies within these territories to foster practical, real-world applications and innovations. The concept of territory, as defined by Löfgren (2020), refers to a spatial unit where natural and human factors interact, forming a complex adaptive system.

In the BeCreative action research project, we organized our activities in a design process that involves three major activities (Prost et al., 2023):

1. Defining the Design Problem: we conducted socio-technical diagnostic approaches that describe the functioning of a socio-technical system built around a dominant technology to understand the systemic phenomena that frame the innovation process and identify the barriers and levers for the development of alternative technologies (Casagrande et al., 2023).
2. Generating Innovative and adaptive Design Solutions: we facilitate the emergence of grassroots and tailored solutions for pesticide-free territories, using participatory design tools, modeling, and experimental setups to capture the complexity of territorial systems and support the co-design of innovative and situated solutions
3. Evaluating Performance and Impact: we create frameworks for multi-dimensional assessments that incorporate diverse criteria and stakeholder values, allowing for ongoing refinement and improvement of solutions based on real-world feedback.

We document developments across the various territories through regular exchanges and collaborative workshops with both academic and local stakeholders, as well as by collecting traces and documentation of the ongoing processes.

Results

We present several outputs of the project and examples that demonstrate how the different methodologies were combined across our nine case study territories over four years and the implications for agroecological transition research. Based on our continuous monitoring and engagement, we are able to analyze both how the action-research processes unfold across territories and what they produce: which actors are involved (or not), what strategies are developed to phase out pesticide use, and what challenges, setbacks, or turning points emerge in relation to local dynamics. The methods, tools, and performances of two territories will be presented in more details, allowing us to highlight the major research questions this raises in co-designing at the territory scale and in supporting agricultural stakeholders.

Preliminary results from our ongoing research in 9 case-study territories indicate that a territorial approach can effectively integrate biophysical and socioeconomic dimensions, leading to more context-specific solutions. Engaging stakeholders in such processes fosters a shared understanding of the problems and encourages effective collaboration. Furthermore, the iterative dialogue between problem formulation and solution formulation, sustained by continuous evaluation, constructs the research process over time.

Discussion and perspectives

By trying to implement a systemic research framework at the territorial level, involving local actors and integrating both biophysical and socio-economic dimensions, we contribute to develop context-specific solutions tailored to local realities. Our research reveals that each territory has followed a distinct trajectory, encountering different challenges and adapting its design objects, partnerships, and actions over time. These evolving strategies provide valuable insights into the dynamics of agricultural transitions, shedding light on how local actors navigate uncertainties, seize emerging opportunities, and refine their approaches. By capturing these lived experiences, we contribute to a deeper understanding of transition processes in real-world contexts through co-design methods (Schuler and Namioka, 2017; Mazzucato, 2018). Our contribution is also methodological, with the aim of providing tools and support for actors involved in advisory and facilitation roles for the transition towards sustainable agricultural systems. The framework we have developed, tested and adapted in return highlights the importance of equipping stakeholders with tools and skills that serve complementary and interactive purposes: building and sharing a common understanding of the situation and its dynamics, fostering creativity by opening up a renewed field of possibilities, and supporting the development of evaluation approaches that address both external expectations and the priorities of local stakeholders.

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Conducting a diagnosis of use situations to design tools aiming to support change in agricultural systems

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Introduction

To support the expected change in the agricultural systems, and more specifically support practitioners to manage complex agricultural systems, many researchers have developed decision support systems (DSSs), often digital ones based on advanced knowledge on the agroecosystem and including management performance criteria. The observed limited use of most DSS emphasized participatory design (Mac Cown, 2001). Yet, involving the future users within the design process does not guarantee a good fit of the tools to the users' needs due to the diversity of the possible users but also to the lack of consideration of their real work situations as pointed by scholars in ergonomics (e.g. Beguin & Rabardel, 2001). To access to real activities and working situations of users, we proposed a method called Diagnosis of Use Situations (DUS) (Cerf et al., 2012), in the view to support designers in the analysis of the diversity of the users' activity situations. We did a transversal analysis of several recent cases where this method was implemented to design DSS (such as new nitrogen or pest management tools, new assessment tool of plots or farms sustainability, new data-base to support agroecological transition) or new objects (such as a cheese ferment). In this paper, our aim is to show the different ways an analysis of the diversity of use situations can fuel a design process of such artefacts.

Theoretical framework

The DUS is based on concepts from the activity theory (Engeström, 1987): the activity is goal-oriented, situated (individuals adjust their activity based on constraints, social contexts...), collective and mediated (between the subjects and their goal, there are tools, rules and social relations). Understanding a potential future practitioner activity which an artefact under design wishes to support, means examining both what drives such activity (the goals, the evaluation criteria, the management principles) and what enables or constrains practitioners in performing it (tools, regulations, community in which they operate). As well, DUS aims at questioning or enriching designer representations regarding the diversity of ways to perform the activity in real work situations. The latter diversity needs to be analyzed by considering not only the diversity of agronomic conditions but also the diversity of ways through which practitioners (farmers and other professionals dealing with the problem which the artefact under design addresses) perform their coupling with their environment (pedo-climatic, social, economic, etc.).

Materials and Methods

We analyzed ten case studies in which a DUS was implemented. The cases were chosen to explore a diversity along three main criteria: (i) the availability or not of existing tools aiming at addressing a similar need or problem; (ii) the existence or not of a first prototype of the targeted tool; (iii) the kind of mediating supports created by the DUS analysts to build dialogue in the design process between the artefact and the activity it aims to enable through supporting the way to address a specific problem.

Similar information was required from the pilots of the various cases. During cross presentations of the various cases, data were collected on: (i) the context of the DUS within the design process; (ii) the public targeted by the DUS and the way data were collected, analyzed and finally presented to feed the design process; (iii) the main findings of the DUS which the designers implemented; (iv) the impact the DUS had on the co-design process either of the artefact or/and on the targeted activity. Convergences and differences between the cases were then highlighted.

Results

In all case studies, the DUS aimed at characterizing the diversity of ways practitioners describe their activity related to the problem the tool aims to equip. The analysis focus on the relationships between what drives the actions, what are the actions, and the resources they mobilize to act. Doing that, cases focused either on the invariants or on the diversity of the users, their goals, the situations or their use of tools.

In all cases, a step aimed at translating the outputs of the DUS analysis as inputs for the design process. They concerned new uses for a targeted tool, the choice of actors (and sometimes their enrolling) involved in the design process, the formulation of design targets, the identification of new properties for the future tool or criteria to assess it. Such feed-back is done through various mediating supports (concept-trees, personae, narratives, sketches, etc.) built to point key discrepancies between designers' representations of use and users and the latter observed in the DUS. The DUS fuels the design process but its impact on the subsequent design process depends on both the stage of the design process (at the very start or after a first computerized prototype for example) and the openness and availability of the designers to reassess their first design choices.

Discussion

The approach described, theoretically based on activity theory, allows future designers to question, during the design process, the co-development of a tool and of the activity they seek to equip through supporting the way to face a specific problem. Such approach goes beyond the question of acceptability, as often discussed in the literature. Representing and debating the diversity of ways a complex system may be managed and the activity this implies, leads to three types of effects: on the tool to be designed, on the representations of the agroecosystem management, and on the designers' own activity. This new skill for future designers of tools aiming to support agroecological transition may be considered as a way to enhance their capacity building for scaling up change in agricultural systems.

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Understanding and supporting a territory's transition towards zero pesticide use: the case of the Western Plain of Montpellier

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Introduction

Issues related to pesticides depend on a variety of actors beyond farmers, such as public policy stakeholders, agricultural advisors or supply chains. This calls for a systemic and ambitious approach to pesticide reduction in research (Jacquet et al. 2022) that would consider the whole system of actors and their interactions, within this system but also beyond its boundaries (Hammond 2017). One way to do so is to consider the question of design agricultural systems at the territorial level, which raises questions about diagnosis and design methods in agronomy (Prost 2021). This approach implies the combination of technical, organizational issues and challenges for the support of this transition. This scientific challenge was addressed in a PhD in landscape agronomy.

This study aims to combine approaches at various scales to support the territory's transition towards zero pesticide use. It was conducted on the Western Plain of Montpellier, a Mediterranean and periurban area in the South of France. We present below the methods used throughout this approach and the results of their implementation. Finally, we discuss our findings and future research perspectives.

Methods

Our research approach combined various methods across different levels to explore pesticide reduction strategies and their implementation (Figure 1). This combination aimed at involving a diversity of stakeholders as well as taking into account decision-making levels below the territory level while integrating insights from other territories.

The first step, diagnosis, was based on the analysis of 19 local pesticide reduction initiatives using a novel framework on collective action (Amblard et al. 2018) and landscape agronomy (Benoît et al., 2012). It allowed us to build an analytical grid that was used to assess (i) territorial factors of the emergence of collective action, (ii) the diversity of existing collective action, and (iii) its potential impacts on agricultural systems. This revealed three different types of pesticide reduction strategies, but also highlighted three initiatives had a more systemic scope, combining these three strategies.

Using the Co-Click'Eau tool (Chantre et al. 2016), we designed crop allocation scenarios aligned with the systemic initiatives identified in the first step and we refined them through workshops with local stakeholders, integrating performance indicators developed both within and beyond the territory. These territorial scenarios were translated into changes at production system-level to evaluate their implications.

An action planning phase engaged stakeholders at multiple levels. Workshops with actors from other territories identified synergies and potential conflicts between scenarios, while discussions at a local level explored local implementation conditions. Future steps include discussing the operational conditions to implement these scenarios at the farm scale.

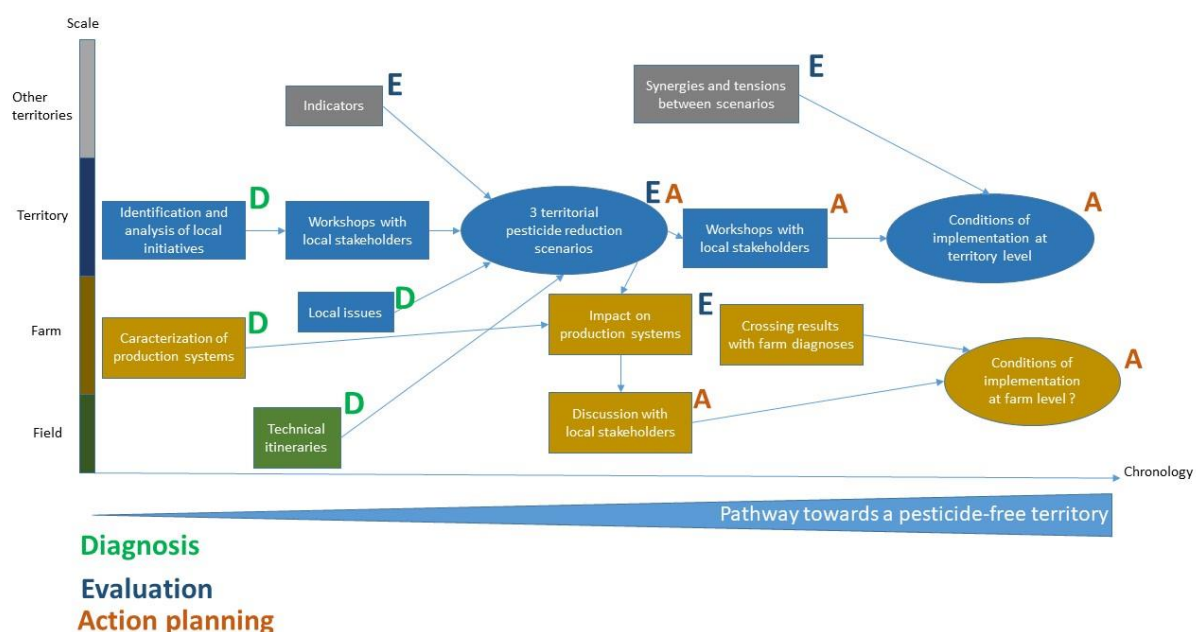


Figure 1. Combination of methods and outcomes in the research process towards action on the territory.

Results

The analysis of 19 local initiatives showed that they intend to transform agricultural systems through 3 strategies: (i) reducing pesticide use across large areas without drastically challenging existing systems (optimization of use) (ii) reconfiguring farming practices and organization, (iii) focusing on biodiversity and agriculture integration. However, the lack of coordination among initiatives and the focus on just one sector (viticulture) limit the systemic impact of these initiatives. Based on this analysis, we identified three systemic territorial strategies for pesticide reduction: (i) diversifying agricultural production towards high-quality local food supply, (ii) preserving biodiversity and fostering biological regulations within an agricultural landscape mosaic, and (iii) developing pastoral livestock systems to maintain natural areas in interaction with farmlands (Parmantier et al. 2024).

The scenarios were designed to encourage exploration in an "optimistic" framework. The participatory approach ensured alignment with stakeholders' perspectives while revealing potential conflicts based on their differing objectives. The workshops with actors from other territories identified both technical (e.g., grazing, local valorization) and organizational synergies (e.g., shared crop allocation, supply chain development), alongside tensions such as conflicting grazing priorities, water resource allocation, and seasonality constraints. Applying the scenarios at the production system scale highlighted the challenges of potential farm-level changes. For instance, we showed that the diversification scenario, designed to enhance local food supply, requires a major transformation of farming systems, leading to shifts in knowledge, work, and agricultural equipment.

Discussion and perspectives

This combination of methods enabled us to integrate different perspectives on pesticide reduction. It helped identify action pathways and create a discussion space bringing together a diversity of local and external stakeholders. The contribution of external territories was both methodological--- highlighting the replicability of the approach---and practical for the territory, through the sharing of experiences, reflections on action pathways, and discussions on synergies and tensions between scenarios, showing how guiding a system toward

transformation requires "non-linear, long-term, multi-actor processes with struggles and tensions between actors operating at regime and niche level" (Leeuwis et al. 2021). It also opens research perspectives at the interface between farming systems design and landscape agronomy, underscoring the need for territorial design closely linked to farming practices, iterative stakeholder exchanges, and methodological improvements, given the challenge of engaging all actors simultaneously. This approach seems capable of fostering collective action at the territorial level and, ultimately, supporting the development of coherent public action, which are needs identified by Jacquet et al. 2022.

This research process shows the importance of identifying synergies between strategies, but also spaces where dialogue should be facilitated. Indeed, materializing multiple stakeholder strategies in crop allocation scenarios is in line with design literature showing that cognitive conflict can lead to more creativity (Badke-Schaub et al. 2010). The role of facilitation in the research process was crucial and should be further investigated to ensure long term evolutions on the territory.

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T4E design approach enabling design of sustainable farming systems

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Introduction

Current intensive farming systems heavily use inputs, produce high yields, and have multiple negative side-effects on greenhouse gas emissions, biodiversity, farm income, and on soil and water quality (Kremen et al., 2012; Titttonell, 2023). Agro-ecological farming systems, by contrast, which are based on the theory of diversified farming systems, rely on "solutions" from the ecological processes in the production system and replace external inputs and/or labour by ecological processes. For example pest and disease are regulated by biology and soil fertilization through plant diversity. When compared to intensive farming systems, the agro-ecological systems need less inputs, produce other beneficial outputs next to food products, and have less negative impact on environment, biodiversity, climate and human health (Kremen et al., 2012; Petersen-Rockney et al., 2021; Titttonell, 2023). The further adoption of such ecological farming systems, however, faces huge challenges. To advance the uptake of such systems and/or diversification processes, we need to fill knowledge gaps, reduce the risk for the farmers and provide technologies facilitating the transition towards agro-ecological farming (Lamine et al., 2012)).

To address these challenges, the Synergia research program, financed by the Netherlands Organization for Scientific Research (NWO grant 17626), IMEC-One Planet and other private parties, aims to foster more ecology-based farming by using a new (re)design approach under the name "Technology for Ecology" (T4E). Within this program, new solutions are sought by interacting and cooperating with researchers from various disciplines as well as stakeholders. The research addresses three agricultural sub-systems, viz. greenhouse horticulture, dairy farming, and arable farming.

What is T4E

T4E is a multi-disciplinary bio-systems engineering approach aimed at the (re)design of the architecture as well as at the management of farming systems to achieve "integral sustainability". This includes economic sustainability (for farmers, industry, society), maintenance and resilience of natural ecosystems and the support and services they provide to agricultural production as well as to society at large.

In this approach, the system to be re-designed extends beyond the farm and includes entities relevant for the design challenge at hand, e.g. natural environment, farms, suppliers, retail, consumers. It aims to include ecological solutions to functions (e.g. crop protection, biodiversity) where possible and identifies the need for and designs technologies to manage such an agro-ecological system for different local and regional circumstances.

The T4E design approach builds on general design approaches (Siers, 2004; Cross, 2008) and on experiences from applying the so-called RIO design approach (a Dutch acronym for 'Reflective Interactive Design') developed for animal husbandry systems (Elzen and Bos, 2019). Key parts of these approaches are a system analysis, an assessment of the needs of the key-actors and an identification of (key)functions that the new design should fulfil. The needs of the key-actors are described and quantified in so-called "briefs of requirements" that

the new design should adhere to. The extended RIO approach also addresses the uptake of new designs in future practices by adding an 'anchoring' stage to the RIO approach (Elzen and Bos, 2019). For T4E, we further adapted the RIO approach as follows:

1. 'Anchoring' will already get the attention starting from step B.
2. In step G, when collecting solutions, also nature technologies are included i.e. ecological and biological mechanisms. Such technologies are preferred in the design.
3. An extra iteration (Step K, L and M) is made to design technological (hardware) solutions for advancing the incorporation of the ecological mechanism from step H.

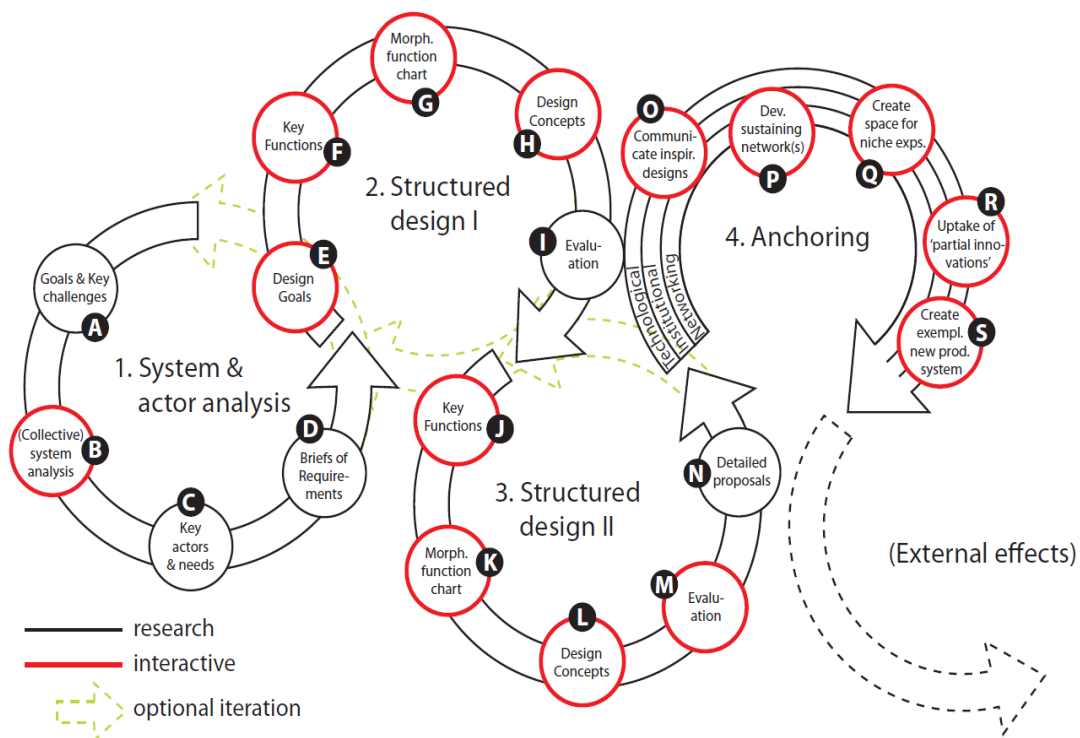


Figure 1. The steps of the extended RIO (Reflexive Interactive Design) approach which also includes anchoring of the design (Elzen and Bos, 2019).

Demonstration of the approach

In the first phase of the Synergia program, the T4E approach was tested to assess and demonstrate its general applicability. PhD students from the Synergia program, all having different specialisms, combined their knowledge within one of the three use-cases (arable farming, greenhouse horticulture and dairy farming). They defined the main problems within each use-case and the main functions related to these problems (key-functions). Next, ecological mechanisms and technologies (hardware and practices) were identified that might serve as a solution for these key-functions. A list with requirements for redesign was produced to select the most suitable and promising solutions. By combining the best solutions for the key-functions, a redesign was accomplished.

Results and conclusions

Though the approach was carried out in a rather crude manner, each use-case group with PhD students was able to successfully produce a draft of a newly designed agro-ecological farming system. These systems featured 1) new ideas and innovative combinations of concepts and

solutions based on ecological mechanisms and 2) various, partly novel, technologies to facilitate uptake of those mechanisms. It was also demonstrated that it is important not to seek solutions to single problems but to target an integral (re)design of a farming system. This diminishes chances that new problems are created elsewhere and allows finding more optimal ecological solutions.

As an example, the redesign of the arable farming system focused on soil compaction, greenhouse gas emission, labour availability and water availability. The selected technologies to manage the system allowed for a diversity of crops under a Gantry system with semi-transparent solar panels which are adjustable in angle and with automated field operations. Energy and water are buffered. Pigs perform the "ploughing", provide nutrients and reduce tubers from root crops after harvest of the main crop.

After the successful demonstration of the approach, the full T4E approach, including the involvement of stakeholders, will be carried out later this year for the dairy and arable use-cases.

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A review of the regulation of plastics used in agriculture and for food to inform public policies and support the transition towards sustainable agrifood systems

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Introduction

The use of plastics has expanded significantly since the 1950s due to their properties, including in food value chains. In 2022, in Europe, plastics used in agriculture and for packaging accounted for around 20% of the plastic consumption. Providing perspective on the regulation of these plastics is complex, as the sources of law applicable are scattered within a wide variety of legal texts stemming from various branches of law and is not structured around a regulation dedicated to plastics.

The objective was to understand the evolution of the regulation of plastics used in agriculture and for food since the 1950s and the construction of the European Union. We aimed to describe the regulations in force and to analyse the difficulties the law has in addressing the issues raised by the use of these plastics, so as to inform public policies and support the transition towards sustainable agrifood systems

Methods

As part of an interdisciplinary comity of European experts, within a collective scientific assessment conducted by the French national research institutes INRAE and the CNRS, we reviewed the available scientific knowledge on the regulation of plastics used in agriculture and for food. In particular, we searched legislative and regulatory texts using official legal databases (Légifrance, EUR-lex) and analysed them with case law, legal opinion and other scientific publications, obtained via legal and scientific publisher databases (e.g. Le Doctrinal, Dalloz, Web of Science).

Results

The European legal framework for plastics used in agriculture and for food was motivated historically by the protection of economic freedoms and, since the late 1970s, by health and environmental protection concerns as well. Plastics used in agriculture and for food cannot be considered in isolation from the broader sociotechnical system of plastics. The legal framework in force can be structured around three distinct legal areas: food contact materials (FCM) law, waste law (including packaging and packaging waste regulations) and chemicals law. FCM law governs the safety of materials that come into contact with food, ensuring they do not transfer harmful substances to the food or substances that could alter their composition or organoleptic qualities. Chemicals law aims at ensuring that the chemical substances used in the manufacture of plastics are safe for human health and the environment. Waste law sets definitions and rules to manage waste with environment and human health protection concerns.

Over the years, the scope of plastics regulation has evolved from a narrow focus on specific lifecycle stages and specific plastic items to a more comprehensive framework with regulations tending towards covering different stages of the life cycle of plastics (Fig. 1). Depending on the

legal area considered, plastics are addressed as a material, an object or a mixture of chemical substances. This reflects a changing perception of plastics, now seen not merely as waste but also as complex materials (Nielsen et al., 2020), trying to integrate plastics into broader systems (Barrowclough and Birkbeck, 2022).

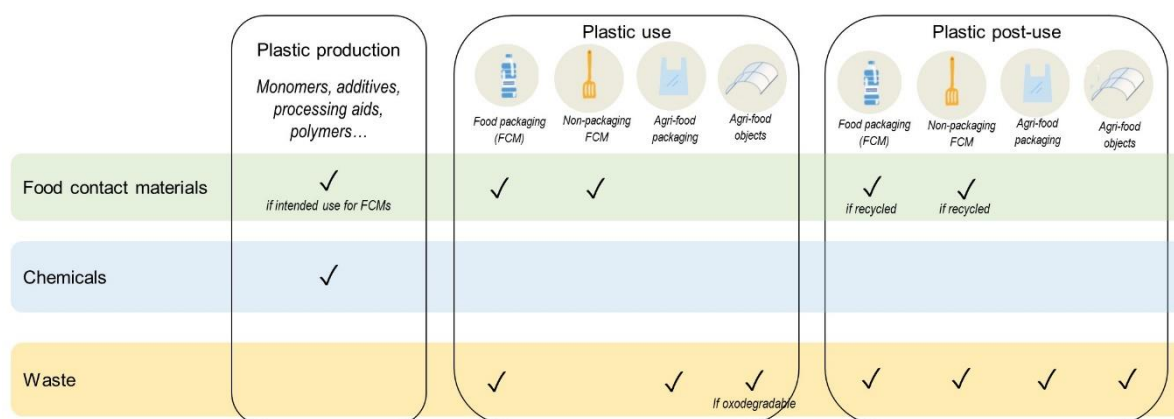


Figure 1. Legal areas applying to plastic ingredients, plastic objects and plastic waste

Discussion and perspectives

Existing European regulations for plastics used in agriculture and for food address only the most visible aspects of the challenges posed by plastics.

Chemicals law focuses on well-known substances, while a large proportion of plastic-related chemicals, including hazardous ones (Wiesinger et al., 2021; Wagner et al., 2024), or polymers (Steensgaard et al., 2017; Wiesinger et al., 2021) remain less regulated. Waste regulations focus on a handful of easily identifiable macro-items, overlooking other forms of plastic. Plastic food contact materials law does not take into account plastics used on farms even though these are in contact with food in the making. More broadly, plastics used in agriculture, except in some specific cases (e.g., oxodegradable plastics), only fall under general waste, chemicals laws or international agreements, without taking into account their specificities.

Plastics used in agriculture and for food cannot be isolated from the wider system of plastics, making their regulation difficult. While the existing regulatory framework tends to better acknowledge this complexity, this work aims to demonstrate that it remains insufficient to support the transition of agrifood systems. The mainstream socio-technical system keeps food value chains locked-in in favour of plastics and current regulations tend to maintain this dependency rather than truly question the production of plastics.

Regulations play a key role in the design of agrifood systems by supporting e.g., the redesign or transition to more sustainable practices. The ongoing work on a European legislative framework for sustainable food systems could be an opportunity to address the plastic issue more systematically.

This work aimed to describe and analyse the existing regulations and could be complemented by a literature review of their impacts e.g., on plastic consumption or waste production, in order to better inform public policies.

Acknowledgments

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Barriers and levers for reintegrating livestock in crop farms and regions -- a transversal analysis in three countries

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Introduction

In the Global North, decoupling of crop and livestock production has generated negative environmental impacts (Garrett et al., 2020). At the farm level, reduced livestock numbers led to a decrease in forage legumes in crop rotations thereby decreasing ecosystem services and increasing input dependency. At the regional level, specialized crop regions rely heavily on fossil energy and imported nutrients, while specialized livestock regions import large volumes of animal feed and produce surplus manure, creating storage and pollution problems. Despite these acknowledged impacts, and the documented benefits of integrated crop-livestock systems, high-input specialized crop systems continue to expand.

However, pioneering farmers around the world are reintegrating (i.e. intentionally organising the return of) livestock in crop farms and regions where the livestock sociotechnical system has nearly disappeared. Livestock reintegration thus consists in the process of change from a specialized crop system to a system that includes both crops and livestock, either at the farm level (on-farm livestock rearing) or regional level (partnerships where crop farmers temporarily host livestock farmers' animals, e.g. for winter cover crop grazing). Although reintegrating livestock can contribute to improve crop farms sustainability (Meunier et al., 2025; Ryschawy et al., 2021), it remains niche and under-documented.

We aimed at characterizing the sociotechnical barriers to and levers for reintegrating livestock into specialized crop farms and regions, to support the development of sustainable forms of livestock reintegration.

Methods

We conducted a transversal analysis in three regions where a few crop farmers have reintegrated livestock --monogastric or ruminants- into diverse cropping systems (cereals, vineyards or orchards). These regions differed in soil-climate conditions, sociocultural dynamics, and political settings, and represented a gradient of crop-livestock disconnection:

- Eastern Scotland, where crop production dominates but remains geographically close to livestock regions and related services, making it the least disconnected.
- Southwestern France, where specialized crop farms predominate and coexist with declining numbers of mixed crop-livestock and specialized livestock farms.
- Northern California, where large-scale crop and livestock production coexist but are highly disconnected, representing the most disconnected.

We interviewed 33 key actors of the sociotechnical system surrounding livestock reintegration from the three regions, including farmers having reintegrated livestock, advisors, researchers, and policy experts. We characterized the forms of livestock reintegration and identified barriers and levers across all levels of the sociotechnical system: the niche of livestock reintegration, the dominant high-input specialized farming regime, and the broader landscape (Geels, 2004). We analysed the interviews inductively and compared the results across regions to i) identify common barriers requiring cross-context action and region-specific challenges, and ii) highlight successful levers that may inspire broader adoption.

Results

In the three regions, livestock reintegration was hindered by similar barriers rooted in the regime of high-input specialized farming regime (Fig.1). The main barrier identified by all actors in all regions was the lack of knowledge from farmers and advisors, e.g. on how to manage animals. Additional barriers included the decline of livestock-related services, e.g. veterinarians and slaughterhouses (France, Scotland) and a shortage of skilled labour and infrastructure (all regions). While these barriers can partially be resolved when reintegrating livestock at the regional level, actors highlighted difficulty to identify a partner and build stable collaborations (all regions).

In addition, landscape-level barriers hinder livestock reintegration scaling up. These include societal concerns over the environmental impacts of livestock---typically aimed at industrial systems but often also affecting reintegration initiatives (France, Scotland)--- and regulatory constraints restricting animal presence in crop fields (California).

To manage reintegrating livestock despite these barriers, farmers mentioned having designed livestock systems limiting the need for new skills, labour and capital, e.g., outdoor meat sheep in all three regions and monogastric linked to highly-integrated value chains in France and Scotland.

Current changes at the landscape level are creating a window of opportunity for scaling up livestock reintegration. Actors highlighted benefits such as on-farm manure production in response to rising fertilizer costs (France, Scotland), and wildfire risk mitigation through wasteland grazing (California). They also mentioned a positive cultural memory of mixed crop-livestock systems (all regions).

Discussion and Perspectives

Barriers to livestock reintegration are mostly similar in the three regions despite diverse contexts. Though aligned with those documented for maintaining integrated crop-livestock systems (Garrett et al., 2020), they are often stronger (e.g. deeper knowledge gaps, disappearance of the sociotechnical system). So far, limited actions at the market and policy levels have been taken to help raise these barriers.

Given the current window of opportunity that could trigger livestock reintegration scaling-up, we encourage policy-makers to favour coordinated actions at all levels of the sociotechnical system through:

- i) supporting collective knowledge production on how to reintegrate livestock sustainably, e.g. through funding participatory research projects and broadly disseminating results ;
- ii) favouring the reestablishment of the sociotechnical system surrounding livestock production, e.g. subsidizing fixed or mobile slaughterhouses ;
- iii) adjusting regulations, e.g. strengthening cover crop regulations, encouraging grass cover in vineyards and orchards ;
- iv) incentivizing agroecological practices e.g., through payments for ecosystem services.

This exploratory study, based on a small and diverse sample, provides first insights on barriers to livestock reintegration. It should be improved with in-depth consideration of specific forms of livestock reintegration, identified as most sustainable (Ryschawy et al., 2021), to better inform policy and practice.

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Integrated crop-livestock systems at territorial scale: the role of agrifood stakeholders in the Ternois - 7 Vallées territory

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Introduction

Crop-livestock interactions improve the autonomy of crop-livestock farms (Martel et al., 2017), while providing ecosystem services (Kremen and Miles, 2012). In specialized production landscapes, integrated crop-livestock systems at territorial scale (ICLS) can be seen as an opportunity to modify agricultural practices towards agroecology (Bonaudo et al., 2014). Research on practices such as crop diversification (Meynard et al., 2018) has highlighted how the agrifood sector influences the diffusion of alternative farming practices. However, the role of the agrifood sector in the development of ICLS remains largely understudied. Therefore, our study focuses on key actors in this sector: farmers and stakeholders involved in collection and primary processing.

The territoire of Ternois - 7 Vallées (T7V) was chosen to address these issues. With a history of mixed farming, this region seems to experience a dynamic of specialization, driven by the presence of major industrial players in the potato, industrial vegetable, and sugar production sectors.

The study enters this issue by pinpointing ICLS practices and analyse how agrifood stakeholders act as barriers and/or enablers of these ICLS.

Methods

To analyze barriers and enablers to ICLS practices development on territorial scale and in a agrifood multi-sector context, we have chosen to draw inspiration from the sociotechnical diagnosis method (Casagrande et al., 2023). The studied system involves a complex diversity of stakeholders, which calls for analyzing their positioning in relation to ICLS practices and understand how these actors encourage or hinder the development of ICLS practices.

Comprehensive interviews with 31 stakeholders in the T7V territory, and in the agrifood sectors that value its agricultural produce were conducted. Obtained data were combined with documents from local institutions, census data, and reports from interviews and workshops conducted in the territory in 2023 and 2024. These data were processed by writing up the narrative of each stakeholder, and by mapping their networks and the role of agrifood stakeholders in these practices. A cross-sectional analysis of processed data was performed insisting both on the agrifood stakeholders' postures and on ICLS practices.

Results

Initial results allow to characterize different ICLS practices and understand their importance (or lack thereof) in the territory (fig.1).

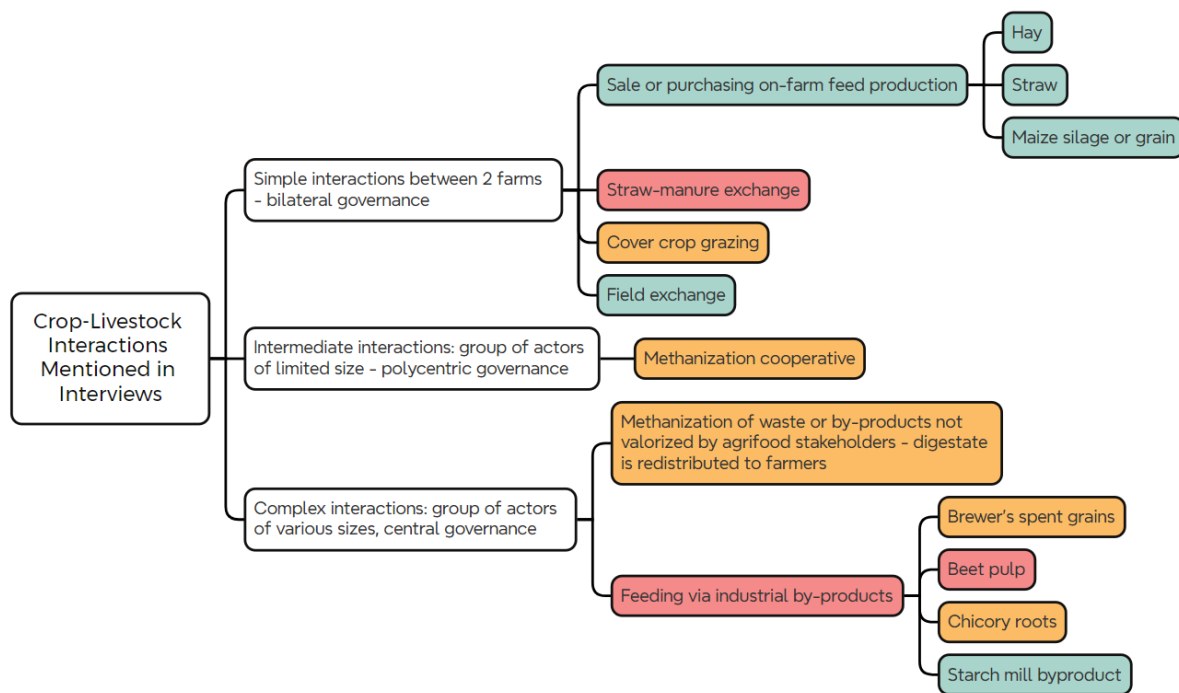


Figure 1. ICLS practices described in T7V. Red: Widespread; Blue: Common; Orange: Marginal

The strategies of agrifood stakeholders mostly hinder the development of ICLS practices, by encouraging some dynamics:

- The expansion of methanization intensifies competition with crop farmers for effluents and with livestock farmers for industrial by-products, affecting both their availability and price.
- The expansion of methanization intensifies competition with crop farmers for effluents and with livestock farmers for industrial by-products, affecting both their availability and price.

On the other hand, some identified interactions are strongly supported by agrifood stakeholders, such as the use of beet pulp for livestock feed, which is supported by sugar companies (fig 1). In these cases, agrifood sectors facilitate an ICLS practice.

Within each sector, there are different sort of stakeholders with similar or antagonistic strategies. For example, there are groups of farmers who own an anaerobic digestion unit and seek to buy all the biomass they can find, making it unavailable to those who used to use it. Conversely, there are mixed farmers who diversify their activity with a micro-methanization unit, fed exclusively by their effluents, which does not amplify the pressure on territorial biomass.

Further work in progress will enable us to better understand stakeholders' organization, and to better describe their role and interrelationship for each ICLS.

Discussion and Perspectives

The role of agrifood stakeholders in the development of ICLS practices is ambivalent and depends on their individual strategies. Another potential driver of the development of ICLS, for which we have found little evidence so far, could be agriculture-related public policies, as

suggested by Garrett et al. (2020). An in-depth analysis of the individual and joint strategies of the various actors (farmers, agrifood stakeholders and public authorities), along with continued data collection, will enrich these findings and enhance our understanding of the obstacles and levers to ICLS practices. This will also help clarify the respective influence of public policies and agrifood stakeholders.

The follow-up to this diagnostic stage is a design phase to support the development of crop-livestock interactions in the area. Once the role of the local stakeholders in the development of these interactions identified, it will allow us to work on the design of coupled innovations, which implies a coordinate innovation process with several stakeholders, (Boulestreau et al., 2023). These innovations might lead to changes in practices for both farmers and agrifood stakeholders.

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A conceptual and analytical framework to understand lock-ins in the agrifood systems transition

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Introduction

Modern food systems have geared towards unsustainable trajectories in the last half-century, leading to significant damage to the environment and society. Despite these alarming realities, the transition of agrifood systems towards sustainability encounters strong resistance (Conti et al., 2021).

This resistance has been studied for some time now under the lock-in concept, which helps understanding the internal inertia of dominant systems' configurations hindering large-scale systematic shifts (Simoens et al., 2022). Despite its wide use nowadays (e.g., Meynard et al., 2018), there remains knowledge gaps regarding the lock-in concept.

Firstly, despite a shared understanding of its core idea, there is a lack of consistency in the terminology used to describe the elements composing a lock-in, and how such elements are related to the concept of lock-in (Conti et al., 2021).

Secondly, most authors overlook the systemic nature of lock-ins (Simoens et al., 2022). The constitutive elements of a lock-in and the interactions between them leading to the "locked" state of the system are rarely acknowledged.

Thirdly, most frameworks about lock-ins lack operationality as they focus on the dynamics of lock-ins emergence in a global, and therefore abstract, system, and are not adequate when it comes to identifying specific actions for change to happen.

Our contribution aims at filling these gaps by proposing a conceptual and analytical framework tackling lock-ins in agrifood systems.

Methods

The framework draws on the extensive research conducted by the Sytra, research team (UCLouvain, Belgium), including two PhDs on specific case studies (Vanloqueren and Baret 2008; De Herde, et al., 2019) and overall analyses across various case studies in four European Projects (DiverIMPACTS, ENFASYS, FoodCOST, IntercropVALUES). These studies span various contexts, e.g., crop diversification, Walloon dairy sector, multi-resistant wheat cultivars in Belgium.

Results

Conceptual framework

Our conceptual framework is grounded in the concepts of barriers and lock-ins, which we distinguish as follows:

- Barriers are specific and concrete elements of the system that, by their existence and their interactions, contribute to its blockage. They are seen as the bottlenecks faced by actors involved in this system,
- Lock-in refers to a state within a (agrifood) system where a specific configuration becomes deeply entrenched, making the system resistant to change. It results from interactions between barriers.

Lock-ins are strongly embedded into path dependence processes, i.e., historical events influence future choices, creating a dependency (Conti et al., 2021). However, our conception of lock-in roots in the present. We focus on understanding the current state of the system, rather than unearthing the past dynamics that led to the lock-ins.

Analytical framework

We propose an analytical framework aiming at identifying and analysing lock-ins in current situations. It uses the barriers as objects of study and consists of five steps:

1. System boundaries definition & actor mapping,
2. Data collection,
3. Data processing & analysis,
4. Barriers & actors' connection,
5. Data validation.

The analytical framework is grounded in two approaches.

Firstly, lock-ins emerge from the co-evolution and interactions between elements of diverse nature, e.g., political, material (Conti et al., 2021). Understanding a locked-in system thus requires grasping all or most of these elements as well as their interlinkages. Therefore, it entails a systemic approach, i.e., an analysis method opposed to reductionism, considering all constituent parts of a system.

We mobilize the systemic approach by (i) looking at a multiplicity of actors and of barrier types, and (ii) going beyond the identification of barriers and considering also the interactions between them.

Secondly, we consider the actors of a system as the gateway to understanding barriers. Grounded in participatory approach, a multiplicity of actors is involved various steps of the research process. Besides being research partners, actors also are a research object, as understanding lock-ins also entails looking at the dynamics between these actors and between these actors and the identified barriers.

Discussion and Perspectives

The framework we propose differs from previous works about lock-ins in agrifood systems by its operability and its strong embedment in participatory and systemic approaches. This posture forces us to limit the boundaries of the systems studied, unlike other authors (e.g., Simoens et al., 2022). Because it is anchored in the present, our framework also lacks dynamism. However, it enables us to study lock-ins more concretely, and to progress towards their resolution. In our opinion, both approaches are complementary, as the meta-analysis of lock-ins to agrifood systems alone, without consideration for the specific actors responsible for the lock-ins and the current blockages as perceived by the actors of the system (e.g., Conti et al., 2021), is not enough to move forward the transition of agrifood systems through levers.

This dual contribution will help advance the study of lock-ins and foster a more comprehensive understanding of their mechanisms. It will also be the basis for the development of conceptual and analytical frameworks about levers, i.e., actions to undertake to resolve the lock-ins. Finally, it is an open call to reflect together about lock-ins in agrifood systems transition.

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Barriers and levers to implementation of crop-livestock integration practices: a case study in guadeloupe

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Keywords: mixed crop-livestock systems, socio-technical lock-ins, recommendations, tropics, Caribbean

Introduction

Conventional agriculture, based on specialization of production and the use of synthetic inputs, is increasingly being questioned due to its negative impacts on the environment. Contemporary agriculture must offer solutions to prevent these negative impacts or even correct the imbalances. Mixed crop-livestock systems (MCLS) that exploit the synergies between plant and animal species, also called crop-livestock integration (CLI), are positioned as an alternative to increase food production on a global scale and enhance system performance. CLI consists of practices mainly revolving around the use of products and by-products from crops to feed livestock, using animal manure to fertilize crops, and utilizing animals for draft power. Organic farming was introduced very late in the overseas departments and regions (DROM), and unlike some plant-based productions, organic livestock farming struggles to develop. Guadeloupe, due to its insularity and tropical climate, is considered a laboratory for analyzing climate change in the context of agroecological transition. Indeed, while 80% of Guadeloupean farm consists of MCLS farms, a low level of CLI is observed on the territory (Fanchone et al., 2020), with most Guadeloupean MCLSs being mainly segregated. A majority of farms developing CLI are rooted in traditional agroecological knowledge (small family farming). However, small family farming is recognized as the main driver of a deep agroecological transition. We hypothesize that small family farming constitutes an innovation niche for the development of CLI. These niches can become resources for a process of unlocking agriculture in the DROM, in a hybridization with the dominant sociotechnical regime (Schot and Geels, 2008).

The goal of this study is to better understand the agronomic and socio-economic processes that underlie the implementation of CLI in Guadeloupean, by identifying the barriers to the development of these practices, especially in organic farms.

Materials and Methods

We used the methodology proposed by Casagrande et al. (2023) to analyze sociotechnical systems. This method consists of 5 interconnected steps: (i) defining the system to study, (ii) mapping the stakeholders and existing technologies, (iii) understanding the determinants of stakeholders' practices related to the identified practices, (iv) characterizing the barriers and levers to innovation, (v) sharing the diagnosis. These steps were carried out by mobilizing CLI practice experts, conducting surveys with various stakeholders, and analyzing scientific and grey literature. Two workshops carried out with 5 experts of Guadeloupian agriculture enable us to propose a first collective definition of the field of innovation, and the main stakeholders involved in CLI practices. 32 semi-directive interviews (including 7 with farmers) allowed to determine the strategies and constraints of each type of stakeholder. The synthesis of all the data collected on the strategies and constraints of the various stakeholders makes it possible to build a systemic vision of the brakes to innovation, and to identify the self-reinforcing mechanisms between them that lead to a lock-in of the socio-technical system.

Results and discussion

The interviews with the key stakeholders identified by the panel of experts emphasized several brakes that were mentioned at different frequency depending position in relation to CLI practices.

The main barriers are:

- **Lack of knowledge about CLI practices:** Farmers are unaware of how to formulate rations based on local resources, or the appropriate dosages for supplements and organic amendments.
- **Lack of organization among stakeholders:** Stakeholders report difficulties in building a value chain around CLI practices, particularly sourcing locally or differentiating their products.
- **Work organization difficulties:** Farmers are reluctant to delegate work with animals and find CLI practices too labor-intensive.
- **Lack of appropriate equipment:** Most CLI practices are manual, and machinery developers struggle to create equipment for these markets, which they find too narrow.
- **Inadequate public policies and funding:** Few public policies focused on agroecological practices explicitly mention CLI practices.

Some of these barriers can be directly addressed. For example, according to the stakeholders, the inefficiency of technical sheets and technical days could be addressed through peer-to-peer training to compensate for the lack of knowledge about CLI.

Other barriers are interlinked and form lock-ins. For example, local public policies no longer wish to fund agricultural machinery in Guadeloupe, considering that there are already enough, even though they are mainly oriented toward export crops. As a result, farmers find few funding sources to acquire small, adapted mechanization to reduce the labor intensity of implementing CLI practices.

Conclusion and perspectives

This work highlighted the presence of a dominant sociotechnical system around conventional practices of feeding animals with imported concentrated feed and fertilizing with mineral fertilizers. The stakeholders in the dominant sociotechnical system share common goals, vision, norms, and rules. The presence of this system limits the deployment of CLI despite its potential to address the challenges of agroecological transition. The method presented here could be used for different issues, such as barriers to the deployment of local breeds (with small populations).

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Exploring the role of agricultural landscape objects for socio-technical system visualization

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Keywords: Agricultural landscapes dynamics, Object-oriented visualization, Socio-technical system modeling, Geoagronomy

Introduction

The study of agricultural landscapes reveals multifold interactions among human activities, technologies, and the environment. These interactions design landscape objects that serve as spatial manifestations of agricultural socio-technical systems. According to Geel (2004), a sociotechnical system is a set of interconnected, heterogeneous elements, such as resources, artefacts, knowledge, actors and institutions, that fulfil a specific societal function, such as food production. Landscape objects, as Antrop (2005) suggests, are spatially discernible elements resulting from a combination of natural processes and human activities, reflecting farming practices, management choices, and technological developments (Sklenicka et al., 2009). Examples include cultivated fields, livestock facilities, and runoff management structures. Deffontaines (2004) refined the definition drawing upon farmers' views on these objects, making explicit the role of farming practices in their ontology and establishing them as tools for visualizing complex socio-technical interactions in agricultural landscapes. However, most studies on agricultural landscape dynamics leave the definition of these objects implicit. This review explores how spatial objects are defined and used within scientific literature for visualizing socio-technical systems, aiming to improve understanding and modelling of farming systems. By 'visualization', we refer specifically to the spatial representation of interactions that shape these systems.

Methods

We conducted a scoping review to examine how the term "object" relates to agricultural socio-technical systems in scientific literature. Initially, we tested search queries in Google Scholar combining terms like "objects" and "agricultural landscape" or "agricultural space"---and the French equivalent terms---to gain a topic overview and refine keywords. Then, we searched Web of Science "Core collections" (all editions) retrieving 1066 documents (1988--2025) on March 6, 2025, using the query "Object" and "Agricultural landscape". We screened this literature body to keep studies that: (i) explicitly deal with landscape objects in agricultural contexts, (ii) address landscapes' socio-technical dimensions by examining how social practices and spatial objects mutually shape each other through stakeholder engagement, knowledge integration, or policy analysis, and (iii) discuss methods for visualizing socio-technical systems. Studies focusing solely on biophysical aspects without considering social factors, were excluded. Sixty-two studies were selected for an inductive, iterative analysis of the full texts, which allowed us to identify how landscape objects are defined and used.

Results

The Role of Landscape Objects in Visualizing Socio-Technical Systems

The early results of the literature review reveal four main roles of landscape objects in visualizing socio-technical systems (Figure 1), illustrated below through selected examples.

Interfaces between technical and social systems. Dimopoulos and Kizos (2020) used object-oriented image analysis to integrate historical events and land use changes, interpreted through stakeholder insights, enhancing understanding of local adaptations to external pressures. Tarolli et al. (2014) interpret a specific object, terraces, as visible evidence of the dynamic interaction between human needs and the environmental management techniques developed by local communities.

Spatialization of changes and processes. For instance, Marignani et al. (2008) employed landscape objects in retrospective data analysis to compare past ecosystem configurations, to address historical land-use changes integrating information on ecological, spatial, and temporal issues.

Support for ecosystem services. Steingröver et al. (2010) demonstrate how green-blue networks serve as spatial objects linking conservation and landscape development, and how stakeholders use them to inform multifunctional landscape management strategies.

Mediation between perceptions and biophysical reality. Zhou et al. (2023) focus on agricultural terraces to develop a matrix combining objective visual sensitivity data with subjective aesthetic preferences, to prioritize landscape improvement areas.

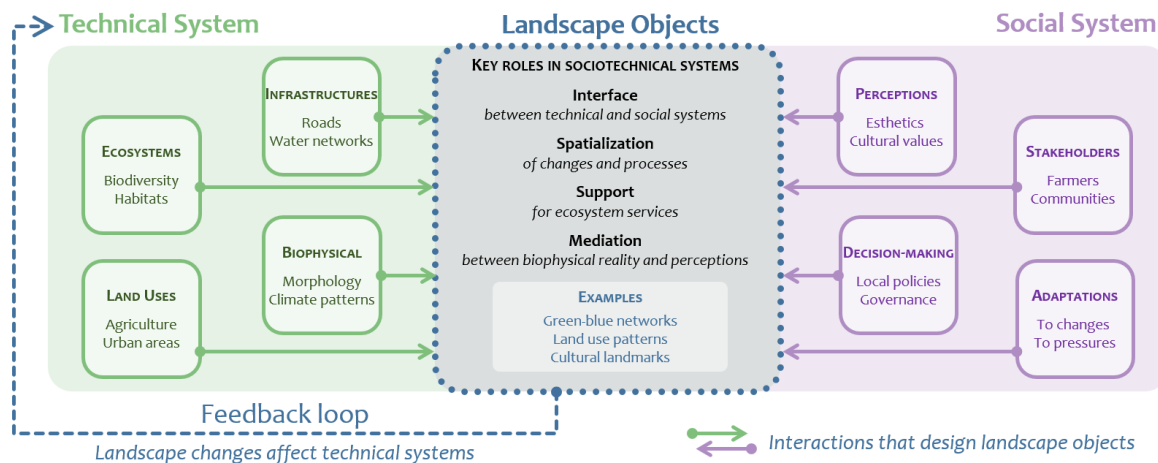


Figure 1. Landscape objects' roles in visualizing socio-technical systems and landscape dynamics.

Discussion and Perspectives

This work explores how agricultural landscape objects facilitate the visualization of socio-technical systems. We identified four main roles ranging from static descriptions, such as interfaces, and supports for spatializations of change or ecosystem services, to dynamic mediation of different perceptions. The review could be expanded to include alternative keywording of "object" such as relevant adjectives (e.g., intermediary, boundary, transactional) or study-specific terms (e.g., structures, components). A systematic semantic comparison of how research addresses these objects would further enhance our understanding of the interplay between visible landscape features and invisible farming practices. Such insights would inform the development of an agent-based model that simulates the influence of intermediate actors and policies on crop choice configurations.

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Comparative prioritization of sustainable agriculture policy targets: a multi-country analytic hierarchy process in North African living labs

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Keywords: Agroecology, Living Labs, Sustainable agriculture, Policy measures

Introduction

Sustainable agricultural practices are crucial for environmental conservation, resource efficiency, and long-term food security, especially given the increasing global challenges posed by climate change, water scarcity, land degradation, and socio-economic shifts that threaten agricultural resilience. North Africa is one of the most affected regions (FAO, 2022; Schilling et al., 2020), where food security is at risk (Abou Zaki et al., 2022; Mesgaran et al., 2017). Population growth and demand for water for agricultural activities are estimated to increase nearly five-times by 2050 (Awaad et al., 2020; Bahn et al., 2021). Therefore, there is a critical need for comprehensive policy frameworks that address these challenges. However, existing policy frameworks in North African countries often lack coherence (Jalk et al., 2024) and fail to effectively integrate the diverse policy criteria that impact agricultural sustainability and resilience (Barasa et al., 2021). As a result, improving the utilization of sustainable agricultural practices remains tricky without clear, prioritized policy targets that address these interdependencies. Farmers face challenges such as land ownership, economic pressures, societal demand for provision of ecosystem services, and water security, all of which affect the path of agricultural sustainability (Biarnès et al., 2021). While some of these challenges have been studied independently, there remains a notable gap in understanding how they collectively influence the prioritization of sustainable agriculture and resilience policy targets across the region. To address this gap, this study examines stakeholder perspectives on policy measures promoting sustainability across seven living labs (LLs) in the North African countries (Algeria, Egypt, Morocco, Mauritania, and Tunisia). Therefore, this study aims to uncover the following research question:

How can policy measures, which foster resilient agricultural systems, effectively be prioritized and integrated coherently into policy frameworks?

As a result, synergies and trade-offs shall be identified, and optimal agro ecological policy strategies shall be derived.

Data and Methodology

Data was collected through a questionnaire distributed across the seven LLs. Stakeholders including farmers and advisors from fields such as agriculture, environment, finance and irrigation evaluated key policy criteria, including land ownership, education and training, economic measures, water management, traditional practices, and cropping practices, using a 5-point Likert scale. Sociodemographic data was collected to control for potential biases. The Analytic Hierarchy Process (AHP) is a structured method that uses a hierarchy and mathematical analysis to prioritize multiple conflicting criteria in complex decisions (Saaty, 1980). The AHP was applied separately to each country's dataset, generating pairwise comparisons from aggregated responses. This country-specific approach enabled the

derivation of relative priority weights for each policy area, facilitating a comparative analysis of stakeholder preferences across diverse regional contexts.

Results

The survey results revealed both shared priorities and distinct differences across the LLS, offer valuable insights for tailoring sustainable agriculture policies to local needs. In Algeria, community-level water governance emerged as the main policy priority (61.9%), highlighting the urgent need to address water scarcity. This was followed by support for farmers on rented land (58.5%), reinforcement of traditional farming practices (57.1%), reliable local seed systems (47.1%), external consulting and technical support (37%), compensation for ecosystem services (31%), market access (29.3%), and price premiums for sustainable products (27.6%). These results emphasised a joint regional focus.

The survey also indicated distinct priorities across the LLS: Algeria is focused on restoring oasis ecosystems and pastoral systems; Egypt emphasizes improving irrigation efficiency; Morocco prioritizes the promotion of organic farming and market access for smallholders; Mauritania concentrates on dryland adaptation strategies and rainwater harvesting initiatives; while Tunisia is investing in youth engagement in agriculture and strengthening agricultural value chain.

Discussion and Perspectives

The findings emphasise policy should target external consultation and dissemination of agro ecological practices, coordinated investment in water governance, seed sovereignty and fair farmer compensation as a crucial factor, as well as a robust land ownership and tenure system. Policy design should integrate both time-tested methods with traditional knowledge, aligning with Requier-Desjardins et al., (2024) findings.

Furthermore, policy co-create should consider local contexts, diversity of farming system and inclusiveness in crafting environment sustainability policies, ensuring that incentives align with landownership structures and that extension services and education programs are accessible to all stakeholders. AHP enables evidence-based, multi-criteria prioritization, guiding inclusive and locally grounded agro ecological policymaking.

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Lock-in to orchard diversification as seen by farmers and downstream stakeholders, case study of the mid-Rhône valley, France

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Keywords: diversification, fruit production, downstream, systemic lock-in

Introduction

Most European specialised orchards require intensive chemical protection against a range of pests, which is not sustainable: impacts on the environment and human health (e.g., Carvalho, 2017), pest resistance to pesticides, and bottlenecks when some toxic compounds are banned. Agroecosystem diversification is a way of fostering ecosystem services, in particular pest regulation, and reducing reliance on pesticide use (Vialatte et al., 2025). But the transition is not easy for monovarietal orchards, whose design was shaped when pesticides were widely available.

A highly-diversified orchard has been experimented for 8 years at INRAE Gotheron experimental station (South-eastern France) to try to produce fruit without pesticides (Simon et al., 2025). What are the conditions for developing such diversified orchards on local farms? Diversification targeting the reduction of pesticide use entails several changes at plot and farm levels (species, cultivars, spatial arrangement, practices, work organization etc.) but also upstream and downstream (Meynard et al., 2017): greater diversity and new types of fruit to market, potential lower aesthetic quality, etc. Marketing was identified in arable crops as a major barrier to crop diversification (Meynard et al., 2018). The aim of this study was therefore to analyse the obstacles and levers perceived by farmers and downstream stakeholders in the management of such diversified orchards and the resulting products, using the mid-Rhône valley, a region historically dedicated to fruit production, as a case study.

Methods

A survey was carried out in 2024 (Bianco, 2024) among farmers and downstream stakeholders in south-east France. Twenty stakeholders potentially impacted by orchard diversification were interviewed, including 10 orchardists, 2 cooperative representatives, 3 fruit processors, 3 sellers and 2 wholesalers. The diversity of profiles was favoured over their representativeness. The semi-structured interviews led the participants to discuss, on the basis of the highly-diversified orchard in Gotheron, (i) their own context, (ii) the implications of orchard diversification for their activity, and (iii) their perception of the potential for scaling up such orchards within the territory. The interviews were recorded and transcribed. All interview verbatims were analysed using an inductive analysis grid based on a few first interviews. It enabled to identify common and specific obstacles and levers for each stakeholder.

Results

What hinders or reinforce the ability of the stakeholders interviewed to adopt diversified orchards or to market products from diversified orchards? Farmers mentioned 110 obstacles and 140 levers, while downstream stakeholders cited 74 obstacles and 91 levers. Some of them were specific to the production activity (e.g., finding plant material for a new species) or to marketing activity (e.g., market competition), while others were commonly cited (e.g., economies of scale and minimum volumes per species). All downstream stakeholders

identified obstacles and levers linked to coordination between farmers and downstream, cultivar choices, the number of farmers supplying a buyer, prices, fruit volumes, maturity, storage and conservation, as well as education and communication. Purchasing criteria on fruit aesthetic quality and downstream requirements accounted for over a third of the obstacles and levers cited by downstream stakeholders. Some specificities were identified (Figure 1) according to the channel (fresh or processed fruit, short or long-channels). Short channels presented the fewest obstacles to the distribution of fruit from diversified orchards. In contrast, long distribution channels for fresh fruit displayed a range of interconnected obstacles, and in particular due to the high requirements of supermarkets on aesthetic qualities.

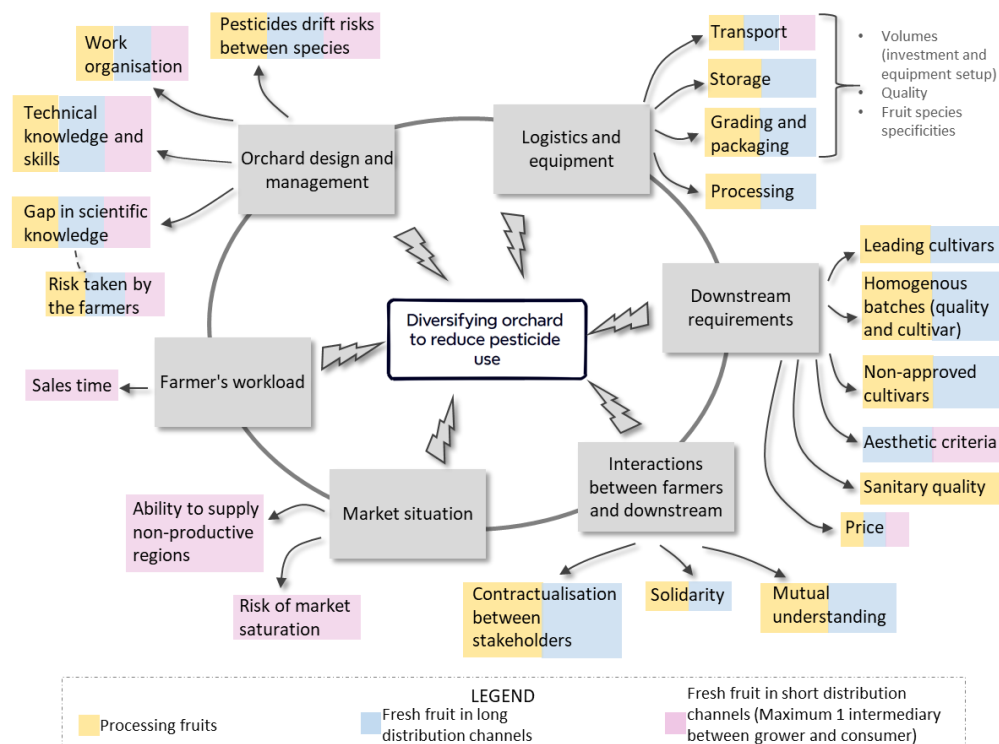


Figure 1: Main interconnected obstacles to the diversification of orchards cited by 20 respondents

The results also showed main levers:

- Designing an orchard that optimizes ergonomics and prevents pesticide drift between species,
- Sharing farmers' economic risks of crop diversification within the food chain and supporting diversification through public policies,
- Stronger coordination between stakeholders to (i) foster inter-knowledge and consideration of each other's constraints in order to reduce power imbalances between farmers and wholesalers, and (ii) organize the pooling of volumes or share processing and sales tools in order to achieve economies of scale.
- Developing fruit processing for marketing fruit with aesthetic defaults despite it raises the question of the profitability for farmers.

Discussion and perspectives

Our results overlap with those on sociotechnical diagnoses carried out on other crops and French territories. Meynard et al. (2018) highlighted the logistical constraints related to crop

diversification and the need for coordination between stakeholders. Boulestreau et al. (2021) showed that the deployment of agroecological alternatives for managing vegetable soil pests is constrained by the lack of knowledge, as in our case study. We identified specific obstacles related to orchards, namely severe downstream requirements for fresh fruits, heavy planting investment and delayed fruit production after planting, which increases the farmers' economic risk, that are similar to results from Hirson-Sagalyn et al. (2024) on apple production in a neighbouring area. More generally, our results on the lock-in from long channels largely echo to previous studies on arable and vegetable crops (e.g., Meynard et al., 2018; Boulestreau et al., 2021).

As the number of interviews was limited, stakeholders such as large wholesalers and mass caterers were missing, and representativeness in relation to the territory was not fully achieved. In addition, the three studied channels could be more accurately characterised, in particular by using the framework of proximity dimensions (Angeon and Fréguin-Gresh, 2022). However, this analysis of the obstacles to orchard diversification can be used to draw up specifications to design diversified orchards that are both ecologically efficient and commercially viable, thanks to coupled innovations (Meynard et al., 2017).

Acknowledgements

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When politics interfere with co-design approach: the case study of herbicide reduction in la reunion island

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Keywords: herbicides, territorial, weed management, lock-in

Introduction

The use of herbicides on La Réunion Island has been associated with significant degradation of water quality, as shown by more than a decade of monitoring in rivers (Martin et al., 2013). Pesticide residues, including glyphosate, 2,4-D, and metolachlor, have been repeatedly detected in surface waters. These findings highlight both the spatial extent (multiple watersheds) and temporal persistence (over 10 years) of herbicide-related pollution in La Réunion Island.

In response, agroecological transition efforts have called for rethinking weed management strategies in ways that better integrate environmental constraints at the territorial scale. Among these, co-design approaches, such as the one proposed by Della Rossa et al. (2022), aim to foster systemic changes in agricultural systems by mobilizing local knowledges, scientific expertise, and stakeholder engagement.

However, while research can play a critical role in revealing environmental risks and facilitating innovation, we expect that it cannot, by itself, trigger transitions if broader political and institutional conditions remain misaligned. This study therefore presents not just a methodological innovation, but the limits of participatory design when confronted with political agendas that actively resist change.

Methods

The study was conducted in the Ravine Charrié and Ravine du Pont watershed (Petite-Île, La Réunion, France) between 2021 and 2024. Our co-design method at the territorial scale was structured around the methodology proposed by Della Rossa et al. (2022), which includes four main steps:

1. Problem framing based on scientific evidence,
2. Building a shared representation of the issue among local stakeholders,
3. Exploring alternative farming practices, and
4. Co-evaluating design pathways.

To support the problem framing, in accordance with the local politics, we implemented a water quality monitoring system composed of three fixed hydrologic stations located along the main stream of the watershed. These stations served as sampling points for weekly pesticide residue analyses, adapted from Mottes et al. (2020). The pesticide residue data were used both as a scientific justification for change and as a contextual input during the co-design sessions.

Once the first year of data also showed herbicides as the main contributors of pesticide pollution in water, we used the ARDI (Actors, Resources, Dynamics and Interactions) method (Étienne, 2009) from the companion modelling approach to conduct a participatory modelling process. Because the participatory method cannot be used as is by large groups of

stakeholders, we split the work into four groups of stakeholders (farmers, agricultural advisors, territorial institutions, and researchers) who developed their own representation of weed management because this is the source of herbicide pollution. These representations described key actors, resources, constraints, and interactions specific to each group's perspective. These were then merged into a single shared representation through cross-group workshops.

This shared representation formed the basis for a territorial innovation process guided by C-K (Concept-Knowledge) theory (Agogu   et al., 2013), where conceptual alternatives to current weed management systems were explored collaboratively.

Results

Between 2021 and 2024, we collected 474 water samples from the monitoring stations, resulting in 787 individual pesticides detections, corresponding to multiple active substances per sample. Among these, 59 concentrations exceeded European threshold for drinking water. Herbicides represented 92% of all detections, with glyphosate and its degradation product AMPA (Aminomethylphosphonic acid), consistently found at all stations. We also identified metolachlor and 2,4D at elevated concentrations, especially at the outlet of the watershed. These findings that highlight the major contribution of herbicide use to water contamination in the study area were shared with the stakeholders.

In each of the four stakeholder representation of weed management, five common themes emerged: weeding techniques, labour, marketing, financing constraints, and regulation and policy which integrated the shared representation (Figure 1). Specific themes, such as marketing, were detailed separately.

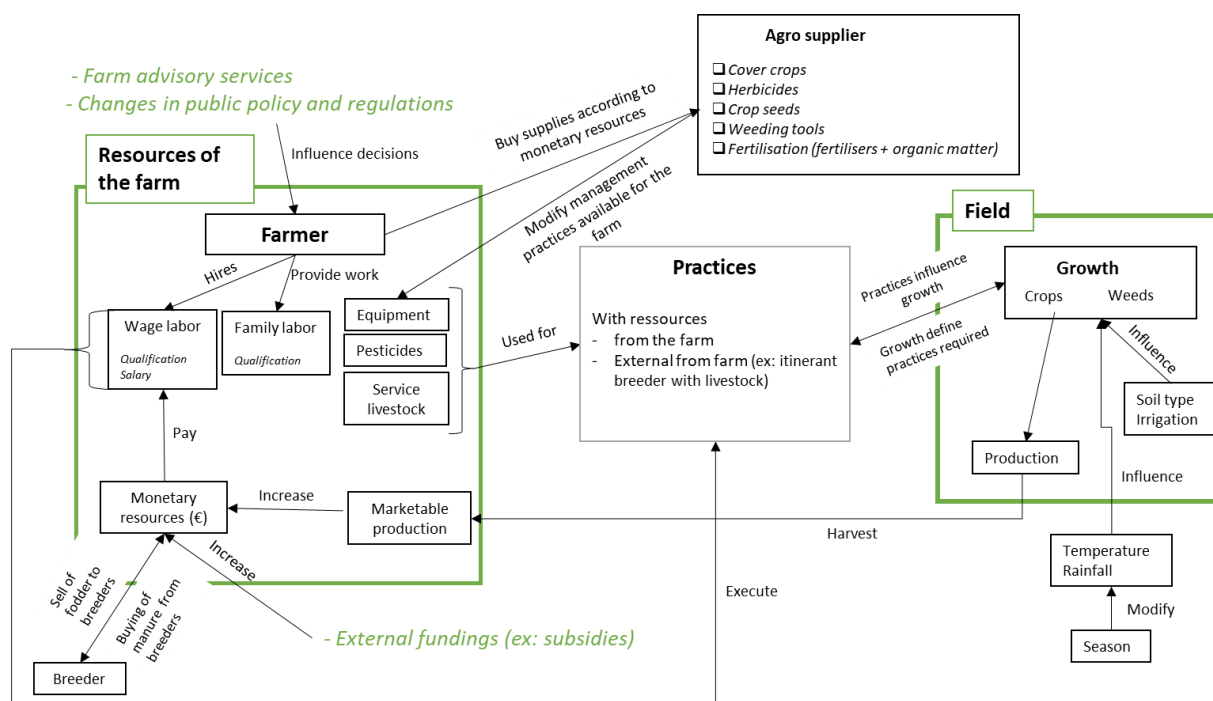


Figure 1. Shared representation of weed management practices built by local stakeholders (adapted and simplified for publication)

Although regulations and policy mechanisms were included in the shared representation, political dynamics were not explicitly addressed by participants. Likely because they were seen as outside their sphere of influence. In practice, however, political actors significantly disrupted

the process of collective exploration of alternative farming practices. Despite they initially endorsed the co-design approach and acknowledged the pollution problem, they later defended herbicide use and sought a derogation for an herbicide used for sugar cane at the national level. They postponed and constrained workshops activities until this derogation was granted, leading to frustration and confusion among other stakeholders, who perceived the process as stalled or strategically blocked.

Discussion and Perspectives

The co-design process led to a shared representation of weed management among stakeholders, grounded in both field data and local knowledge. However, the transition to actions was disrupted by political interferences: although political actors formally supported the initiative at first, they later opposed the outcomes by defending herbicide use and seeking national derogations. Their absence from the workshops, followed by their interference, exposed a gap between participatory intentions and local governance. This raised important questions about how co-design approaches should be adapted to politically sensitive contexts and highlights that an underestimation of misalignments between research design and political dynamics can lead to an interruption of such process. This could be linked to behavioural lock-in as pointed out by Hüesker and Lepenies (2022). This case echoes past failures in France --such as the chlordecane crisis--- where scientific insights were not integrated into policy (Fintz, 2009) and underlines once again the need for closer alignment between scientific and political action, especially in contested environmental transitions.

In order to continue our work and bounce back, we started another approach through the estimation of environmental costs of pesticide use on the scale of La Reunion, and comparing them with local farm incomes. We hope that using a shared indicator to represent the impacts of the current farming systems will be entry point for renewed dialogue, though its effectiveness will depend on whether stakeholders accept this indicator and local politics support further investigations with the farmers.

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Coupling innovations between on-farm crop diversification and downstream marketing strategies in fruit and vegetable systems

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Keywords: coupled innovation, fruit and vegetables, marketing, crop diversification

Introduction

As current farming practices are causing damage to both ecosystem and human health, more sustainable agrifood systems are expected. In Europe, since the 50's, farming areas have become largely specialized in a limited number of species. This specialization disconnected areas of production and consumption, requiring the development of longer distribution channels. And yet, crop diversification is a relevant lever for making agroecosystems more sustainable (Vialatte et al., 2025) and increasing food sovereignty with a higher potential to relocate food (Marzin et al., 2021).

Nevertheless, crop diversification comes up against several obstacles, which are particularly tricky in the fruit and vegetable (F&V) sector and in large farms engaged in long channels (Alaphilippe et al., 2021). These farms have to produce large volumes of homogeneous products to satisfy national or export distributors who have built their organization on economies of scale. This is difficult to reconcile with crop diversification, which reduces the volumes per species produced per farm (Boulestreau et al., 2023). Overcoming systemic lock-in on crop diversification requires the design of coupled innovations at agrifood system level (Meynard et al., 2017; Boulestreau et al., 2023). This concept refers to innovations designed in a coordinated way, even though they belong to fields of innovation generally managed by different actors and independently. During a coupled innovation process, technical, organizational, institutional and/or social innovations are coherently combined to solve a complex problem and/or contribute to unlocking socio-technical systems (<https://dicoagroecologie.fr/>).

Literature on the ways to overcome brakes to crop diversification with coupled innovation is scarce in the F&V sector (Boulestreau et al., 2023). Our aim was to draw generic learnings on the topic, with a focus on commercial outlets, which are a major brake.

Methods: a cross-case analysis of contrasting empirical studies

We compared five French F&V case studies that offer complementary ways of supporting crop diversification. We hypothesized that the coupled innovations linking farming and marketing activities in agrifood systems depend on the types of downstream actors involved (cooperatives, local or national private sellers, national distributors, fruit processors, collective catering) and on what is targeted with crop diversification (increasing ecological regulations, reducing economic and climatic risks, securing fruit processing, improving food sovereignty in an isolated territory). We carried out a cross-analysis of the qualitative data collected through surveys and/or workshops (actors' strategies, brakes to crop diversification, room for manoeuvre to change). We looked for generic lessons by comparing the five case studies (Table 1).

Results

Both conceptual and operational results are provided.

(i) Common brakes and lock-in processes have been identified. One of the main difficulties for farmers was that increasing the number of crops grown on a fixed farm area alters the characteristics of production (types of products, marketable volumes per species, harvest dates, qualities, etc.). Farmers involved in long marketing channels indicated that this weakened their bargaining power with downstream actors, and also conflicted with the current commercial standards of distributors or processors.

(ii) To cope with these new production characteristics, coupled innovations have been designed, combining new crop diversification patterns (number of species cropped and their arrangement) with economic, social and organisational innovations: coordination between farmers to transport small quantities of each species and produce larger batches acceptable to distributors or processors, creation of local plants to wash and cut F&V for canteens, adaptation of processing plants to the greater variability due to crop diversification, etc.

Discussion

Our results highlight on how crop characteristics, diversification schemes, downstream actors (fresh/processing, local/national, private/public actors) influence innovations to support crop diversification. They all call for collective action and consideration of power games for effective coupled innovation. The main limitations of the study stem from the limited number of case studies, which will require further validation. A comparison with sectors other than F&V would be useful to develop more generic knowledge. However, this study represents a first step in the search for new ways to support crop diversification, the beneficial effects of which no longer need to be demonstrated.

Case study	System under study	Targets for diversification	Fresh (F) or Processed (P) outlets	Innovations coupled to favor crop diversification (built B or in progress IP)
Interlude project	Market-gardening (South-East France)	Manage soil pests and diseases and lower pesticide use	F	B: Equipment or land exchange between farmers; logistics for transporting vegetables from farms to sellers marketing innovations to support consumption of rarely cooked vegetables (boxes with mixed vegetables)
Be Creative project	Orchards (South-East France)	Optimize ecological regulations to crop fruits without pesticides	F+P	IP: new outlets (collective catering, artisanal processing), complementarity between fresh and processed outlets, mutualisation of fruit batches between farmers, logistics for transporting fruits from farms to sellers
Diveract project	Orchards (South-West France)	Design innovative fruit processing to support crop diversification	P	B: Design of a diversified orchard specifically intended for processing
PhD Thesis	Orchards (South-East)	Increase ecological	P	IP: Innovative transformation of a mixture of different varieties or species in a processing

	France)	regulations, reduce economic and climatic risks, secure fruit processing		facility
Territoires Durables project	F&V (Martinique, French Antilles)	Improve food sovereignty of an island	F+P	IP: Organisation between farmers, schools and institutions to aggregate produce and align production with collective catering criteria; innovation in processing facilities, public incentives

Table 1. Five French case studies exploring the relationships between crop diversification and downstream channel strategies

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Novel cooperation mechanisms for crop-livestock integration in china -- a network of 10 experimental integrated crop-livestock systems

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Keywords: Farming Systems, Manure, Resource Use Efficiency, Nutrient Use Efficiency

Introduction

China's rising animal-source food consumption has driven livestock sector expansion, causing spatial decoupling of crop-livestock systems and disrupting traditional nutrient cycles (Bai et al., 2018). Recent policies and research attempt to address these challenges but lack experimental validation in implementing integrated crop-livestock systems (ICLS) (Wei et al., 2021; Hou et al., 2021), manure and feed management, and nutrient recycling.

A network of 10 experimental ICLS across China was established to: (1) explore sustainable ICLS configurations, (2) develop best management practices, and (3) demonstrate economically attractive, socially acceptable, and environmentally sound ICLS. This study aims to characterize novel cooperation mechanisms and evaluate nutrient use efficiency across different integration models.

Methods and Results

1. System Distribution

We developed a framework identifying three ICLS types reflecting current Chinese agricultural systems:

1. **On-Farm Integrated Crop-Livestock System (OFICLS):** Spatially and temporally integrated within single farms, including livestock housing, manure management, cropland, and feed production subsystems.
2. **Inter-Farm Crop-Livestock Cooperative System (ICLCS):** Autonomous crop and livestock farms collaborating through formal agreements or verbal arrangements, with shared decision-making and coordinated resource flows.
3. **Third-Party Mediated Integration (TMICLS):** Multiple independent farms coordinated by third parties responsible for centralized manure collection, processing, and distribution.

Currently, the network has 10 ICLS, which includes 8 ICLCS, 1 TMICLS, and 1 OFICLS systems across varied agroecological zones, demonstrating cooperation mechanism diversity.

2. Nutrient Flow Analysis (two case studies)

Quzhou ICLCS: External N input 2,319 kg N·ha⁻¹·yr⁻¹, with 31.7% nitrogen use efficiency (NUE) and 13.0% phosphorus use efficiency (PUE). Total losses: 57.9% N and 18.7% P input. Manure storage contributed 47.7% of N losses and 67.4% of P losses.

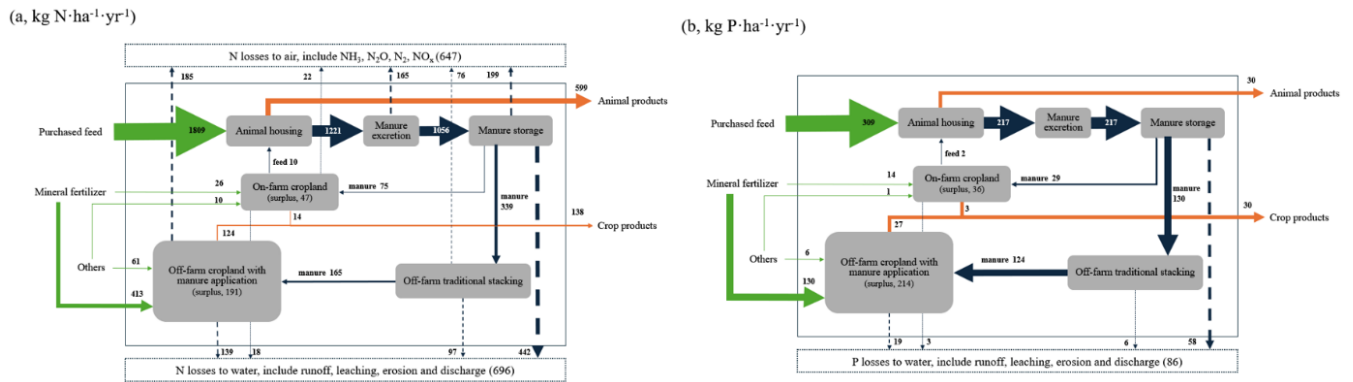


Figure 1 N (a) and P (b) flows in ICLCS of Quzhou ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). Green arrows: inputs (feed, fertilizers, other sources); Orange arrows: outputs (animal/crop products); Dark blue dashed arrows: system losses; Dark blue solid arrows: internal cycling.

Erhai TMICLS: External N input $501 \text{ kg N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$, achieving 29.1% NUE and 25.9% PUE. Total losses: 51.1% N and 17.5% P input. Manure storage accounted for 59.8% of N losses and 68% of P losses.

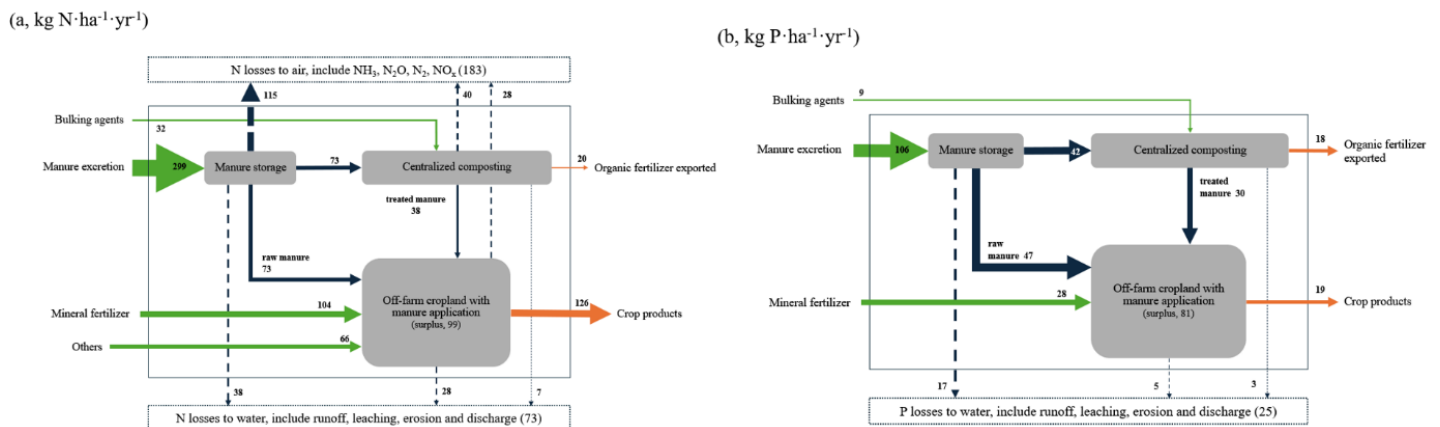


Figure 2 N (a) and P (b) flows in TMICLS of Erhai ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). Green arrows: inputs (manure, fertilizers); Orange arrows: outputs (animal/crop products); Dark blue dashed arrows: system losses; Dark blue solid arrows: internal cycling.

Discussion and perspectives

Both systems show NUE within China's typical range (20-40%) (Chen et al., 2023), but Quzhou's PUE (13%) falls below the national average (22%), while Erhai exceeds it (25.9%). The TMICLS demonstrates more effective nutrient recycling despite similar NUE, suggesting better balanced input-output relationships and potentially more sustainable long-term management.

Compared to global well-managed farming systems reporting up to 72% PUE (Chowdhury & Zhang, 2021), both Chinese systems show significant improvement potential. Key limiting factors include insufficient internal nutrient recycling and high losses during manure storage, the dominant loss pathway across systems.

The cooperation mechanisms reveal trade-offs: ICLCS offers better traceability but requires intensive coordination, while TMICLS enables regional-scale integration but complicates nutrient flow tracking. These findings support ongoing policy debates in China regarding optimal integration scales and management approaches.

This network represents the first systematic attempt to characterize cooperation mechanism diversity in Chinese ICLS. Long-term monitoring will provide comprehensive economic, agronomic, and environmental indicators to evaluate sustainability across China's diverse agroecological contexts. Results will inform policy development for agricultural green development and guide scaling up of effective integration models. Due to the network's recent establishment in early 2025, current analysis focuses primarily on feed management, with crop co-products data collection ongoing. Future research priorities include optimizing manure storage and treatment technologies, developing economic incentives for cooperation, and establishing regional nutrient cycling standards tailored to local conditions.

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A mathematical approach to manage fruit diversity and align stakeholder strategies towards diversified orchards

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Keywords: crop diversification, stakeholder constraints, processing, fruit blend mathematical model

Introduction

The world is facing major challenges to ensure both food security and ecosystem resilience. Crop diversification is key in the move towards more sustainable farming and food systems. However, agrifood diversity is no longer determined by upstream production but by downstream actors, i.e. industrial forces (Soler, Réquillart et Trystram 2011). There have been two key consequences: diminished genetic variability and crop specialisation, better suited to processing specifications in terms of efficiency and cost-effectiveness. Today, the food industry's business models, which are based on the standardisation of agricultural raw material, are struggling to cope with climate change and agroecological transition. One solution could be to design agrifood systems that promote crop diversification and favor their economic valorisation. While crop diversification offers many economic and environmental advantages over monoculture (Beillouin et al. 2021), food processing offers significant advantages in terms of food preservation and microbiological safety, as well as minimising agricultural losses (Fellow 2005). But the current organisation of the food systems is a source of sociotechnical lock-in towards crop diversification (Meynard et al. 2018).

The objective of this project is to address the question: "How can the cultivated biodiversity of fruit farms be enhanced through sustainable food processing that can manage this biodiversity?". A participatory approach is currently combined with mathematical modelling to define conditions to design both diversified and resilient orchards and adapted fruit processing scenarios.

Experimental strategy and methods

1. The first step of the strategy is to collect farmers' and processors' constraints to cultivate or process a diversity of fruits. Different methods are used to collect information. A collective survey is scheduled within a processing factory to understand the determinants of quality and each actor's constraints at each step of the organisation (fruit grading, quality analysis, processing, marketing). This knowledge will inform the design of the model in the second step.
2. The second step is to build a mathematical model that enables to describe how to blend fruits to reach a target puree that is marketable by the processor, therefore with specific organoleptic and technological characteristics. The model is based on data from different batches from fresh and processed fruits (up to 19 apple and 9 pear cultivars) over 3 years, each characterized by biochemical and physical properties : sugar, acid, color, Near and Med Infrared, Volatile Organic Compounds, texture (fruit) and viscosity (puree). The aim of the model is to provide combinations of species and cultivars that meet a target puree. In a first step, a toy model was built consisting in a multi-criteria

optimization model on organoleptic and technological characteristics and on a set of stakeholders' constraints.

3. The last step consists in co-designing with farmers and processors coupled innovations combining innovative fruit production and processing methods, using stakeholders' knowledge and the model created.

After presenting the project strategy, this communication will focus on the first two stages of the research work.

Results

We identified blends of fruit purees capable of meeting the target apple or apple and pear puree profile with few criteria (sugar, viscosity, color). A variety of combinations (number and proportion of cultivars) make it possible to achieve the desired purees. A first experimental validation of model predictions is under progress.

Farmers' and processors' constraints and objectives toward fruit diversification were formalized on the basis of their narratives expressed during the collective survey: prioritization of quality criteria, harvest calendar, maximum number of varieties to crop on a farm or include in a blend, storage and maintenance facilities, etc.. This work is ongoing, and strategies for integration into the model are being tested.

The global mathematical model that takes into account both quantitative and qualitative data, with the fruit blend mathematical model at its core, will be a tool for thinking.

Discussion and Perspectives

The originality of this work is to consider the value chain as a whole, integrating farmers and processors to innovate both upstream and downstream to explore how to manage cropped and processed biodiversity.

We managed to build a toy model representing both quantitative data on fruit quality and qualitative stakeholders' constraints. It provides insights that need to be verified against real-world conditions. Indeed, we need to understand the parameters sensitive to diversity in the production-processing-consumption continuum. For example, Cerutti et al. (2013) showed that Golden Delicious is more interesting from a mass point of view than an ancient cultivar, whereas an ancient cultivar seems more ideal from an economic point of view. It is a compromise which encourages to get stakeholders to discuss with each other.

The challenge is then to use the model simulations with stakeholders to search innovations recoupling cropping and processing activities to surmount each stakeholder's brakes in order to favor orchard diversification. This was initiated by Meynard et al. (2018) for on arable crops and by Boulestreau et al. (2023) for fresh vegetables. It requires to combine complementary areas of expertise coming both from scientists (agronomy and food science), and economic stakeholders.

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Insights on the supply of organic and local dairy and beef products to institutional catering by french cattle farms

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Keywords: livestock farming systems, organic farming, agroecological transition, short food supply chains

Introduction

The French dairy and beef organic sectors are confronted to many challenges, including a market crisis since 2021 which has led to a recent decline in the number of certified farms and cattle heads. Against this overall context, the institutional catering sector (IC), has increased its demand for organic products, likely influenced by the French EGalim law (Agence Bio, 2024). IC thus represents a potential opportunity for organic farmers amid the current crisis (Fernandez-Inigo et al., 2022). However, this opportunity remains underutilized by organic dairy and beef farmers (Agence Bio, 2022). The aim of this study was to investigate why and how dairy and/or beef cattle farmers already provide IC with organic and local products, the advantages they find, and the factors that enable or hinder their success.

Methods

We conducted semi-structured interviews with 25 organic cattle farmers supplying IC, from three French regions with contrasting contexts (lowland vs mountainous, peri-urban vs rural areas; Figure 1).

The interview guide, designed for each type of production, was composed of four parts, addressing the following topics: farm structure and management in 2024 and when starting selling to IC; the determinants underlying farm management and the changes made after starting selling to IC; the advantages, drawbacks, barriers and levers associated with selling to IC; and farmers' perspectives on their relationship with IC. All interviews were transcribed and analyzed using grounded theory coding (Glaser & Strauss, 1967). An analytical grid was applied, which included thematic categories corresponding to the four interview topics. Variables and attributes were extracted from the narratives within each category for each farmer, enabling the identification of patterns and variations across the sample

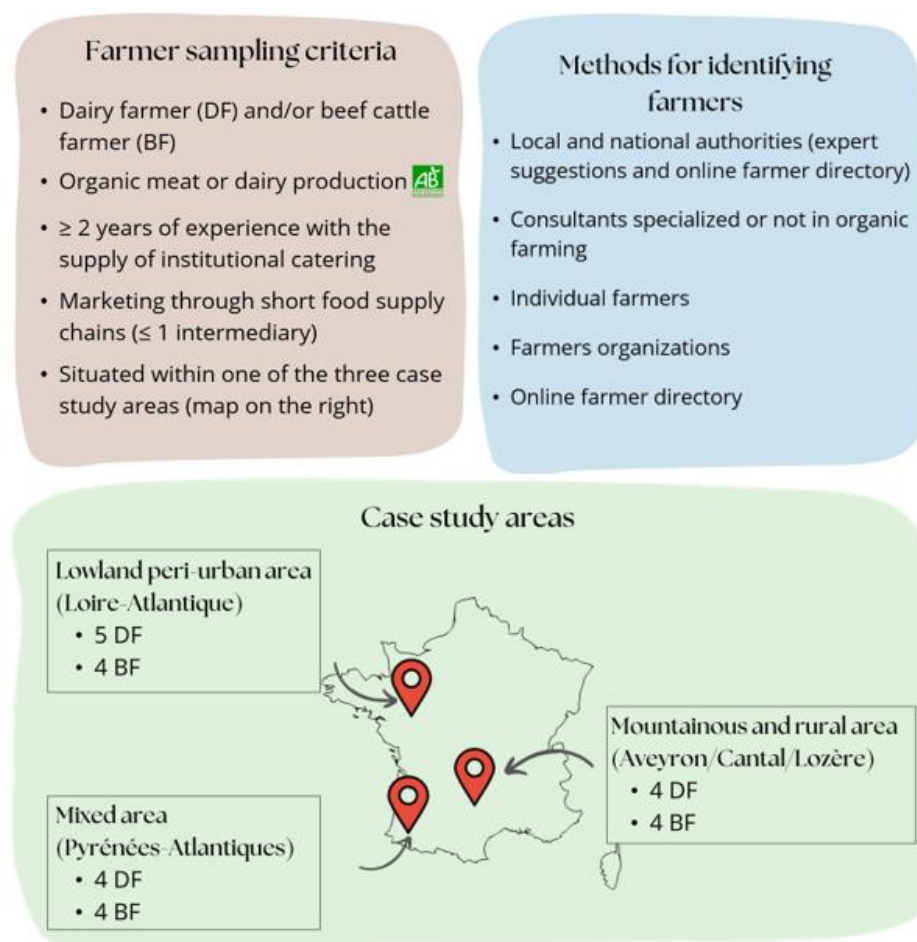


Figure 1. Sampling criteria and methods for identifying dairy and beef cattle farmers (DF and BF, respectively).

Results

Three main reasons were mentioned by both DF and BF for supplying IC: selling larger amounts of products at once compared to direct selling, feeding and educating to support the nourishment of young and vulnerable populations (ex: hospital patients) with healthy products, and ensuring that both their products and production methods are recognized and respected.

The main technical management changes had occurred during the conversion to organic farming rather than after starting to supply IC. Most farmers combined outlets in local and short supply chains, and in long supply chains. This mix of marketing channels emerged as a critical factor for the economic sustainability of the farms. BF usually sold young cattle cheaper cuts to IC. Animals were either fed exclusively with grass or with grass and grain flour. DF supplied IC with yogurts, pudding, cottage cheese and rice pudding. BF usually worked in groups to supply IC, while DF supplied IC individually but belonged to networks providing technical support from production to processing and marketing.

DF and BF faced common challenges. These included difficulties in organizing production and delivery, as some ICs did not adequately anticipate and communicate their needs. Additionally, farmers struggled with responding to calls for tenders when they first began supplying IC. They also expressed a feeling of vulnerability due to the reliance on IC actors' commitment, as there was no obligation for IC to source from farmers. The high turnover of cooks and IC managers further exacerbated this issue, causing demand to fluctuate unexpectedly. Furthermore, farm

location was a significant barrier, particularly for farmers situated far from consumption areas, with unfavorable topography and limited road access to the cities. BF encountered additional challenges related to the planning and logistics of animal slaughter and meat delivery. As IC primarily requires cheaper cuts, BF found hard to value the entire carcass satisfactorily.

Discussion and perspectives

We provide initial insights into the supply of IC from livestock farmers' perspectives, distinguishing our study from most previous research which focused on governance structures and collective dynamics (Lamine et al., 2012) or IC sustainability transitions (Martin et al., 2022). Our findings emphasize that the main changes for successfully supplying IC lay in marketing practices rather than in technical management, highlighting the need to analyze both aspects (Nozières-Petit, 2014). We highlight that farmers' economic sustainability relies on combining IC supply with long supply chains, without accounting for labor and learning costs (Enthoven and Van den Broeck, 2021). The difficulties reported by farmers reflect the substantial demands of "market mediation" (Le Velly, 2017), understood as the diverse adjustments needed to establish and sustain commercial relations. Our findings indicate that this process, which is both time- and labor-intensive for the upstream and downstream actors, is rarely supported by public authorities is predominantly assumed by the farmers themselves, potentially jeopardizing farmers' long-term engagement in these marketing channels. This study reflects farmers' views from a limited sample and area. Future research should broaden the scope and include institutional catering actors' perspectives on the issue.

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The coupled design of innovations between farmers and public catering operators, a lever for agroecological transition

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Keywords: Agrifood system, action logic, institutional food service, territorial impact

Introduction

Coupled innovation design refers to processes in which actors from different sectors of activity coordinate to design innovations (Meynard et al. 2017). The underlying assumption is that if actors share a common transition goal and manage to change together, this will facilitate the design and implementation of agroecologically centered innovations. Thus, this way of designing innovations between the agriculture and food sectors is a research front that could be conducive to agroecological transitions and facilitate work on engineering agroecological food systems.

Public catering is seen as a lever for transition in many territorial food policies in France. In 2024, public catering accounted for around 2.5 billion meals per year (Ministère de l'agriculture et de l'alimentation 2024). Significant amounts of food are purchased through public procurement contracts, which can be directed toward specific production and distribution methods (Fernandez-Inigo et al. 2022). Regulatory targets have been set in the Egalim (2018) and Climate and Resilience (2021) laws to activate this lever. Today, however, these targets are only being met by a minority of catering structures (Ministère de l'agriculture et de l'alimentation 2024). Socio-technical lock-in can explain the difficulties for agroecological innovations to emerge in the value chains (Gaitán-Cremaschi et al. 2022).

This research aims to generate knowledge on coupled innovation design by studying the public catering and agricultural sectors. We investigate how coupled innovation between these sectors is a lever for agroecological transition, by analyzing the features of a coupled design process, the scaling of this kind of design process, and their impacts on sustainability.

Description of the general approach

We carried out a three-axis approach based on two case studies in two contrasting areas of France involving public catering structures and farmers.

The first axis aimed to shed light on the characteristics of a long-term process of coupled design between farmers and public catering actors. To do this, we applied the step-by-step design framework (Meynard et al., 2023) to unravel the process of coupled design between a group of farmers, a logistics service provider, and a local authority in charge of a catering service, focusing on the supply of organic and local potatoes.

The second axis aimed to identify the characteristics of an innovative support program dedicated to public catering operators and farmers in the view to foster coupled innovation design processes. We studied a strategy implemented by a local authority to support its

catering services towards 100% organic sourcing, with a maximum of local purchases. We conducted individual and group interviews with the actors who designed and implemented the support and those who received it (cooks, managers, farmers, intermediaries, etc.) to highlight the conditions and modalities of this program that allowed scaling of coupled innovation design.

Finally, the third axis consisted of investigating the impact of the implementation of coupled innovation design on farm and catering structure sustainability. We analyzed the consequences of innovations resulting from a coupled design on various criteria of existing sustainability assessment methods. We chose the IDEA4 method (Zahm et al. 2019) for the farm, and a territorial impact diagnosis tool for catering structures (Leclere et al. In prep.). To collect data required to feed those tools, we conducted individual interviews with cooks and farmers working with a variety of products in the two case studies.

Results

We have shown that coupled design between actors from the agricultural and public catering sectors has facilitated and enabled the implementation of radical innovations that bring about change (e.g. supply in 100% organic products; processing by farmers). We have also shown that coupling design processes requires dedicated exchange spaces, shared visions, action-induced innovations, and multi-actor combinations of step-by-step processes. However, these processes are characterized by their complexity and long-term nature.

The scaling of coupled design processes can be fostered by specific support programs and context features. We identified the modalities of a support program that encourage the scaling of coupled design : (i) a systemic design of the program to jointly support all actors in innovation and suit to the local context ; (ii) the provision of a variety of resources (tools, knowledge, networking activities,...) aimed at empowering the networks of supported players.

Innovations resulting from coupled design can influence different dimensions of the sustainability of farm and catering sites. Socio-territorial dimension and economic dimensions are improved by the valorization through short or local circuits and also productive and contractual diversification. Existing practices prior to the introduction of the coupled design, and which were agroecological in nature, have been maintained by the farms (organic agriculture; extensive farming...). We have identified the consequences not only of innovations but also of the coupled design process itself, notably through its action on the evolution of the designer's transition objectives.

Discussion

This research approach, which involved analyzing two existing cases of coupled design, generated new knowledge on the characteristics of coupled design processes and generative support programs, as well as their impacts at farm and territorial levels. The next step is to confirm this knowledge through further case studies and consider how it can be used to encourage the adoption of coupled design for transition.

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Using design theory to build cross-disciplinary research agendas for sustainability transition: learnings from four experiences

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Keywords: C-K theory; innovative design; agrifood systems; cross-analysis

Introduction

Due to a long-term and institutionalized scientific specialization, many scholars from different disciplines (agronomy, genetics, food sciences, etc.) have lost the habit and the skills to work together to innovate and are struggling to coordinate their research (Béné et al., 2019). Therefore, there is an urgent need to formalize new methods to support academics in the identification and the articulation of trans- and cross-disciplinary research questions to foster innovation in agrifood systems (Cardona et al., 2024). The usual methodology to elaborate research agendas consists of literature review. Such systematic approaches enable to identify knowledge gaps in a range of fields of research but not so much in an interdisciplinary way. We propose to explore innovative design (Hatchuel and Weil, 2009) as a more generative approach. For several years now, we (the authors) have been involved in projects aiming at the identification of cross-disciplinary research questions. Our ambition is to draw generic lessons from these experiences regarding the organization of the design processes and their outputs in order to support other researchers engaged in cross-disciplinary project design, especially during the generation of research questions.

Materials and methods

This *on-going* reflexive study relies on a cross-analysis. For now, 4 projects, covering a certain diversity, have been selected to feed the cross-analysis (Table 1). Some of these projects have been published (Project 1 and 2) and other are still under development (Project 3 and 4). Similarly to what have been done for other design methods such as design workshops or step-by-step design (Jeuffroy et al., 2022; Meynard et al., 2023), the methodology that will be used is to develop abductively a heuristic framework to be applied to each case in order to compare them. Currently, the framework is organized around two main guiding questions: (i) how the design process was organized and why? and (ii) did the explorations have stimulated the emergence of original cross-disciplinary questions and/or projects?

Preliminary results

Regarding the organization of the design process: while a significant proportion of researchers tend to practice design in their daily work, using innovative design methods to identify new research questions is quite unusual and was sometimes bewildering for the scholars that were involved in our projects. Indeed, whereas building cross-community research projects is often led by a problem- solving approach, here, we identified research priorities from a reflection aiming at defining the proprieties of a desirable unknown. Therefore, this resulted in the four cases in the implementation of "long-term" dynamics (from several months to several years

depending of the project), all organized around the four same steps: explore innovation concepts that respond to the problem raised; specify these innovation concepts by drawing on available knowledge; identify the knowledge that is lacking to complete the design. However, the preliminary analysis also highlights that the fourth processes were also adapted to each situation which was traduced by an unique succession of workshops with different aims (perimeter definition, knowledge sharing, exploration, knowledge gaps identification) and analysis phases.

Regarding the outputs of these design processes: compared to classical ways to elaborate research agenda, the use of innovative design allowed each time to identify original and not-expected priorities of research with a high proportion of cross-disciplinary questions (as reported for instance in Brun et al., 2021). Beyond the elaboration of original research agendas, we also identified that this approach resulted in the construction of long-lasting community of multi-disciplinary researchers such as new research team within a lab (Brun et al., 2019). Finally, for the oldest projects, we analyzed that the proposed approach contributed to ease the emergence of cross-disciplinary projects (most of the time involving researchers that were involved in the innovative design process) in response to calls for projects.

Discussion and perspectives

After several years of testing this approach in different contexts and with different scientific communities, it seems important to conduct such reflexive analysis to assess the impact of using innovative design in the way that researchers are producing knowledge. Current results still need to be consolidated in the next months. Especially, the originality of the research questions that emerged from the process (for now only, the confrontation to literature reviews was done only for 1 project). On the long-term, with the increase of "real-world labs", an interesting perspective would be to experiment and adapt this approach to design trans-disciplinary projects, i.e. including not only academics but also socio-economical stakeholders and to compare it to other existing approaches (Pachoud et al., 2023).

	Project 1	Project 2	Project 3	Project 4
Main topic of the research agenda	Ecophysiology of field crops	Interface between agricultural and food sciences	Agricultural and food waste management	Animal health and welfare
Operational objective of the project	Merging of two research teams; preparing the research plan for the next 5 years.	Development of cross-disciplinary projects at INRAE on a little explored topic	Defining common interdisciplinary research questions leading to the creation of collaborative projects	Development of cross-disciplinary projects at INRAE on a little explored topic
Year	2018	2019	2021-2022	2024-2025
Example of cross-disciplinary research questions/topics that have emerged from the process	Multi-scale modelling	Small-scale processing technologies, sociotechnical conditions for their development	Innovative valorization of biowaste at territorial scale; Environmental benefits and maximization	Sociotechnical lock-ins around farm animal health practices
References	Brun et al., 2019	Brun et al., 2021	Under development	Under development

Table 1. Overview of the four case studies used for the cross-analysis

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Designing coupled innovations to reduce pesticide use in vegetable production: a case study in the south of France

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Keywords: market-gardening, agricultural practices, actors' coordination, territory

Introduction

Reduction of pesticide use is at the centre of many debates, both for health and environmental reasons (Carvalho 2017). In France, farms selling vegetables to long supply chains (e.g. national distributors) face several difficulties to significantly reduce pesticide use while they cover large areas. For instance, strict quality standards from distributors and risk of visual defects limit farmer's ability to adopt less pesticide-intensive practices (Lefèvre et al. 2020, Chiaverina et al. 2024).

Coupled innovation processes aim at combining different solutions (e.g. technical, organisational, institutional) and enhancing coordination across scales (e.g. farm, supply chain, territory) to overcome the barriers faced by the different actors of the agrifood system (Meynard et al. 2017). Few studies dealing with coupled innovations have jointly addressed the issues of production, upstream and downstream supply chains (Boulestreau et al. 2023). We present here the lessons learned implementing a participatory and multi-actor process to design coupled innovation prototypes involving production, upstream and downstream actors, to reduce pesticide use in vegetable production.

Materiel and methods

The study was carried out around Perpignan (France), where vegetable sector is strongly oriented towards long supply chains. A small range of crops are grown in large areas and volumes: lettuce, artichokes, celeriac and cucumbers. Except for cucumbers, they are also the crops with the highest pesticide use per hectare. From 2020 to 2024 and in collaboration with a local partner supporting farmers, we developed a three-step process aimed at designing coupled innovations to reduce pesticide use in lettuce production.

- Identification of barriers and levers related to pesticide reduction based on interviews with 25 actors from the territorial agri-food system (Casagrande et al., 2024).
- Exploration and design of innovation prototypes combining 2 multi-actor workshops and individual interviews with selected actors.
- Assessment of the novelty, usefulness and feasibility of the prototypes by workshop participants and non-participants.

We conducted an ex-post analysis of the process and its outcomes. First, we described the designed prototypes and characterized them according to two dimensions following Navarrete et al. (2024): (i) the degree of change required by the technical innovations, and (ii) the type of coordination required between agri-food actors. Then, we took a reflexive look on the methodological choices we made to favour participation and innovation during the workshops.

Results

Two coupled innovation prototypes were co-designed: P1, a value chain capable to produce and sell lettuce without pesticide residues, and P2, a production environment that limits lettuce pest pressure, with P2 intended to facilitate P1 (Figure 1). P1 relies on input substitution and redesign, but is specific to lettuce. P1 involves for instance a change in the expected weight of lettuce to harvest earlier and avoid end-of-cycle biotic risks. P2 involves a more comprehensive redesign of vegetable production in the territory to allow crop diversification in lettuce-specialized farms. For instance, to achieve the volumes needed to access long value chains, producers and collectors coordinate to identify a limited number of diversification crops.

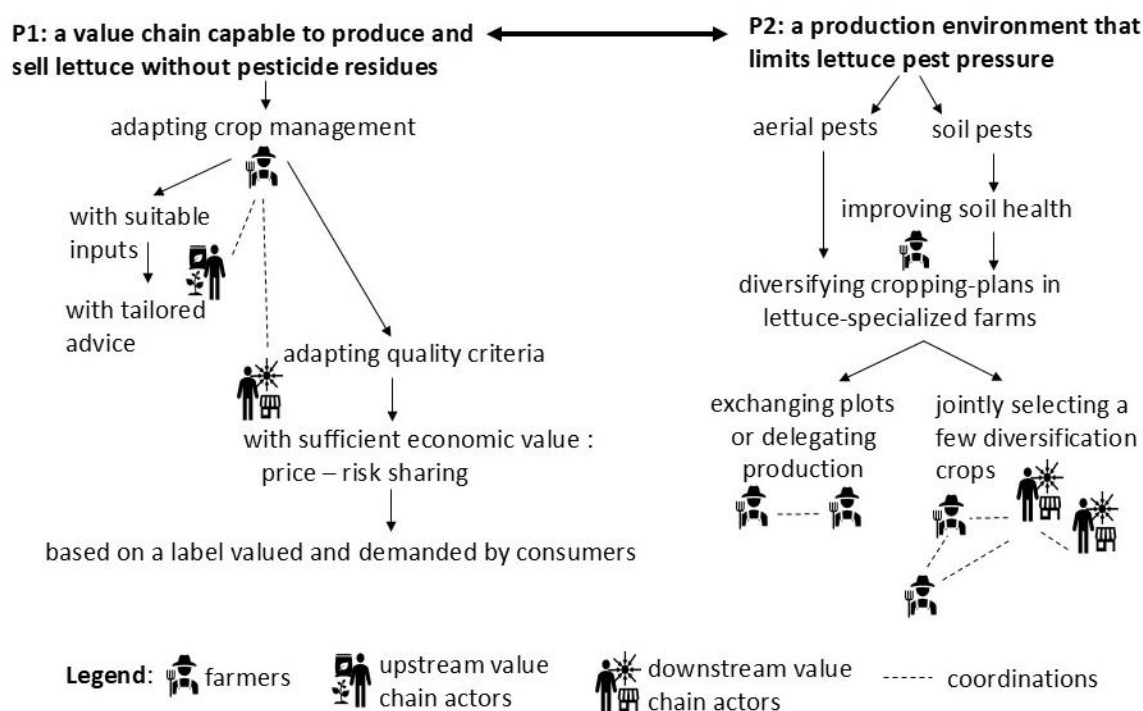


Figure 3. Simplified representation of the proposals embodied in the coupled innovation prototypes and of the required coordinations between agri-food actors

To favor participation of agri-food actors, we made 2 choices when designing the workshops: (i) explicitly addressing economic value creation, (ii) tackling issues beyond those directly related to pesticide reduction. Both workshops had enough participants for lively discussions. However, downstream actors (collectors, wholesalers, local distributors) were underrepresented compared to upstream actors (farmers, advisors, input suppliers, experimenters). As a result, prototypes were more technically refined than economically.

During the assessment step, most actors did not perceive the proposals embodied in the prototypes as new: some of them were seen as already implemented, both locally and elsewhere, while others existed but had failed in the past. Nevertheless, we argue that the novelty of the prototypes lies in the coherent combination of proposals toward a common objective, as promoted by the concept of coupled innovation.

Discussion and perspectives

Most of the proposals were considered useful by the actors interviewed during the assessment step, but their feasibility was the subject of much more divergent opinions. For instance,

coordination with different categories of actors, especially actors from outside the area (e.g. national distributors), was questioned. Prototypes may have been considered too complex in the sense that their implementation requires the coordination of a large number of actors with, as described in Braun et al. (2022), one of them driving the process. It would probably have been beneficial to include in the process a step aimed at identifying one or more transition paths (Duru et al. 2015), which would allow the situation to change gradually.

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Co-design of socio-technical innovation bundles: lessons for sustainable intensification of smallholder farming systems in Malawi

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Keywords: innovation design, adoption, participatory, conjoint experiment

Introduction

Agriculture is vital to Malawi's economy, but it also contributes to negative environmental impacts, including the degradation of soil fertility. The urgent need for increasing farm productivity while minimizing environmental impacts calls for the transitioning to more sustainable smallholder farming systems (Burke et al., 2022). This transition requires the introduction of innovative agricultural practices and technologies - sustainable intensification (SI) options - such as multi-functional legume crops into cereal-dominated cropping systems. Current research on farming systems mainly focuses on the technical suitability of SI options, often overlooking the social and institutional contexts that influences smallholders' adoption decisions. This signifies the need to consider innovation bundling, coupling social and/or institutional innovations (e.g., financial services, markets) to technical innovations (Barrett et al., 2020). However, it is largely unknown which approaches can effectively support the design of socio-technical innovation bundles (STIBs). In Malawi, recent research initiatives, that integrate legumes into maize-dominated smallholder farming systems, seek information on the required socio-institutional bundle components to underpin promising technical innovations. The aim of this paper is, therefore, i) to explore which social and institutional innovations to bundle with the integration of legumes, and ii) to assess to what extent bundles need to be tailored to specific farm types.

Methods

We used mixed methods combining participatory research with the conjoint technique (Rao, 2010), typically applied for designing products and services, and cluster analysis. We first conducted focus group discussions that lasted, on average, one and half hours to understand perceived advantages, barriers to adoption, and farmers' needs, engaging farmers involved in trials for Mbili-Mbili strip cropping. Mbili-Mbili is a crop intensification practice in which two maize rows are alternated with two legume species in three rows, enabling efficient use of land to boost productivity while enhancing soil fertility through biological nitrogen fixation (Kihara et al., 2022). This makes Mbili-Mbili a suitable technical innovation. Based on these assessments we defined potential social or institutional innovations to be combined with the technical innovation. The social and institutional innovations are referred to as 'attributes', with each attribute having two or more fixed values, or 'levels' (Kuhfeld, 2003). Using a fractional factorial design (Kuhfeld, 2003), we combined attribute levels and generated 18 hypothetical STIBs. In a conjoint experiment involving 246 farmers, pictorial representations of the hypothetical STIBs were presented one after the other for preference rating. When selecting participants, we tried to consider differences in resources and gender. Cluster analysis was used to determine farmer segments based on their preference scores to the attribute levels.

Results

The qualitative assessments highlight the need for complementary services (institutional innovations) to enhance the integration of legumes into the smallholder system in Malawi. These included joint supply of seeds combining legume seeds with maize, stable and profitable markets, micro-financing, and climate advisory services. The aggregate results from the conjoint experiment (Table 1) show that, overall, microloan service influences farmers' preferences most strongly. Farmers attached positive and higher utility value (0.95) to a microloan service to be paid back after harvest compared to the other microloan services. The second most important attribute is seed bundle, with a relatively high positive utility for a full seed bundle. Crop insurance and provision of climate information are the other important institutional innovations to consider in the design of STIBs.

Bundle attributes and levels	Relative importance scores (%)	Utility Estimates	df	F statistic	Sig.	Partial Eta Squared
(1) Seed bundle	25		3	150,86	<,001	0,09
maize alone		-0,60				
+ soybean		0,21				
+ pigeon pea		-0,13				
+ soybean, pigeon pea		0,52				
(2) Premium price	5		1	8,68	0,003	0,002
5% on group sales		-0,04				
5% on quality		0,04				
(3) Flexible sourcing arrangement	5		1	5,69	0,017	0,001
buyer contract without early purchase		0,04				
buyer contract with early purchase		-0,04				
(4) Seed loan	9		2	2,51	0,081	0,001
paid back in cash		0,04				
paid back in seeds		0,00				
paid back in grains		-0,04				
(5) Microloan service for inorganic fertilizer (maize)	40		2	1678,89	0,000	0,432
no microloan		-1,12				
microloan paid in installments		0,17				
microloan paid once after harvest		0,95				
(6) Crop insurance	10		2	46,45	<,001	0,021
offered to farmers		0,06				
offered via seed supplier		0,14				
offered via loan supplier		-0,19				
(7) Climate information on anticipatory action	6		1	91,10	<,001	0,020
not included		-0,13				
included		0,13				

Table 1. Relative importance, utility estimates and effect sizes (partial eta) of socio-institutional bundle attributes and levels related to the technical innovation Mbili-Mbili (n=246).

Farmers were subdivided based on their preferences for attribute levels (Figure 1). Cluster 1, representing 26% of the sample, showed strongest preference for the full seed bundle. Cluster 2 (representing 30%) preferred the microloan service, regardless of the repayment schedule, while Cluster 3 (representing 36%) favored loans with repayment after the harvest. Cluster 4, the smallest in size (8%), was the only cluster with a positive preference for maize seed alone.

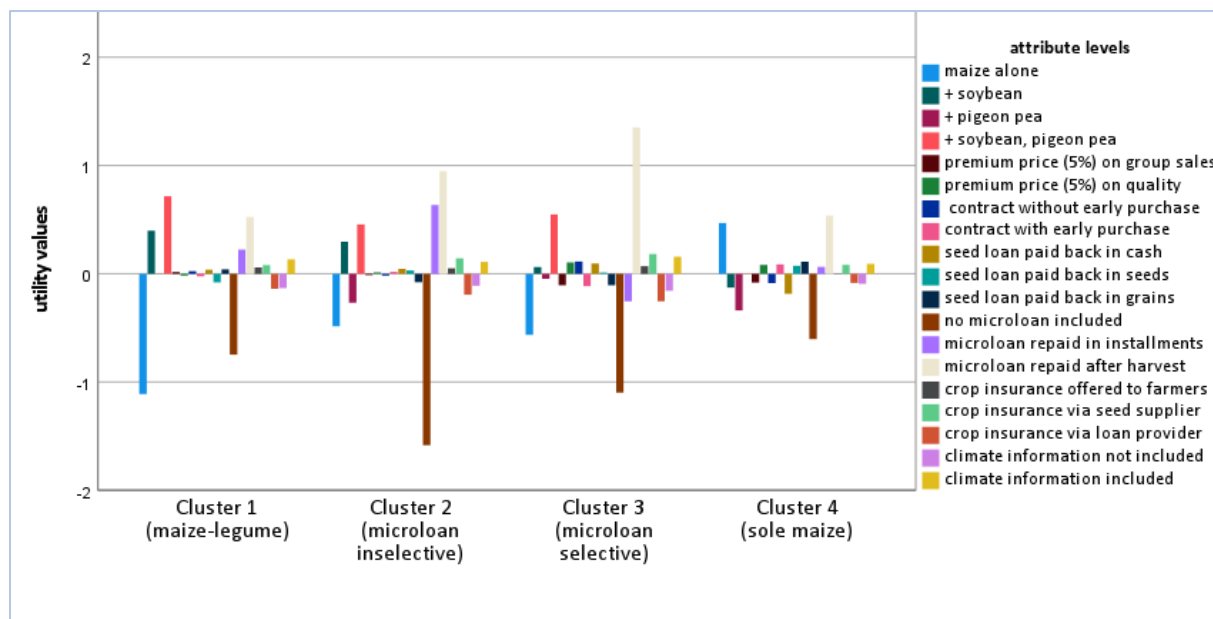


Figure 1. Farmer segments based on attribute-level utility values.

Discussion and Perspectives

The strong preference for microloan services suggests that farmers face financial constraints in adopting technical innovations, highlighting the need for bundling such services (Barrett et al., 2020). Farmers' interest in a full seed bundle reflects their willingness to adopt mixed maize-legume farming, if supportive seed market systems are in place. These findings indicate that smallholder adoption of diversified farming systems can be enhanced through the integration of institutional innovations, guided by the effective design of STIBs. However, the design of STIBs need to consider the heterogeneity in farmer preferences.

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A serious game to explore the compromise needed between stakeholders to implement sustainable soil fertility management practices

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Keywords: serious game, agro-ecological practice, social learning, trade off

Introduction

Agro-ecological practices are promoted to address soil fertility decline, but their adoption remains low in Benin's cotton-growing areas. Their implementation requires both technical knowledge and stakeholder collaboration. Serious games offer a promising approach by fostering dialogue, shared understanding, and collective learning among farmers and researchers (Andriamasinoro et al., 2020). This study aims to explore two key practices, rotational herd corralling and seeding under crop residues. Our objective is to identify farm- and village-level constraints, and facilitate the emergence of locally-adapted compromises through serious games to improve adoption.

Method

The study was conducted in Kandi, Pehunco, and Savalou, three communes in Benin with distinct agro-ecological zones. Kandi and Pehunco have an unimodal climate, Savalou a bimodal one. Annual rainfall averages 1057 mm, 1187 mm, and 1137 mm respectively. The regions vary in livestock density and crop production, including maize and cowpea. An iterative, step-by-step approach was used to build the serious game we call GANA (Fig. 1). The game was developed using the PARDI approach (Problem-Actor-Resources-Dynamics-Interaction) (Etienne et al., 2008) to build a conceptual model. This helped identify the core problem, describe farm types, highlight biomass as a shared resource, and define interactions between farms. The first game version was designed based on previous studies, literature, and PARDI results. It was tested and refined in sessions with researchers, extension service staff, and farmers. The board game includes 37 plots managed by four players based on their type. Soil fertility improves with organic inputs (manure or biomass), and yields depend on initial fertility. At each site, several sessions were held, six in Kandi and five in Pehunco and Savalou. Each session involved four rounds (representing agricultural seasons), with three phases: sowing, harvesting, and collective discussion on outcomes and future decisions. Choices of practices, crops, and all discussions were recorded.

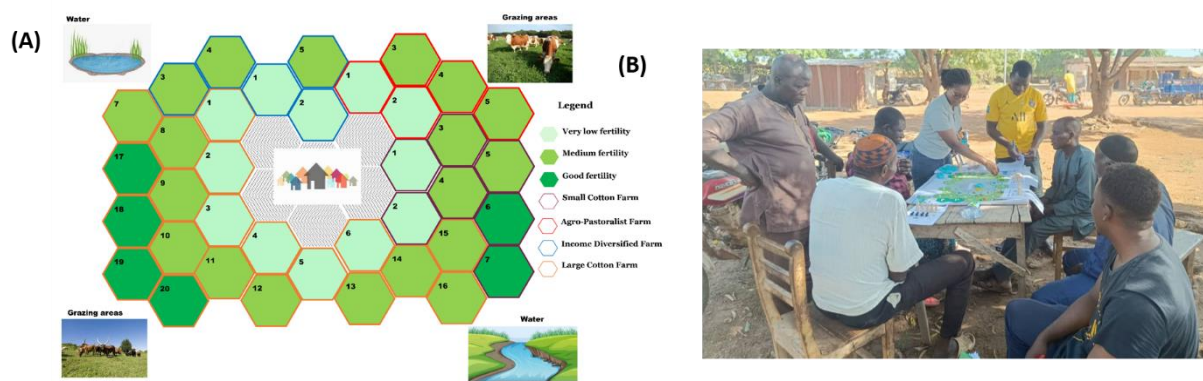


Figure 1: GANA serious game board (A), Game session in Kandi (B).

Result and discussion

Figure 2 shows a decline in soil fertility levels for all actors during the first cycle. This is due to a similar choice made by all participants across sites and sessions: they applied conventional practices, i.e. deep ploughing without organic inputs and removed all crop residues. At the end of the first round, farmers with livestock grazed their animals briefly on harvested plots, then collected the biomass to store it for the soudure season. Once the biomass from their own plots was depleted, agro pastoralists moved on to graze animals on farmers' plots, sometimes with permission (specifically in Savalou), but often without. Back home, animals were always corralled in the same location, meaning only a small part of the agro pastoralist's land received manure. Overall, biomass was systematically removed from plots and consumed by animals, with no organic matter returned to the soil. This led to the fertility decline observed in the first round (Baudron et al., 2015). This trend continued in the second round for cotton-based farms (LCF and SCF), except during sessions 4 and 5 in Pehunco, the session in Kandi for LCF, and session 5 in Savalou for SCF. In contrast, agro-pastoral farms (APF) showed increased fertility levels, while diversified farms (DIF) remained stable, except for a rise during session 5 in Savalou. APFs adopted rotational livestock corraling on at least 2 hectares, enhancing nutrient returns to the soil. DIFs restricted herders' access to their biomass, which helped retain soil cover. Although cotton farms also restricted access to their plots, agro pastoralists fearing animal starvation resorted to secret grazing, feeding their animals with biomass from cotton farms. These dynamics explain the mixed trends in the second round. From the third cycle onward, all farm types generally showed improved soil fertility, except for LCFs (session 5 in Kandi and session 4 in Pehunco) and DIFs (session 4 in Pehunco and Savalou). This improvement reflects a growing awareness among farmers of the need for dialogue and compromise. Rotational herd corraling became systematic, improving manure distribution and soil fertility (Castellanos-Navarrete et al., 2015). Access to biomass by external herders was better regulated through cooperation with local herders. On no-grazed plots, biomass was retained and incorporated into the soil.

Overall, the serious game enabled farmers and researchers to co-construct a shared understanding of soil fertility management at the village level (Assogba et al., 2025).

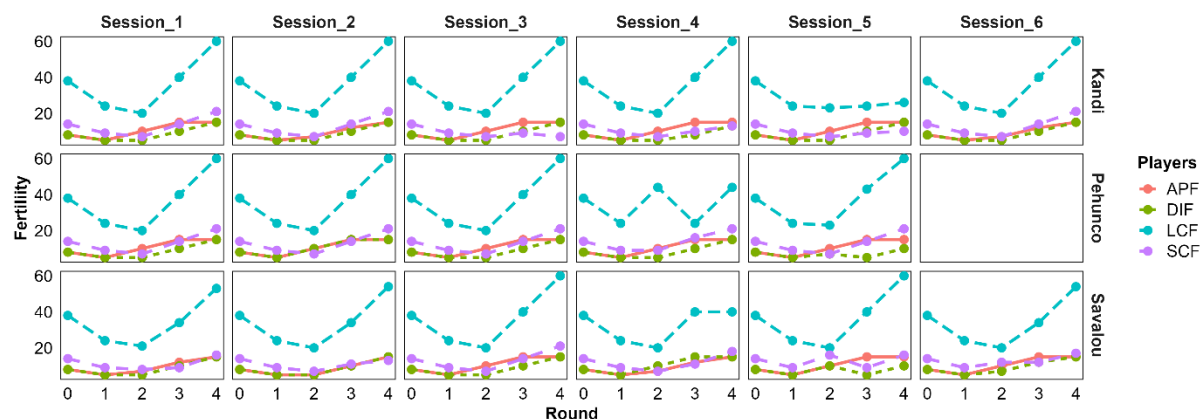


Figure 2: Trends in soil fertility over the sessions for each site. **DIF:** Diversified Income Farm, **APF:** Agro pastoralist Farm, **SCF:** Small Cotton Farm, **LCF:** Large Cotton Farm.

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Strengthening systemic innovation in Walloon's food systems through coupled innovation coconstruction

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Keywords: Coupled innovation, Coconstruction, Transition Arena

Introduction

Food systems' transition is locked by several processes that reinforce the industrial regime main characteristics based on the triptych specialization-intensification-concentration despite such systems negative social and environmental impacts (IPES-Food, 2016; Maréchal et al., 2008). To counter such lock-ins, different strategies are investigated by researchers in the field of transition management.

Among such strategies, Transition Arenas (TA) have been suggested by Derk Loorbach (2007) as instruments combining strategic and operational governance gathering "change agents" to design systemic innovations targeting long term objectives. To constitute such TA in Wallonia (Belgium), we aim at 1) identify change agents and their innovations' characteristics, 2) facilitate the coconstruction of coupled innovations with local stakeholders. Coupled innovation aim at "reconnecting the dynamics of innovation in agriculture and food, with a view to improve the whole agrifood system" (Meynard et al., 2017).

Methods

First, we analyzed three programs about food systems' innovation in Wallonia, namely, the TERRAÉ program about agroecological transition, the Manger Demain strategy about sustainable food systems and the Wagraim competitive cluster about innovation in the agro-industrial sector. We compared these three programs considering the innovations they support and the actors they involve.

Then, we conducted 14 semi-structured interviews with Walloon stakeholders to characterize innovations depending on their objectives. We distinguished the objectives following three targeted types of stakeholders (producers, intermediaries and consumers).

Finally, considering the previous results, we designed a two-workshops facilitation to coconstruct coupled innovation with Walloon food systems' stakeholder in the TA.

Results

Innovations' characteristics and objectives

We identified 5 main innovation domains gathering 70 innovations answering 33 objectives depending on the three stakeholder types. When agroecological agricultural practices' innovations focus inevitably on farmers (1 type of stakeholders), 10 innovations from the four other domains were answering objectives for the three stakeholder types (Table 1). Even if many innovations target one or two stakeholder types, we note that systemic innovations were already implemented in Walloon food systems.

Innovation domains	1	type	of	2	types	of	3	types	of	Total

	stakeholder	stakeholders	stakeholders	
Agroecological agricultural practices	17	1	0	18
Biotechnologies and industrial processes	5	6	2	13
Local and healthy food access for consumers	2	7	1	10
Food value-chain structuring	1	8	4	13
Territorial food governance	9	4	3	16
Total	34	26	10	70

Table 1: Number of innovations from the five domains answering different stakeholder types' objectives

We observed that the objectives are tackled by innovations from one or two domains, and more rarely from three domains (Table 2), independently from stakeholder types. When systemic innovations are already implemented, coupled innovations are rarer.

Type of stakeholders	1 domain	2 domains	3 domains	4 domains	5 domains	Total
Farmers	4	7	3	0	0	14
Intermediaries	4	5	2	0	0	11
Consumers	4	1	3	0	0	8
Total	12	13	8	0	0	33

Table 2: Classification of objectives depending on stakeholder types and the domains from their related innovations

Creating territorial transition arenas for coupled innovation coconstruction

To coconstruct coupled innovations, we design a workshop that will be used in each TA. We design five territorial TA at the Walloon province scale. Such scale allows enough stakeholders diversity and sufficient geographic proximity to design coupled innovations while covering all the Walloon territory. These arenas will gather eight to ten "change agents" involved in the five innovation domains.

For each territorial TA, two workshops will be planned in 2025. The first workshop consist on designing coupled innovations, while the second workshop will focus on the necessary conditions to execute such coupled innovations.

For now, the first workshop's methodology relies on three steps:

1. Participants will choose one high-priority objective per stakeholder's type from the 33 objectives listed by researchers.
2. After the facilitator associates several innovations to the chosen objectives, participants will add missing innovations.
3. They will underline contradictions between innovations and objectives
4. After focusing on positive links between innovations, they will suggest innovations groups or "new" coupled innovations that target the three stakeholder types and bring together as much innovation domains as possible.

Discussion

Focusing on these three regional innovation programs involves a specific bias, because it relies mostly on institutional and administrative approaches which are not necessarily representative from all innovations in food systems. However, such a basis allowed us to rapidly get in touch with local stakeholders identified through these programs as well as giving perspective to our work. Indeed, the territorial TA coupled innovations will be compared and presented to regional stakeholders to foster their support to local systemic innovations.

Moreover, our empirical observations are based on a granular analysis of innovations from different domains. To compare such innovations, we consider concrete activities to formulate innovations fields that were not too specific, nor too broad. Therefore, we inevitably focused on narrow innovations, sometimes preventing the description of already implemented coupled innovations. However, our approach allows, on one hand, stakeholders that are not familiar with coupling to better understand this concept, on the other hand, to describe more precisely existing coupled innovations.

Finally, we notice that some synergies between innovations from the same domain can be very effective and reproducing the specialization-intensification-concentration triptych (Maréchal et al., 2008). It's specifically the case about some innovation of the structuring value-chain domain. To avoid "new" undesirable regime and lock-ins instauration, we will analyze the effect of such innovation's amplification. That hypothesis will be further investigated thanks to TA workshops' results.

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A regional interactive design approach for developing and implementing future visions in peat meadow areas

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Keywords: Future visions, co-design, peat meadow areas, regional approaches

Introduction

Despite the many efforts of different stakeholders in Dutch agriculture, many challenges remain, such as the impact on climate change, loss of biodiversity, or outdated business models and animal housing systems. Until 2024, a number of these challenges were addressed through the policy instrument National Program for Rural Areas (acronym in Dutch, NPLG). This research focusses on specific methodological aspects to facilitate some of these processes from a regional perspective. Empirical analyses are conducted in the form of four case studies in which farmers, together with other stakeholders, developed a future vision for their polders in the peat meadow areas of the Netherlands. The aim of this research is to produce generic knowledge on how to facilitate regional interactive design processes.

Methodology

The process in four polders, in three different provinces of the Netherlands, was facilitated by researchers of Wageningen University & Research together with ORG-ID (consulting firm) in a participatory co-design fashion -- inspired by the Reflexive Interactive Design (Dutch acronym, RIO) methodology (Bos et al., 2009; Elzen & Bos, 2019; Puente-Rodríguez et al., 2019). In each polder a network of stakeholders was created, formed by local farmers (the majority of whom are dairy farmers), representatives of the industry and NGOs, researchers, civil servants of municipalities and provinces, etc.

In each polder a series of activities and workshops were organized for about a year. Firstly, individual ('kitchen table') conversations took place and 'polder safaris' organized to explore the regional need for and willingness to engage in such a process -- sense of urgency/relevancy and network formation. Afterwards, depending on the needs and availability of participants, and the complexity of content, network and processes, a series of design sessions in each region was organized. For example, in one region, three day-sessions and one half-day workshop; in another region one day session and four half days; in yet another region three day-sessions and two half days; and in yet another region five day-sessions. The first design session was used to facilitate a collective problem and system analysis. Then, objectives (timescale 2030-2050) were formulated. The facilitators explicitly pointed out the contradictions and mutual exclusion between some objectives in order to gain a better understanding of the definition of objectives and problems, and the analysis of functions within the current and proposed system -- i.e., social, ecological, economic, technical, landscape, etc. aspects. In subsequent workshops, the objectives were redefined, clustered and better articulated; also, specific actions/measures, responsibilities and steps were formulated that were required to achieve the objectives. The future-vision document was written by the facilitators and commented on and validated by participants.

Formal and informal knowledge fed the process. At the beginning, a summary of socio-economic, water system and ecological information and figures (the baseline) was made and presented to the participants. Every time that a knowledge gap was identified, experts were

consulted or invited to participate in one of the sessions. Some of the measures and objectives (ammonia deposition, etc.) were quantified to show the effect and scope of the future vision.

Results

In each polder a future vision document was written and made public. The vision included long-term objectives and specific measures and steps to reach those objectives, including specific responsibilities of stakeholders. It was supported by some calculations about the expected results of measures and by drawings to make it more attractive and tangible (see Figure 1). Moreover, a process manager was appointed to guide the follow up. For each polder, a cooperation agreement was signed by landowners (farmers), individual participants and decision-makers from participating organizations.

In some provinces the future vision document was included in the provincial plans within the NPLG to guarantee funding and the implementation of the vision because it was aligned with the provincial future perspective. The objectives and future visions had an integral character:

- Circular agriculture and nature inclusive agriculture.
 - Aimed at a more extensive character.
 - Agreements with farmers that stop their activities to use their land for agricultural use by other local farmers and for nature conservation purposes. Among others, to meet the ammonia emission objectives of EU directives.
 - Taking care of biodiversity, particularly meadow birds and water flora and fauna.
- Improving the water system.
 - Quantity, hydrographic aspects (note that these regions lay below sea level; in one case even -6.5 m).
 - Ecological quality. E.g., by developing nature-friendly ditches and ditch edges (Figure 1).
- Maintaining and improving the agrarian cultural landscape of polders.
- Engaging with and accelerating the energy transition.
- Living quality and prosperity in the polder: Development of new business models (short chains, producer-consumer; development of regional concepts); Improvement of accessibility; Facilitating hiking and cycling routes.
-

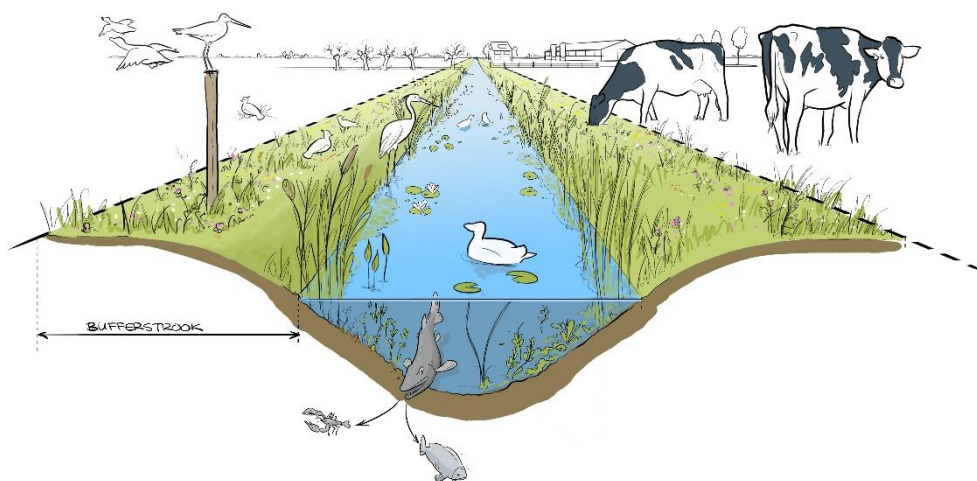


Figure 4. Drawing supporting measure: 'Nature friendly ditch edges

Discussion and perspectives

We are currently conducting a reflection/evaluation of the process, which has identified two success factors so far: (1) A structured design process, facilitated in an interactive fashion of knowledge brokering, which was able to bring relevant (formal/informal) knowledge and experts into the process. (2) Trust. In a context of distrust at national level, it was possible at local level to identify conflicting problem/goal definitions and to make agreements on long-term objective and short-term steps.

At the time of writing the new government of the Netherlands has canceled the NPLG. The NPLG was intended to guide and finance provinces and other stakeholders to achieve sustainable future-proof rural areas. Most processes in the rural areas are therefore in a stand-by situation. Nevertheless, some of the activities proposed in the vision documents have been initiated. From the perspective of our process design approach, a new research project has been initiated to reflect on the applied regional design approach in these polders, which are now approached as pilots within a broader territorial context. The aim is to scale up the structured approach to design more sustainable Dutch western peat meadow areas.

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Roles, forms, and functions of intermediary objects for co-design and scaling: application to small agrifood equipments in West Africa

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Keywords: Co-design, Intermediary Objects of Design, Equipment, Scaling

Introduction

Intermediary Objects of Design (IODs) are central tools in co-design processes (Mer, 1995; Kerr, 2020). Prototypes, models, blueprints, and digital simulations offer concrete solutions for communication, planning, decision-making, and evaluating design options among stakeholders (Jeantet, 1998). However, the specific role of IODs in supporting the scaling-up of prototypes remains underexplored. This issue is particularly critical in the agrifood sector in West Africa, where many projects struggle to progress beyond the prototype stage, despite the active involvement of multiple stakeholders to ensure suitability to local needs and usage conditions.

This study aims to identify the IODs utilized during the co-design of small agrifood equipments, analyze their forms, and determine their specific objectives. More specifically, we seek to understand which types of IODs support the development and anticipation of prototype scaling-up.

Method

To address these questions, we adopted a qualitative multiple-case study approach (Yin, 1996). Over six months, we analyzed four pieces of equipment developed within the BioStar project in Senegal (<https://www.biostar-afrique.org/>): a cashew softening boiler, a peanut roaster, a cashew shell boiler, and a peanut shell briquetting machine. These cases were selected based on their diverse co-design practices and technological maturity. We conducted 32 semi-structured interviews with key stakeholders involved in the design of these devices (researchers, equipment manufacturers, and end-users, both in Europe and Senegal). The interviews focused on critical design phases, structural decisions, and modifications made in response to technical constraints and user feedback, enabling us to reconstruct the design trajectories (Temple et al., 2016). We also engaged in immersive fieldwork, participating in design workshops and on-site trials for several weeks, collecting extensive observations to complement our analysis. Additionally, we compiled and examined project-related grey literature (workshop reports, diagnostics, etc.). This dataset allowed us to trace the design trajectories of the four devices and identify the IODs involved in the process. These IODs were then analyzed based on their functions (alignment, evaluation, or anticipation) (Vinck, 2009) and their forms (commissioning/mediating, open/closed) (Mer, 1995).

Results

The findings reveal three main categories of IODs, each serving distinct objectives in co-design. The first category consists of closed, non-modifiable IODs that act as commissioning tools, conveying the designer's intent without expecting feedback from users. For instance, training materials help standardize knowledge levels by communicating information without room for adaptation. The second category includes mediating yet relatively closed IODs, which facilitate evaluation, decision-making, and planning for subsequent design stages. The third

category comprises IODs that foster stakeholder engagement and increasing participation, through their mediating role and openness, for example some technical specification documents or participatory prototyping workshops.

These three types of IODs appear at different stages of the design trajectory of each four equipment. For example, when the peanut roaster was transferred from the laboratory to the field, collaborative adjustments were made based on user feedback, enhancing the equipment's performance (see figure 1). Conversely, the cashew shell boiler and the briquetting machine have a completed different use of IODs to enhance adhesion with limited flexibility for local adaptation.

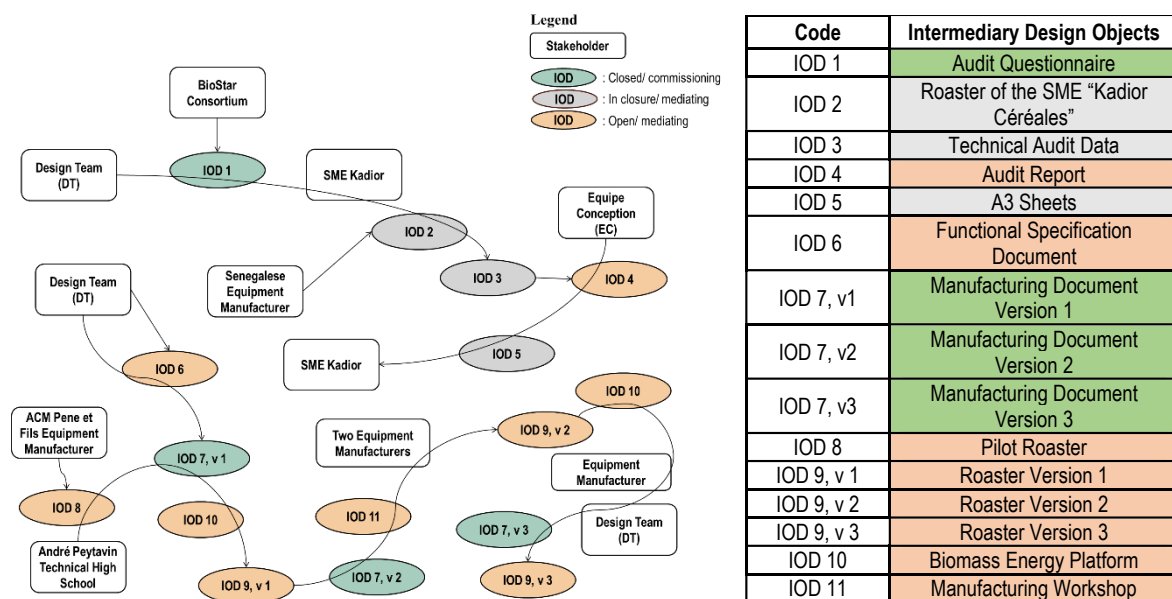


Figure 1. Mobilization of IODs during the peanut roaster design trajectory

Finally, our analysis highlights a relationship between IODs types and potential scaling-up strategies. For example, in the case of field-tested prototypes like the cashew softening boiler and the peanut roaster, scaling relied on IODs maintaining their mediating and open functions to enable adaptation in different contexts.

Discussion & Perspective

The results of this study provide two important insights. First, integrating IODs in the analysis of design trajectories allows for a more nuanced analysis of co-design dynamics, as traditionally described (Suurs et al, 2010). To improve agrifood equipment scaling strategies, it is essential to design coupled innovation that combine design tools, technical support and the structuring of stakeholder networks. Second, in contexts of absence of institutionalized support mechanisms, these IODs emerge as critical levers for technology adoption and scaling strategies, providing the right function and roles in the design trajectory. This goes beyond classical dialogue functions between designers (Vinck, 2009 ; Jeantet, 1998). Involving local stakeholders more closely in the design and development of IODs would guarantee their flexibility and ensure that agri-food SMEs and equipment manufacturers take long-term ownership of innovations. Future work could involve the analysis of services provided to support IOD use and design, in particular in supporting long-term appropriation, which was not the focus of this study. This work has important implication in designing and managing small agrifood equipments in Western Africa.

Acknowledgment

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OccitAnum, an archipelago living-lab to evaluate and co-design digital technologies as enablers of the agroecological transition

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Introduction

Today, the agricultural world is undergoing several transitions, e.g. climate transition, agroecological transition, digital transition. We hypothesize that digital technology can help the agroecological transition (Bellon-Maurel et al, 2023). In this perspective, we have set up OccitANum, an agricultural living lab in Occitanie Region, co-financed by the France 2030 Innovation Territory program and by the Occitanie Region. In OccitANum, digital technologies are mobilized to serve farmers, the agroecological transition and local food systems. OccitANum has ca. 50 partners, from various categories of the AKIS ecosystem: users (farmers, agricultural cooperatives), suppliers (AgTech), local authorities, R&D, education partners and development organizations (agricultural extension services, innovation hubs, associations).

Objective

The objective is to introduce the OccitANum organization, first results and lessons learnt so far.

Methodology

OccitANum is an archipelago Living-Lab based on two interacting components. On the one hand, there is a set of 15 "real-life" sites organized in 7 Open-Labs (OL) standing for 7 agricultural sectors: field crops, viticulture, arboriculture, vegetables, livestock, beekeeping and local food. Most OL have two or three specific real-life sites, in which innovative projects are set up through participatory approaches. On the other hand, the CORE is the resource center set up to support the OL and the sites.

The CORE is made up of players from R&D and education partners and some facilitators. It aims at bringing together and training site facilitators; designing and making available tools to support innovative projects building; designing and implementing capitalization tools; defining and implementing assessment tools; developing OccitANum for today and for the future and create new knowledge on this type of open-innovation design. An important role of the CORE is also to analyse the farmers' transformation process.

OL and sites are the operational heart of the OccitANum Living-Lab archipelago. In each site, communities are managed by a site facilitator. Putting the farmer at the center of the process, his/her task is to encourage the emergence of "innovative projects" (i-project) through participatory approaches, starting with the expression of technical bottlenecks by farmers. Then, companies are invited to propose digital solutions to address the problem. Next phase is to build an i-project, including users, companies, facilitators and research, and to assess the

technology in real life, regarding its economic, environmental and social costs and benefits (Gobrecht et al, 2023).

Results

First outputs

After five years of operation, the general layout is now fully operational. Several i-projects have been launched, to co-design digital technologies addressing issues in viticulture (detecting anomalies in vineyards, modulating fertilization of vines, simply managing the vine water status), in arboriculture (facilitating mechanical weeding of orchards with current equipment, managing voles) and in livestock (innovative digital advisory application for sheep farming). Evaluation of Costs and Benefits of existing digital technologies have been carried out (probe for irrigation, LIDAR-led autoguidance, agri-photovoltaism ...). AgTech companies strongly adhere to this approach which allows them to save time in the innovation cycle.

Importantly, OccitANum also explore the co-design/co-building of digital technologies, named "high-lowtech" associating users, in perfect coherency with agroecology human principles. A special device, the MobiLab, has been created by L'Institut Agro. It is a mobile fab-lab which is brought to the countryside to raise farmers' awareness on digital tech and codesign lowtech digital devices with them, provoking a big interest. Some examples of the MobiLab outputs: a connected vole trap, a capacitive probe (PiLowTech) in vegetable production. Another example of high-lowtech is the CentipOc, which has emerged in a bottom-up process from OccitANum actors, to deploy Centipede-RTK Open-source GNSS network in Occitanie.



Figure 5. Creation of a PiLowTech irrigation sensor during a highlow tech session

Difficulties, lessons learned

First lesson, the time taken to acculturate all the players to this bottom-up research-action was long and even more delayed by COVID. This may be due to several reasons: 1) the living lab's object, ie digital technology, often poorly understood by farmers and site facilitators; this led us to set up awareness raising sessions; 2) facilitators are experts more used to address farmers' problems than to make farmers' need emerge collectively; therefore, we created a community of practice for facilitators and regularly trained them, 3) OccitANum is only a small part of facilitators' activities; this led us to reinforce the system with extra support staff.

Second lesson is the importance of reflexivity, to increase the impact of the Living Lab, which is a learning process, by implementing methods for impact-driven steering (Joly et al, 2015).

Third lesson, data and information management, necessary for capitalisation and evaluation purposes, is a delicate point, technically (difficulty in building dedicated databases adapted), psychologically (farmers' sensitivity to the use of their data) and legally (GPDR).

Fourth point is that first feedbacks from AgTech players show that they appreciate this type of interaction with research and users. This has to be confirmed by specific inquiries.

Conclusion

The OccitANum Living Lab is a unique innovation device in Occitanie region regarding its object (digital technology for agroecology) and the role of research (general animation, reflective and capitalisation processes). It has also a long duration (8 years) which is a real advantage to absorb the initial phase of acculturation and of trust creation. The role of research in coordination is also questioned. Even if research is absolutely necessary to impulse changes and to innovate, managing this kind of large multi-origin partnership is a real challenge, regarding the missions of research. Specialized entities eg dedicated Science-Society mediation specialists are urgently needed to foster these multi-partner new innovation devices.

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Sustainability framework for local food systems solution design: the ESDU case study

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Keywords: Climate change, Circular economy, Sustainable development, Systems thinking

Introduction

Local food systems face mounting challenges, including environmental constraints and socioeconomic disparities, particularly in low- and middle-income countries (LMICs), all of which threaten food security (Mirzabaev, 2023). Research and Development (R&D) plays a crucial role in addressing these challenges by translating scientific insights into practical solutions (Sharifulden, 2024). However, traditional R&D often struggles with scalability and community adoption, highlighting the need for frameworks that more effectively integrate research within local contexts (Wang, 2022).

Transitioning to a Research, Development, and Extension (RD&E) model helps in overcoming these limitations (Wesley, 2014). Yet, short-term funding and fragmented efforts frequently undermine RD&E's effectiveness. (Wang, 2022). The 3x3 Sustainability Framework, developed by the Environment and Sustainable Development Unit (ESDU) at the American University of Beirut (AUB), provides a structured approach aimed at ensuring the continuity and long-term impact of these solutions.

This paper explores how the 3x3 Framework can offer an effective approach for transitioning food systems in LMICs towards sustainability.

Methods

ESDU has been at the forefront of promoting sustainable agro-food solutions for over 25 years, through RD&E activities. To achieve this, the unit has developed a process to streamline the viability of its solutions. A multistakeholder participatory approach with donors, policymakers, and others helps in creating and disseminating adapted solutions. On the other hand, seeking sustainability across its activities, processes, and partnerships helps to maintain its viability and the impact of its actions.

Dimension	Economic	Social	Environmental
Internal	Financial self-reliance of the RD&E unit	Staff development and inclusive growth	Eco-friendly office operations
Upstream	Co-financing and strategic partnerships	Stakeholder dialogue and policy collaboration	Research influencing environmental policies
Downstream	Increased income and market access	Community adoption of innovations	Community adoption of climate-smart practices

Table 1. 3x3 Framework Dimensions

The 3x3 Sustainability Framework

RD&E is a scientific process where a promising solution is identified, tailored to local needs, and then shared with communities through training and support. This methodology, while essential for driving tailored solutions, must be coupled with the right partnerships and financial sustainability to ensure long-term persistence. Without these critical elements, the impact of solutions can be limited. To overcome this challenge, it is crucial to embed RD&E within a broader framework, such as the 3x3 Sustainability Framework initiated by ESDU.

The 3x3 Sustainability Framework is composed of two interrelated sets of three components: the three domains of operation (internal, upstream, and downstream) and the three pillars of sustainability (economic, social, and environmental).

Pilot assessment based on the framework

To assess the effectiveness of its RD&E solutions within this model, a Monitoring and Evaluation plan was developed using a single indicator for each of the nine sustainability cells:

- Internal -- Economic: Percentage of ESDU's annual budget derived from self-generated revenue
- Internal -- Social: Average number of training hours completed per staff member annually
- Internal -- Environmental: Percentage reduction in office resource use
- Upstream -- Economic: Total amount of co-financing mobilized for publicizing ESDU research
- Upstream -- Social: Percentage of invited institutions participating in at least one multi-stakeholder dialogue per year
- Upstream -- Environmental: Number of regulations or guidelines citing ESDU research
- Downstream -- Economic: Average percentage increase in agricultural income among beneficiary households
- Downstream -- Social: Percentage of beneficiary households still applying introduced innovations 6 months after project completion
- Downstream -- Environmental: Percentage of participants showing reduction in non-climate smart practice usage

A mixed-method approach is used to evaluate results.

This study covers the period from 2018- when the 3x3 Framework was introduced- through 2024. Quantitative data were drawn from pre-post tests with 600 rural beneficiaries across 10 RD&E projects, complemented by qualitative insights from 10 key informant interviews. Findings were triangulated with ESDU's institutional records.

Results

Internally, in 2024, 95% of ESDU's budget was covered by self-generated revenue. Staff completed an average of 24 training hours annually- double the 2018 baseline- and office resource use declined by 27% compared to 2018.

At the upstream level, USD 15,000 was secured in co-financing to promote ESDU's research- three times the amount mobilized in 2018. Institutional engagement in multi-stakeholder dialogues rose to 89%, and ESDU's work was cited in 15 national guidelines, reflecting a 20% increase from 2018.

Downstream, beneficiary households recorded a 20% increase in agricultural income. 6 months after project completion, 50% of households continued to apply introduced innovations, and 50% reported reducing non-climate-smart practices.

Discussion and perspectives

By adopting the 3x3 Framework, ESDU has enhanced the stability of its internal and upstream dimensions. Internally, economic sustainability was strengthened through high financial self-reliance (FAO, 2020). Institutional capacity and inclusive professional growth advanced the social pillar, while reduced office resource use reflected improved environmental practices (UNEP, 2021).

Upstream, the framework enabled greater financial leverage in research dissemination. Socially, increased institutional participation in multi-stakeholder dialogues fostered inclusive governance and collaborative knowledge exchange. Environmentally, the rise in research citations underscored ESDU's growing influence on evidence-based environmental policymaking (OECD, 2019).

These internal and upstream improvements directly shaped downstream outcomes, confirming the viability of the RD&E solutions. By 2024, compared to the 2018 baseline when the framework was not yet applied, significant gains were observed across social, economic, and environmental dimensions.

These results affirm the 3x3 Framework's value as a replicable tool for sustaining food systems in LMICs. While this evaluation was based on pillar-specific indicators, future assessments should incorporate quantification methods to better capture cross-pillar dynamics and guide adaptive, evidence-based impact analysis.

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Transformative scaling: setting a new agenda for scaling of agricultural innovations

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Keywords: Transformation, Scaling, Innovation Systems, Advisory Services

Introduction

Scaling is increasingly recognized in international agricultural research, with CGIAR actively integrating it into its programs. The "Scaling for Impact" initiative exemplifies this shift by tracking innovation demand, testing pathways, linking innovations to finance, and systematically managing innovation portfolios. Scaling is However, scaling concepts continue to evolve within the CGIAR. With regard, responsible scaling acknowledges ethical dilemmas (McGuire et al. 2024), while others advocate for sustainable system change over mere expansion (Woltering et al. 2019). A user-centered, demand-driven approach has gained traction, emphasizing co-creation (Mikkelsen and Røiseland 2024). In this paper, we argue that transformative scaling could integrate these perspectives into a coherent framework. Transformation refers to profound change with depth, scope, and speed dimensions. The depth dimension looks into shifts in paradigms, values, and worldviews (Coburn 2003). The scope dimension refers to a deliberate transition towards a normatively positive outcome, multi-actor, and systemic (von Braun et al. 2023). The speed dimension refers to the urgency needed (Webb et al. 2020). This paper aims to develop a transformative scaling framework and provide insights on implications for scaling science and practice.

Methodology

A theory-based case study approach was employed. A transformative scaling framework was developed from existing literature on transformation and its critiques. The International Livestock Research Institute (ILRI) work on feed and forage innovations scaling in Ethiopia's mixed farming systems is used to illustrate challenges to drive transformation. The discussion section reflects on what needs to be done to drive transformative scaling and the challenges ahead.

Results

Case Study Context

Ethiopia has Africa's largest livestock sector but suffers from low productivity due to genetic limitations, poor animal health services, weak market linkages, and acute feed shortages. Shrinking natural pastures and low-nutrition crop residues exacerbate seasonal feed gaps, particularly in dry seasons. Agro-industrial by-products offer high-quality alternatives but are costly and inaccessible to many smallholders. Cultivated forages, such as Napier and desho grass, present a promising solution, yet adoption remains low due to land competition, weak extension services, and limited seed access. Scaling efforts require coordinated action to enhance forage production, integrate it into farming systems, and establish supportive policies.

Transformative Scaling Lens for Feed and Forage Innovations

On the dimension of depth, ILRI's efforts to scale feed and forage innovations in Ethiopia have shown early signs of institutional engagement, such as the development of the country's first national forage seed certification training and policy dialogues that raised awareness of certified seed needs. However, these efforts remain largely project-driven and have not yet been fully embedded into national extension systems or policy frameworks. Farmers have participated in demonstration activities, but their role has largely been as recipients rather than co-creators or decision-makers. Structural improvements in seed supply chains and advisory services remain fragmented and under-resourced.

On the scope of change, ILRI's scaling efforts have engaged a range of actors, including research institutions, extension agents, and local farmers. The "Mother-Baby Demonstration Approach" has reached hundreds of farmers per village, and community radio and mobile platforms have extended outreach beyond direct project participants. Despite these efforts, scaling remains localized. As a result, large-scale changes in farmers' use of cultivated forages is yet to be realized despite many years of scaling efforts.

On speed of change, ILRI and its partners employed several strategies to accelerate scaling, including the introduction of improved forage species, feed conservation practices, and seed system innovations. The revolving seed model and market-based seed business approach show potential for broader uptake. However, adoption remains slow and incremental due to logistical constraints, limited seed access, and weak market incentives.

Discussion

Applying a transformative scaling lens reveals that while ILRI's feed and forage innovation efforts in Ethiopia have made progress, they remain largely project-based and fall short of achieving deep, large-scale, and rapid change. To enable deep change, innovations must be embedded into national systems (Moore, Riddell, and Vocisano 2015). Although initiatives like forage seed certification training and policy dialogues show promise, they lack institutional ownership and long-term sustainability. Achieving large-scale change requires broader actor engagement and systemic integration (Schut, Leeuwis, and Thiele 2020). For rapid change, adoption bottlenecks must be addressed (Gebreyes et al. 2021). Despite promising models like revolving seed systems and market-based approaches, uptake is slow due to logistical constraints and limited incentives.

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Scaling coupled innovation design between public catering and farming sectors: analysis of a support program

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Keywords: agrifood system, institutional food service, coordination, swarming

Introduction

The agriculture and food sectors have to innovate to reduce their environmental impacts and support the transition towards more sustainable and healthier agrifood systems (HLPE 2019). However, socio-technical lock-ins hinder the emergence of innovations that would be conducive to sustainability (Meynard et al. 2018). Coupled design is considered a lever for agroecological transition, as an original way of designing innovations via coordination between actors in the agricultural and food sectors (Meynard et al. 2017). However, coupled design processes are complex to implement, long-lasting, and still remain scarce (Migairou-Leprince et al. submitted). Therefore, there is a need to support the scaling of such innovation processes. Public catering is seen as a lever for transition in many territorial food policies in France (Loudiyi et al. 2022) and appears as a potential ground for coupled design processes (Martin et al. 2022). This paper analyzes support activities as an instrument for this deployment by addressing the following questions: What are the conditions and modalities for scaling coupled design between public catering and farming sectors? To what extent can a support program lead to the coupled design of innovations between agrifood systems stakeholders?

Materials

We specifically studied the support program implemented by a Departmental Council, located in a rural area in southwestern France. The agricultural context is characterized by a diversity of production systems. The political objective is that, by 2028, all secondary school catering sites managed by the local authority will be supplied with 100% organic food, with a maximum of local products, and no price increase for families. Therefore, a territorial food policy is managed by implementing a transition support program for stakeholders involved in the activity or supply of catering services in secondary schools (farmers, processors, logistics intermediaries, kitchen teams, and management teams). To our knowledge, no comparable initiative in France provides such support to collective catering sites and their farmer-suppliers.

Methods

First, we verified that the actors we were working with were implementing coupled design processes in several groups in various situations across the region. We conducted individual interviews with farmers, cooks, and managers of collective catering sites. During these interviews, we asked them specific questions about their innovative practices, how they coordinated with other actors, and the conditions and characteristics that led to coupled design processes. We complemented this analysis by organising collective workshops gathering cooks, managers, and farmers at two collective catering sites. These workshops aimed to build the multi-actor trajectory of practices and learning; and identify the characteristics of the territory and support program that facilitated coordination.

Secondly, we interviewed the local authority staff who designed and are currently implementing the support program. Analyzing these interviews enabled us to identify the features of the support program that favored the scaling of coupled design in the supported networks of actors, and to complete the data on the territory's facilitating characteristics.

Results

We demonstrated how certain types of coupled innovations have been scaled in the farming and public catering sectors within the region. Since the start of the support program, several groups of stakeholders have implemented coupled design processes. Scaling coupled innovations relied either on an increase of the quantity of products derived from such processes, or on an increase of the number of stakeholders involved, sometimes through swarming to new groups.

We then identified the characteristics of the area that facilitated coupled design. The diversity of agricultural products, the high number of organic farms and the history of innovation fostered coupled design with catering. Some of the interviewed farmers have been supplying public catering sites since 2010. All the secondary schools studied have their own kitchens, which means that cooking activity has been maintained. Furthermore, some cooks in this area initiated a national movement for eco-friendly kitchen training.

Finally, we identified the features of the support program that enhance coupled design scaling :

- *A program designed to initiate systemic change, through simultaneous and combined actions dedicated to the various involved actors.* It can be adapted to suit the specific catering site context, as well as the knowledge and resources of those being supported (e.g. collective catering sites and farmers).
- *The provision of a variety of resources* aimed at empowering the networks of supported players. The program implemented tools to facilitate coordination between sectors (e.g. a calculator to forecast purchase volumes for each foodstuff according to the food plan), networking activities (e.g. meeting groups for cooks), and the consolidation of a collective supply solution that serves as a 'safety net' for individual coupled designs.

Discussion

These features provide tools for future stakeholders in designing support programs aiming at enhancing multi-actor networks to implement coupled design for agrifood system transition. This case study could be compared to other cases worldwide, to consolidate and generalize our results. Finally, this research opens avenues for further assessment of territorial impacts of coupled design processes between food and farm sectors.

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Methods for systemic design in agrifood systems

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Keywords: Design methods, innovation, exploration, assessment

Introduction

The urgent need of innovations to address the wicked issues in agriculture and food calls for a strong involvement of the actors in systemic innovation processes. We describe as "systemic" an innovation whose properties are linked to interactions and feedbacks between its components. This systemic character is frequent in agriculture and food innovations, as shown in the terminologies in these domains (e.g. cropping systems, farming systems, pest management systems, agroecosystem, agrifood systems). While literature on participatory design processes is abundant, gaps still exist in the development of methods allowing to address the systemic character throughout the innovation process. This study aims at describing how several methods, developed to fuel multi-actor design processes, were chosen and combined when implemented in various case studies aimed at systemic innovation toward healthier agriculture and food production.

Material and Methods

The study is based on a cross-analysis of 13 case studies, all involving multi-actor design processes. They were chosen to cover various subjects and objects designed (e.g. territorial innovations to limit pesticide use in a water catchment area; cropping systems enhancing soil fertility in Africa; practices to assess sustainability of urban agriculture projects). They all involved various types of actors (e.g. farmers, advisors, input providers, wholesalers, supermarket managers, public authorities).

In all cases, design of systemic innovations was reached by specifically choosing and implementing methods known to fuel multi-actor design processes : diagnosis of use situations (Cerf et al., 2012) ; on-farm innovation tracking (Salembier et al., 2021) ; collective design workshop (Jeuffroy et al., 2022) ; sociotechnical diagnosis (Casagrande et al., 2024) ; territorial scenario design (Chantre et al., 2016) ; system experiment (Debaeke et al., 2009) step-by-step design (Meynard et al., 2023).

Our cross-case analysis aimed at identifying how the systemic character of the designed objects was reached throughout the design process, by analyzing the choice of the methods used in each situation, and their linkages throughout the design process.

Results

First, we show that the systemic character of the innovations, in the various cases, was linked to (i) the interactions between the designed object and the situation in which it was to be implemented, and/or (ii) the coordination between actors, which contributes to reinforce such interactions.

Second, we highlight some characteristics of the methods used for design, that enhance the systemic character of the innovations. As examples derived from the case studies : a/ The

sociotechnical diagnosis aimed to analyze how the diverse actors of an agrifood system influence farmers' decisions, and led to identify the interconnected levers to be designed for agroecological transition at the territorial and value chain scales ; b/ The *diagnosis of use situations* aimed at analyzing the problems actors face when implementing a task in their own situations, thus taking into account the systemic links between a practitioner, the object of his/her action, and the context in which it takes place ; c/ The *design and ex ante assessment of territorial scenarios* aimed at designing synergic practices to achieve an ambitious target for the territory (e.g. pesticide-free cropping systems); d/ The on-farm innovation tracking resulted in shedding light on the systemic links between innovative practices under study and the situation components in which they were designed and successfully implemented by farmers.

Third, we show that the choice of the methods used in each case was strongly tailored to the characteristics of the situation in which the design process was conducted. For example, a sociotechnical diagnosis was implemented only when the design process appeared hampered by strong interconnected barriers from a diversity of actors (sociotechnical lock-in); design workshops were organized when fixation effects hindered the exploration of new avenues to reach an ambitious target ; the step-by-step design approach was performed when the design of an innovation could not be ended unless being confronted to its real environment and use.

Finally, we shed light on the ways various methods were articulated throughout the design process, thus allowing to maintain and develop the systemic character of the innovations. As example, in the cases where tracking farmers' Innovations was followed by design workshops, the systemic links highlighted in the innovative practices were valued during the design workshop. In the cases with a combination of system experiment and step-by-step design, the interactions between practices, determinant for high performance, were highlighted in the experiment, and still considered in the step-by-step design of new practices.

Conclusion

When systemic objects are to be designed and anchored in real situations, their systemic character can be reached through (i) the use of specific system-oriented methods, (ii) the tailored choice of methods used in the design process, and (iii) the ways they are combined throughout the innovation process. In the future, it would be essential to enhance the use of such design approaches, by a diversity of actors, to scale up innovation in agrifood systems.

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Meynard J.M., Cerf M., Coquil X., Durant D., Le Bail M., et al., 2023. Unravelling the step-by-step process for farming system design to support agroecological transition. *European J Agronomy*, 150: 126948. # Using design theory to build cross-disciplinary research agendas for sustainability transition: learnings from four experiences

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Motékar: resilience of paddy farmers in West Java, Indonesia

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Keywords: Peasant Resilience, Agricultural Squeeze, Subjective Resilience, Actor Oriented Approach

Introduction

In Indonesia, rice is both a staple food and a policy focal point, placing smallholder farmers at the center of national food security. While the government must keep rice affordable, farmers face increasing production costs, price controls, and environmental risks such as climate change and seasonal variability. This creates an ongoing tension, often referred to as the agricultural squeeze, where farmers are expected to sustain livelihoods under tightening constraints.

This study explores how paddy farmers in West Java experience and respond to these pressures, emphasizing their own perspectives on resilience. Drawing on the concept of subjective resilience (Jones & Tanner, 2015) and using the Actor Oriented Approach (Arce & Long, 2000; Long, 2003), we examine how farmers maintain autonomy, adapt to change, and draw upon cultural and spiritual resources. By focusing on lived experiences, this research offers insights into the everyday strategies of peasant resilience that are often overlooked in policy and development discourse. When exploring agricultural resilience, it is important to highlight the ever-changing nature of farming as we could conceptualize farming "as an open process of becoming, composed of heterogenous relations that are continuously made and remade" (Darnhofer, 2020). Our findings highlight resilience as a dynamic, adaptive process rooted in autonomy and local knowledge, offering insights for building more inclusive and sustainable food systems.

Methods

We conducted qualitative fieldwork in three West Java regencies: Subang, Purwakarta and Tasikmalaya, selected for their agroecological and socio-economic variation. We interviewed 58 respondents: 26 farmer group leaders, 11 village elders, 8 community figures, and 13 individual farmers with distinctive trajectories. We also conducted direct field observations of farming activities, religious events, and community rituals to contextualize the interview data.

All interviews were audio-recorded, transcribed in local languages (Sundanese and Bahasa Indonesia), and analyzed using thematic coding in MaxQDA software. An inductive coding approach was applied following the steps of Clarke & Braun (2017) thematic analysis: initial familiarization with transcripts, generation of open codes, identification of themes, and refinement of thematic categories. Codes emerged around farmers' understandings of risk, adaptation, and resilience, as well as cultural and spiritual expressions such as *panceg* (steadfastness), *ikhtiar* (effort), and *pasrah* (surrender to God's will). Patterns were compared across the three sites and triangulated with field notes and observations.

Sampling adhered to the principle of thematic saturation (Guest et al., 2020), reached after approximately 45 interviews. The remaining interviews provided cross-validation and deepened contextual understanding.

Results

The analysis revealed that farmers in West Java articulate resilience not primarily in terms of material adaptation, but as a moral and spiritual stance toward hardship and uncertainty. More than 80% of interviewees used one or more of the terms *panceg*, *ikhtiar*, and/or *pasrah* to describe how they persist in farming despite rising costs, uncertain markets, and climate disruptions. These terms reflect a culturally embedded grammar of resilience.

For example, a farmer in Purwakarta explained: "as long as we are *panceg*, keep putting in effort, and trust in God's will, we will find a way to survive." This framing emphasizes dignified persistence over calculated risk mitigation.

While some technical adaptations were noted, such as switching from high-yield varieties to local ones, reducing fertilizer uses (n=18), or reverting to organic pest management (n=9), these were described not as strategic optimizations but as expressions of *kamotèkaran*, or creative flexibility grounded in cultural identity. Thus, rather than viewing resilience as a technical capacity, farmers expressed it as a way of being rooted in spiritual beliefs and collective values.

Discussion and Perspective

These findings highlight the importance of incorporating subjective and culturally grounded notions of resilience into farming systems research. Whereas dominant frameworks often define resilience as the capacity to absorb shocks and recover functionality (Walker et al., 2010), our data reveal that West Javanese farmers frame resilience as moral persistence supported by cultural scripts. The terms *panceg*, *ikhtiar*, and *pasrah* are not merely linguistic artifacts but represent ethical orientations that guide decision-making and sustain livelihood under stress.

This perspective resonates with Darnhofer (2020) proposition that resilience should be understood as "an open-ended process of becoming," and supports Van der Ploeg (2012) notion of farming styles as socially constructed responses to agrarian pressures. The farmers' reliance on *kamotèkaran*, a Sundanese concept of adaptive creativity, illustrates how local knowledge and identity are mobilized in response to global challenges.

Rather than seeking to prove whether farmers are resilient by external metrics, our study underscores the need to recognize how farmers themselves define, value, and perform resilience. This shift has important implication for policy: efforts to support resilience in farming systems must move beyond technical fixes and engage with farmers' cultural frameworks, lived experiences, and epistemologies.

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A systemic analysis of barriers to pesticide reduction at the farm level

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Keywords: action logic, farmers' rationale, obstacles, system redesign

Introduction

As elsewhere in the world, pesticide reduction is not achieved in France (Hossard et al., 2017) despite an ambitious public policy aiming to foster practice change on commercial farms (the Ecophyto plan). Most of the studies analyzing obstacles to pesticide reduction at the farm level compile generic lists of factors hindering change without showing how these factors interact with one another, or how they relate to farmers' practices and their agricultural context (e.g. Bjørnåvold et al., 2022; Darnhofer et al., 2005). Indeed, these studies mainly emphasize generic constraints linked to the characteristics of alternatives (e.g., their limited availability, low effectiveness, or high labor requirements) or to farmers' motivations and attitudes towards agroecological transitions, but they rarely investigate how farmers' practices choice, and the agronomic functioning of their cropping systems may impede pesticide reduction. The aim of our study was to explore farmer's practices and their rationale, in order to decipher the farmer's logic of pesticide use and unuse.

Methodology

Within the DEPHY-Farm network (a national farmer network enhanced to develop alternative practices to pesticide use), we selected farmers who showed contrasted trajectories of their Treatment Frequency Index (TFI) across years since their entry in the network (increase, reduction or stability at a high level, Table 1). We conducted interviews with 25 farmers in four different regions in France, in order to understand farmer's practices and the rationale behind them. For each farmer, we produced a narrative using the action logic framework (Quinio et al., 2022; Salembier, 2019) to organize the systemic links established by the farmer during the interview between his/her practices, the interpretation he makes about agronomic processes at play, the information he uses to manage his crops, his satisfaction criteria, and contextual elements. By comparing the logics of farmers with different TFI trajectories, and drawing on agronomic literature, we identified, through the action logics, key systemic mechanisms explaining the high dependency on pesticides, thus depicting a systemic analysis of the obstacles to pesticide reduction on farms.

	INCREASE	STAGNATION	DECREASE
HIGH INITIAL TFI	3 farmers	5 farmers	10 farmers
LOW INITIAL TFI	4 farmers	3 farmers	Ø

Table 1: Number of farmers interviewed for each type of TFI evolution

Findings

We found that obstacles mentioned by the interviewed farmers varied from one farm to another, and an obstacle for one farm may not be an obstacle for another farm. Most often, obstacles are not related to a particular practice or pest, but are closely interlinked with the way farmers design their cropping systems.

For instance, one farmer who prioritizes yield as a satisfaction criterion chooses a late-maturing corn variety and opts for early sowing to extend the crop cycle and therefore maximize yield. He systematically applies an insecticide while sowing the crop, as he reports high wireworm pressure in his plots, which could lead to significant yield losses (obstacle to pesticide reduction). Corn frequently returns in the crop rotation on irrigated plots, as it is considered the most profitable crop by the farmer, who has invested in a corn drying unit that needs to be cost-effective. As a result, he cultivates a large area of corn every year, which make it more difficult to shift sowing dates. By contrast, his neighbor, who had a similar rationale in the past, decided to reduce his corn acreage and to introduce other crops in order to break the cycle of weeds and pests while also spreading the economic risk associated with a single crop. He now selects an early-maturing variety that can be sown later, allowing the crop to establish under conditions where corn is more vigorous and quickly becomes less vulnerable to wireworm attacks. As a result, he applies no insecticides on his corn crops and is satisfied with this cropping system, as it helps reduce input costs (irrigation, pesticides, drying costs). However, he mentions that this logic is more suitable on relatively small farms like his, as a delay in sowing dates is easier for a small maize acreage. In contrast, farmers with large maize areas often need to start sowing as soon as possible, as the operation is spread over a longer period. This example show that pest pressure and pesticide use depend on farmer's combination of practice (here crop rotation, crop variety and sowing dates), driven by specific satisfaction criteria and contextual elements (here farm size and specialized equipment).

Using a cross-analysis of farmer's action logics, we identified several systemic mechanisms that hinder pesticide reduction at the farm level in arable systems, among which "system simplification to reduce workload" and "cash crops oriented diversification" depicted in Figure 1. We also identified systemic mechanisms related to pesticide reduction and the conditions of their achievement in farms.

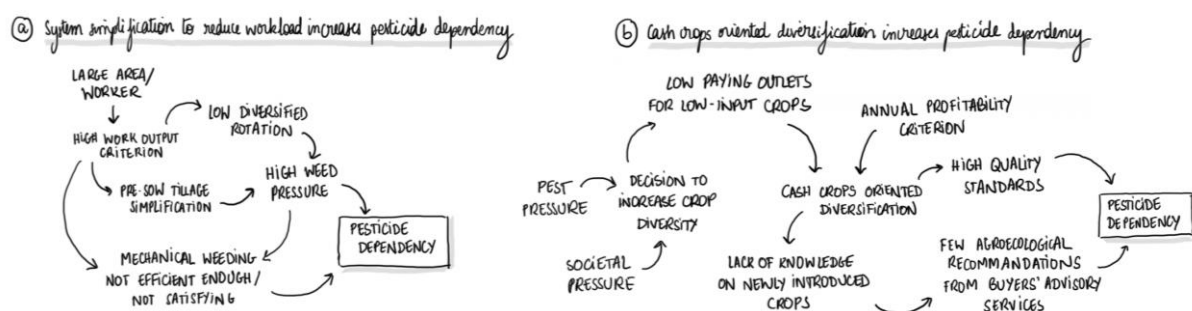


Figure 1: Systemic representation of two blocking mechanisms highlighted through farmers' action logic analysis]

Discussion and Perspectives

We identify two key methodological contribution of this work. First, we used an in-depth analysis of the action logics of farmers who have reduced their TFI to put into perspective the logics of those who have not. In doing so, rather than identifying a list of generic obstacles, we unraveled strongly interlinked mechanisms at the farm level, which alert on certain trends in the agricultural sector (among which the increase of farm size and over-equipment of farms

with cutting-edge equipment not well suited to system redesign). Moreover, the action logic framework so far has been used to highlight innovative agroecological practices, through innovation tracking for instance (e.g. Verret et al., 2020). In this study, we used the same concept to highlight systemic barriers to pesticide reduction at the farm level. A possible extension of this work would be to assess whether this systemic analysis could help farmers, agricultural advisors, researchers or other stakeholders to overcome the identified obstacles and design new strategies to support pesticide cut in arable systems.

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Optimizing sustainability in rice-crayfish co-culture: evaluating input inefficiencies and pathways for improved environmental performance

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Keywords: Rice-crayfish system, Environmental efficiency, Green agricultural development, Farm household survey

Introduction

Globally, reducing carbon emissions has gradually become a significant policy agenda for greening agricultural development. For decades, agricultural development strategies in most countries have focused on intensification by increasing external inputs such as fertilizers, concentrates, and energy (Khatri-Chhetri et al., 2023). Although these methods have enhanced yields, the widespread adoption of intensive production practices has increased greenhouse gas (GHG) emissions. The IPCC, for example, estimated that 23% of the total anthropogenic GHG (2007–2016) is derived from agriculture, forestry, and other land-use activities (IPCC, 2019). In terms of single gases, agri-food systems generated 21% of CO₂, 53% of CH₄, and 78% of N₂O emissions globally in 2019, and the total emissions from agri-food systems have increased by 16% from 1990 to 2019 (FAO, 2021). Agricultural growth which mainly depends on the intensive input of production factors inevitably causes severe resource wastage and carbon emissions, threatening green agricultural development (Luan et al., 2013; Qiu et al., 2014).

The integrated rice-fish system (RFS) has been rapidly promoted as an important model for green agricultural development. As the most popular model of RFS in China, the rice-crayfish system (RCS) can theoretically increase economic output and improve the ecological environment of farmlands, but practically often struggle to achieve the expected performance. Most of the existing research is based on field experiments and observations. It is necessary to estimate the environmental efficiency (EE) of the smallholder RCS and analyze its limiting factors, since farmer's behavior plays a key role in technology selection. The objectives of this study were to (1) estimate environmental efficiency, (2) determine the causes of environmental inefficiency, and (3) analyze the factors that restrict the performance of the RCS at farm household level.

Materials and methods

Calculation of RCS productivity and profit

The possibility boundary was constructed by considering the rice-crayfish farmer as the decision-making unit (DMU). Following Ahmed et al. (2011) and Tan et al. (2021), we selected land, labor force, machinery, seeds, fertilizer, feed, and some chemicals as input indicators. Productivity in this study refers to land productivity, namely physical or economic output per unit area, and the net profit of RCS implies total revenue per unit area minus total cost. As the coculture fields produce both rice and crayfish by applying fertilizers, seeds, and labor force, etc. as inputs. We used economic output to measure land productivity, as it is difficult to aggregate the two outputs physically.

The slack-based measure (SBM) model to estimate the eco-efficiency

EE was estimated using the SBM. The rice-crayfish practice produces the expected output as well as discharges undesirable outputs (environmental pollution) (Färe and Grosskopf, 2009). The expected output from the RCS can be divided into rice production and crayfish production. We use the revenues of rice and crayfish to denote the desirable outputs. The undesirable

output primarily includes water pollutes such as excessive nitrogen and phosphorus, as well as carbon emissions. It can be distinguished into non-point source pollution (TN and TP) and carbon emissions from fertilizer overflow in this study.

The water pollute emissions were calculated the amount of non-point source pollution (TN and TP) produced by the RCS using the following equation:

$E_m = \sum(E_{ij})$ where E_m is the total pollutant emissions from non-point sources of fertilizer; E_{ij} is the emission of the j th pollutant in each DMU $_i$; C_{ij} is the production amount of the j th pollutant in unit i ; T_i is the statistics of unit i ; and ρ_{ij} and μ_{ij} are production pollution coefficient and fertilizer loss rate, respectively.

The indirect carbon emissions of fertilizers were calculated using the following equation: $C_i = F_i \times \xi$ where C_i is the carbon emission of fertilizer in the production activities of the i th farmer; F_i is the amount of fertilizer used; and ξ is the carbon emission coefficient of fertilizer.

The SBM based on undesirable output was used in this paper. Undesirable production is measured by non-point source pollution and carbon emissions caused by farmers' overuse of chemicals.

The combined least absolute deviation (CLAD) model to analyze factors affecting EE

This section identifies the factors that influence EE based on farm household characteristics and external environmental factors. We considered that the EE calculated by the SBM is a variable with a non-negative truncated feature. The Ordinary Least Squares method often yields biased estimation results for restricted dependent variables. Therefore, we considered the Tobit or CLAD model to identify the limiting factors. The Tobit model makes strict assumptions, namely normal distribution and homoscedasticity, in terms of the distributional characteristics of the target variables. Therefore, we employed CLAD if the prerequisite assumptions were not met. The Conditional Moment (CM) and Lagrange Multiplier (LM) tests were used to verify whether normality and homoscedasticity were satisfied.

Results

On average, the land productivity and net profit were 10,119 and 4,364 \$/ha, respectively. Land productivity of the small-, medium-, and large- scale group averaged 10,730, 9,741, and 9,887 \$/ha, respectively.

Productivity, profit, and environmental efficiency (EE) distribution

	Total samples	Small-scale	Medium-scale	Large-scale
Productivity (\$/ha)	10,119	10,730	9,741	9,887
Profit (\$/ha)	4,364	2,930	4,626	5,537
EE	0.618	0.532	0.620	0.701

Notes: The results in the table are the average values of the variables.

The average EE of the RCS was 0.618, with notable variations among different-scale farmers. Redundant inputs, such as drugs and feeds, resulted in the overall EE. Enhancing farmers' education level, technical training, organic fertilizer application, and decreasing their part-time employment can further and effectively improve EE of the RCS.

EE performance. The SBM results revealed that EE varies greatly among farmers. Differences in EE performance can be elucidated through a study of input, desirable output, and undesirable output, according to Cooper et al. (2007). The input, desirable output, and undesirable output inefficiencies of the surveyed farmers were 0.311, 0.201, and 0.214, respectively, indicating that input redundancy has a greatest negative impact on EE.

The input redundancy ratios of each production factor were drugs (50%), feed (44%), labor (35%), crayfish seeds (33%), rice seeds (31%), pesticides (23%), fertilizers (17%), and

machinery (16%). Higher redundancy rates indicate greater overuse of inputs and a major contributor to environmental inefficiency. Specifically, farmers overused drugs and feeds in crayfish production and failed to appropriately allocate the labor force. Excessive drugs and feeds, etc., were used in crayfish disease control, feeding, harvesting and routine management, thus increasing undesired outputs and carbon emissions. Factors limiting EE. some household characteristics such age and education level of household head and policy promotion are found to improve EE.

Discussion and Perspectives

The RCS performance of different-scale farmers

To initially explore why RCS failed to optimize, we divided the total sample into three farm-size groups. The results showed that the small-scale farmers had the highest revenue but lowest profit and EE values. Appropriate scale for RCS is about 2-3.33 ha.

Causes of limited RCS performance

Our results suggested that although one-third of RCS farmers achieved effective status, more than half were ineffective (EE value < 0.5). The result of SBM showed that input redundancy might explain the overall EE values. Specifically, the redundancy rate of each factor of production was drug (50.02%), > feed (43.59%), > labor (34.58%), > crayfish seedlings (33.12%), > seeds (30.88%), > pesticide (23.11%), > fertilizer (16.85%) and > machinery (16.40%).

Socio-economic factors affecting EE

Strengthening farmers' technical training and increase their knowledge of modern production can enhance EE. Farmers with higher education levels have more extensive knowledge of applied technology and management methods, contributing to efficiency improvements. Their part-time behavior makes them reduce resource inputs in agricultural production, and fragmented lands are more likely to be underutilized, resulting in rough agrarian management and a low-efficiency level.

Perspectives

This study helps improve existing production practices targetting green agricultural development, and offers some references for the government to formulate related policies and for farmers to better select the RCS. To realize "dual uses of one water, double harvests in one field," farmers need to reduce unnecessary inputs to improve EE as much as possible. Enhancing farmers' education level, technical training, and organic fertilizer application, and decreasing their part-time employment will further optimize EE performance of RCS.

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Toward sustainable development of family farming: insights from the oases of Ghannouch in southeast Tunisia

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Keywords: Family farming, Competitiveness, Productivity, Profitability

Introduction

Family farming represents 80% of Tunisia's agricultural holdings and is crucial for rural development and food security (Elloumi, 2015). However, it faces major constraints that limit productivity, profitability, and competitiveness. These include poor access to technology, weak mechanization, and underinvestment in infrastructure (Suess & Fuetsch, 2016). Farmers also suffer from limited market integration and dependence on intermediaries (Carpentier, 2023), as well as high input costs and limited financing, which hinder sustainable investment (Rebai, 2022). This study focuses on family farms in the oases of Ghannouch and aims to identify key limiting factors to develop a competitive, sustainable model.

Methods

Our methodology, inspired by the work of Gutiérrez et al. (2025), was structured into two interconnected phases. The first phase, conducted between February and March 2025, focused on characterizing the socio-demographic, economic, and environmental conditions of family farms in the oases of Ghannouch, through the design and validation of a data collection tool. A total of 100 surveys were conducted with farm households. The second phase involved an in-depth statistical analysis of the collected data, using Multiple Correspondence Analysis (MCA) to explore relationships between categorical variables and identify structural barriers affecting competitiveness. Ordinal Logistic Regression (OLR) was used to assess the impact of key factors on competitiveness-related indicators, such as land use efficiency and profitability.

Results

Characterization of Agricultural households

The characterization of family farmers in the oases of Ghannouch was conducted along socioeconomic and environmental dimensions. The average cultivated area per household is 1.11 hectares, with a standard deviation of 1.02 hectares. All surveyed farmers have access to a public irrigated perimeter and benefit from regular irrigation cycles based on an 18-day water rotation schedule. Regarding education, 50% have attained secondary education, while 14% have completed university level. The average annual agricultural income is estimated at 17,054 Tunisian Dinars (approximately 5 035 euros, based on an exchange rate of 1 EUR = 3.3 TND), with a standard deviation of 15,964 TND, indicating high income variability among households.

Multiple Correspondence Analysis

The Multiple Correspondence Analysis (MCA) of 100 farmers in Ghannouch reveals two main axes explaining 40.57% of total inertia: Axis 1 (24.43%) relates to the modernization of agricultural practices, and Axis 2 (16.14%) concerns the technical and social organization of

farms. Key contributing factors include access to irrigation and credit, diversification, and technical training.

The analysis identifies two distinct profiles. On the right of Axis 1 are better-organized farmers with credit access, diversified production, and stronger links to short marketing circuits. These farmers benefit from public support and report higher perceived competitiveness. In contrast, the majority, located on the left and lower parts of the map, face limited access to credit, water, and mechanization, depend on intermediaries, and show low diversification—resulting in reduced productivity and profitability.

The MCA highlights a strong link between competitiveness and public support. This reflects broader challenges: only 30% fully use their land, and 80% report insufficient income to meet basic needs.

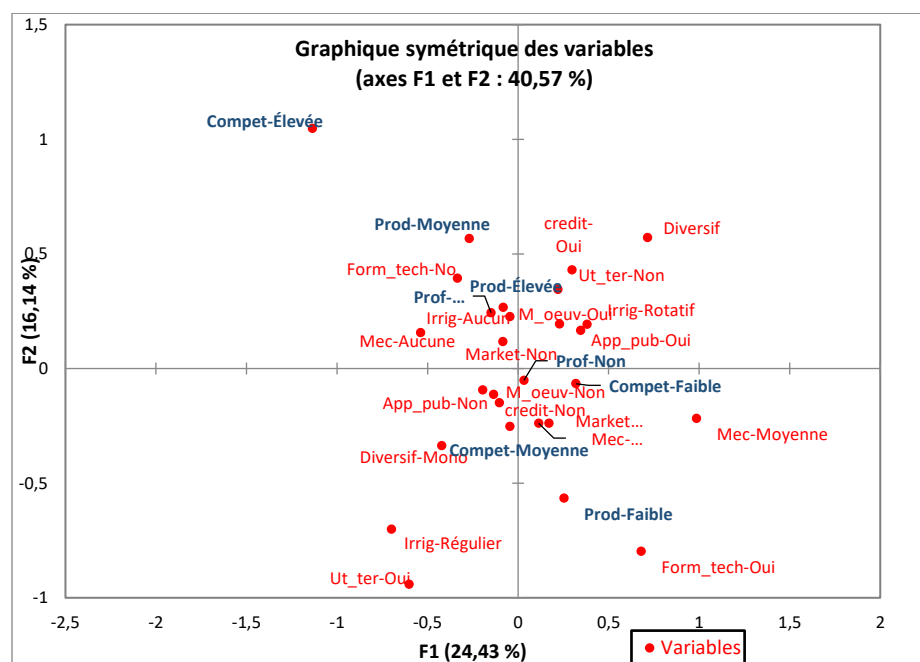


Figure 1: Multiple Correspondence Analysis of Key Perceptions Among Oasis Farmers

Correlation Analysis

The ordinal logistic regression (OLR) analysis identified key drivers of four competitiveness indicators: resource use efficiency (EFFIC), innovation adoption (INNOV), resilience (RESIL), and production costs (COUTPROD). Resource efficiency improves with modern infrastructure (+3.27) but is hampered by labor shortages (−2.48). Innovation adoption rises with education and training (+5.12) yet is limited by poor credit access (−3.98), showing that financial constraints persist even for trained farmers. Surprisingly, labor shortages negatively affect efficiency, as some innovations require intensive labor and technical maintenance. Resilience increases with agroecological practices and crop diversification (+4.89) but drops with monoculture and weak climate adaptation (−3.53). Mechanization and subsidized inputs reduce production costs (−4.23), while high input prices and labor costs increase them (+2.79). These results highlight the need for integrated strategies combining access to finance, training, and infrastructure to strengthen the productivity and sustainability of oasis-based family farming systems.

Discussion and Perspectives

The findings highlight key constraints to family farming competitiveness in Ghannouch's oases: inefficient land use, limited water access, labor shortages, and high input costs. Structural barriers—including poor infrastructure, limited financing, and climate risks—further weaken productivity and profitability (Martin et al., 2017). The lack of government support for modernization and market access exacerbates these challenges (Rebai et al., 2022; Carpentier, 2023). These results imply the need for integrated policies that enhance financial inclusion, improve infrastructure, and support climate adaptation. Strengthening resource efficiency, innovation adoption, and market integration is essential to build a competitive and resilient model for oasis-based family farming (Suess-Reyes & Fuetsch, 2016).

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Labor constraints limit adoption of innovative intercropping in smallholder farms in Rwanda

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Keywords: multicriteria, preference, dissemination, agroecology

Introduction

Population growth in sub-Saharan Africa poses a challenge to food availability and requires a sustainable intensification of agriculture. Among the basket of sustainable intensification options available to smallholder farmers (Descheemaeker et al., 2019), cereal-legume intercropping is often mentioned as a strategy with the potential to increase and stabilize crop yields (Namatsheve et al., 2020). Yet, suboptimal intercropping management can limit yield and net benefits compared to sole crops. Row intercropping (RI), a planting arrangement that places two or more crops in an intentional row pattern, has been promoted to perform better than sole crops and current mixed intercropping systems but there is limited evidence of the performance across a large range of farm conditions (soils, climates, managements, socioeconomic contexts, ...). Numerous studies have examined the yield performance of cereal-legume RI systems on smallholder farms but few have conducted a comprehensive multicriteria analysis to evaluate their nutritional, economic, and social benefits. Additionally, limited research has examined the barriers to their widespread adoption such as increased labor due to the demanding planting patterns in row intercropping (Thierfelder et al., 2024). This study aims to evaluate the on-farm multi-criteria performance of RI along with causes of adoption and potential for widespread dissemination over contrasting conditions in smallholder farms in Rwanda.

Methods

We conducted a unique large-scale multi-season on-farm study of RI in sub-Saharan Africa on 225 farms across a range of environments in Rwanda. We assessed through on-farm trials and surveys: productivity (yield, land use efficiency), nutrition (energy, protein and fat yields), labor requirements (at planting, weeding, and top dressing), economics (total cost, gross and net benefits), and farmers' preferences while uniquely following adoption rates four years after the trials. Land use efficiency in intercropping is measured by the land equivalent ratio (LER), indicating how effectively land is used compared to sole cropping. The four cropping systems evaluated were: i) sole crop maize, ii) sole crop bean s, iii) multiple rows intercropping of maize and beans (RI), iv) local practice of intercropping of maize and beans, and iv) local practice of intercropping of maize and other crops.

Results

We found that RI had better land use efficiency and higher energy yield and profitability than sole crops and other mixed intercropping systems (Figure 1.A). Yet, row intercropping required more labor, resulting in a medium preference among farmers (Figure 1.A). Farmers criticized the higher labor required at planting in RI, which is the period when labor is most limiting (Figure 1.C, Figure 1.D).

Four years after the end of the trials, 30% of the surveyed farmers had adopted RI for at least one season (Figure 1.B). The proportion of farmers who indicated during the trials that they would adopt RI was similar to the proportion who adopted it in the 2024 survey (Figure 1.B). However, there was no direct correlation between stated intentions and actual adoption. Interestingly, pioneer farmers who adopted RI in the four post-trial years achieved significantly higher land use efficiency in their trials compared to non-adopters (Figure 1.E). Additionally, adopters tended to have more neighbors who also adopted RI, whereas the majority of non-adopters were surrounded by neighbors who similarly did not adopt (Figure 1.B).

Discussion

Although RI demonstrates higher multi-criteria performance in most of the farms, farmers have a relatively low preference, and adoption at 30%. The main reason indicated by farmers for non-adoption is the extra labor required for RI, particularly at planting, which is a critical time on the farm calendar that coincides with many competing activities. High labor demand at periods when labor is a limiting factor is often a deal breaker, regardless of other advantages (Anders et al., 2020). Yet, a key novelty of our study is the identification of positive relationships between the land use efficient and adoption, and adoption and diffusion (via neighbor adoption). Thus, prioritizing demonstration plots and extension campaigns in areas and field conditions with higher expected land use efficiency outcomes could substantially boost both adoption and diffusion. To enhance adoption, we also found it important to involve farmers in locally adapting RI designs, providing them with the flexibility to tailor the system to their needs and reduce agronomic and labor-related challenges (Bakker et al., 2021).

Perspectives

Reducing planting labor is crucial for the transition from current mixed cropping systems to RI. Cost-effective tools like hand seeders and row openers can ease the process, while advanced mechanization, such as two-wheel tractors, can significantly reduce labor demands (Baudron et al., 2019). Moreover, discrete choice experiments could help understand farmers' preferences by evaluating trade-offs in factors like labor, costs, and production. The effectiveness of these interventions is hindered by the current extension support system in Rwanda, which focuses on sole cropping despite the widespread practice of intercropping. This disconnect leaves a considerable number of farmers underserved, lacking specific recommendations tailored to their needs and/or preferences. Establishing dedicated support for intercropping could bridge this gap, ensuring that RI practices are more effectively implemented and scaled to benefit a broader population of farmers. By addressing these challenges, RI could play a transformative role in enhancing food security and resilience for smallholder farmers in Rwanda and similar contexts.

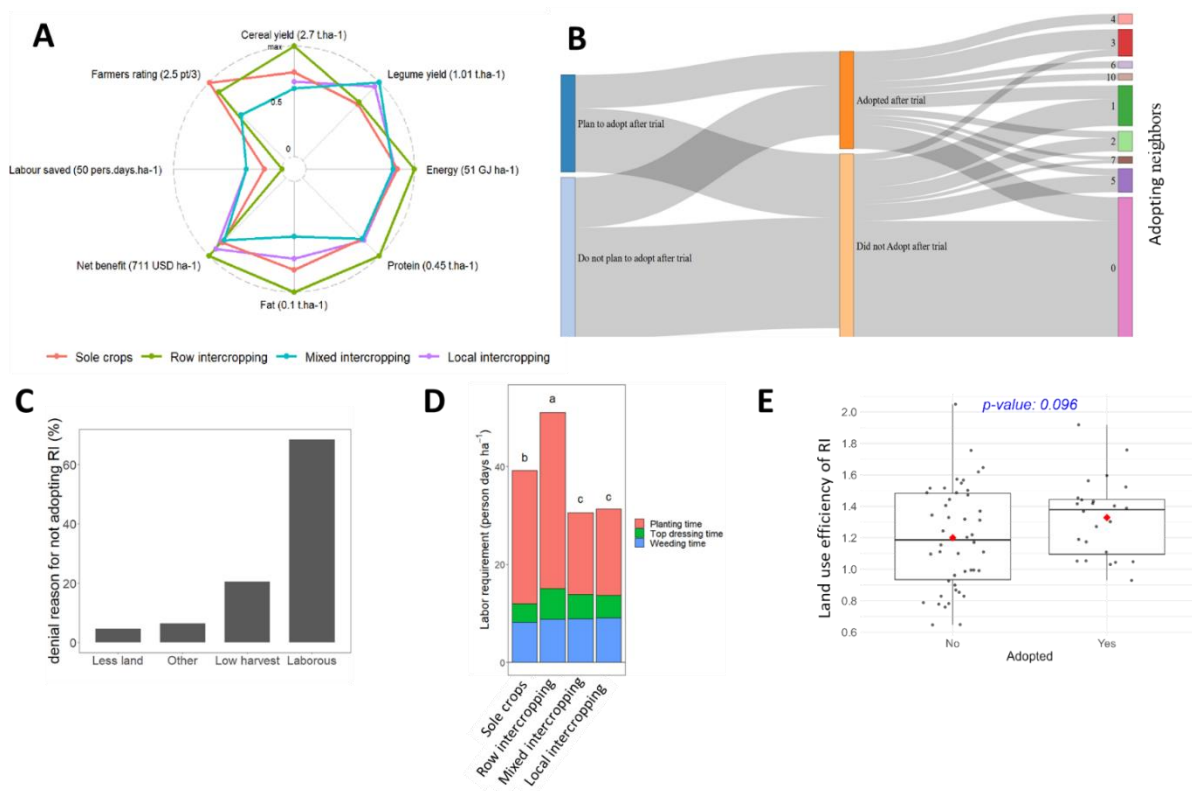


Figure 1. Cropping systems' multicriteria performances averaged across 225 farms and two growing seasons in Rwanda (A). Evolution of the proportion of farmers who planned to adopt row intercropping versus those who adopted it four years after the study, along with the number of neighboring farmers who adopted the practice (B). Reason for not adopting row intercrops (C). Labor requirement for planting, topdressing, and weeding (D). Land use efficiency for farmers who adopted row intercropping compared to those who did not (E).

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Understanding farmers' motivation for mixed farming system re-design: a case from Ethiopia

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Keywords: Mixed Farming Systems, Farm Redesign, Qualitative Methods, Farmer-Centered, Sustainable Intensification

Introduction

Ethiopian farming systems primarily rely on rainfed small-scale agriculture, making them vulnerable to climate variability as well as socio-economic and environmental shocks. This, in conjunction with population growth and increasing land fragmentation, has rendered the design of farming systems imperative for enhancing and sustaining resource use efficiency, productivity, and income.

While many studies have documented farmers' growing interest in diversification, intensification, and integration across core system components, a critical gap remains in better understanding the systemic motivations and rationale that inform their decisions (Hammond et al. 2021). The study was conducted in the context of the Mixed Farming System initiative of the CGIAR (<https://www.cgiar.org/initiative/mixed-farming-systems/>). The initiative, which runs from 2022-2024, is currently consolidated under the Sustainable Farming science program (<https://www.cgiar.org/cgiar-research-portfolio-2025-2030/sustainable-farming/>). Conducted towards the end of the initiative period, the objective of the study was to challenge the 'expert-led' system analysis that was dominating the initiatives' interventions and pave the way for better farm redesign options through a better understanding of farmers' motivation. Beyond the CGIAR programs' interest, this paper presents insights that could improve the relevance, desirability, and scalability of mixed farming system innovations. The study was conducted in the Mixed Farming System initiative operational area in Ethiopia, in Shurmo village, Lemo District, in the Hadiya Zone of the Central Ethiopia Regional State. The village served as a demonstration site where various CGIAR centers collaborated to enhance the farming system through the promotion of different technology packages and agronomic practices.

Methodology

Participatory rural appraisal methods, including focus group discussions (12 FGDs), key informant interviews (5 KIIs), farm visits (5 visits), and transect walks, were used to understand village farming systems from stakeholders' perspectives, including technical experts, government representatives, and farmers. The process began (in March-April 2024) with a desk review, expert consultations, and quantitative system analysis conducted in the past by the initiative research team. The review was used to characterize the system and draft a cognitive map of farming systems of the study area.

The map, identifying key interactions across core components, was then presented (on April 29, 2024) to three mixed group FGD (with one female FGD) farmers in Shurmo village, Lemo, for validation and refinement. This participatory process examined farmers' motivation for keeping complex farming system, drivers of system transformation over time (changes farmers adopted and why) and explored opportunities for improving the existing system. This was followed by 2 FGDs, one mixed group of farmers and one expert group on appraisal of MFS

initiative innovations implemented, designed, and deployed based on expert-dominated farming system analysis.

On May 1 and 2, 2024, serious games (Adolph et al. 2023) were played with 8 groups of farmers disaggregated by gender, age, and wealth status. The games facilitated discussions on sustainable intensification dimensions (Musumba et al. 2017), covering productivity, economic, social, human, and environmental aspects. Farmers' stated preferences and choices were assessed, analyzing differences in prioritization (economic, social, and environmental benefits) influencing decisions and identifying key constraints to system transformation.

The process concluded with a workshop in November 2024, in Lemo district, where experts discussed findings and set gendered scaling strategies (McGuire et al. 2024) for key innovations identified as relevant and acceptable to farmers.

Results

The farming system in Shurmo Village consists of diverse crops (wheat, maize, teff, barley, faba bean, enset, avocado, and vegetables) and livestock (cattle, sheep, goats, and poultry). Farmers often manage 20 or more enterprises. Key production constraints include climate variability, water shortages, crop diseases, and limited access to improved seeds and extension services. Gender-based differences emerged in system perceptions: men prioritized cash crops and livestock feed, women emphasized home garden crops and food security, and youth focused on technology and land optimization.

Socio-technical interventions had mixed results. Improved faba beans boosted productivity, profitability, and soil fertility. Oat-vetch forage increased milk yield but had limited environmental benefits due to small-scale adoption. Poultry production improved nutrition but was less profitable due to high feed costs. Improved avocado and durum wheat were in early stages, limiting impact assessment. Farmers adjusted land use, increasing allocations for profitable, sustainable crops like avocado, wheat, and forage.

Potential system redesign options revealed shifts in land use based on sustainability indicators. High-value crops like avocado, coffee, and pepper were prioritized, while land allocated for wheat, maize, and teff is expected to be reduced. Farmers demanded expansion of forage crops cultivation and practices like crop rotation and tree planting identified as options to improve soil health. These are options that farmers prioritized that subsequent interventions, such as the new CGIAR science program, Sustainable Farming, need to consider in their future interventions.

The gendered scaling analysis highlighted risks of reinforcing inequalities. While increased productivity and income benefited households, women often lost financial control and faced higher labor burdens. Addressing this requires gender-transformative strategies, such as joint decision-making, financial access for women, and collaboration with gender-focused organizations.

Discussion

The study highlights the complexity of designing small-scale mixed farming systems and the need for integrated interventions. Farmers' motivation for keeping a complex farming system includes diversification to reduce risk, intensification to earn better income, household food consumption, and complementarity between different farm enterprises (Meunier et al. 2024). Redesign options often incur a cost, as managing trade-offs can have livelihood

consequences. This partially explains the reason why smallholder farmers often resist external interventions that do not fully understand the complexity of their farming systems.

Gender-responsive approaches are critical as male, female, and young farmers aim to achieve somewhat different objectives, which in turn influence their preferences and the challenges they face in achieving them (McGuire et al. 2024). For instance, the youth expressed greater interest in technology-driven solutions, emphasizing the potential for innovation in sustainable agriculture. The findings underscore the importance of context-specific interventions, such as improved seed access, water management solutions, and targeted extension services.

Future efforts should focus on scaling innovation that responds to farmer's needs, strengthening farmer cooperatives, and enhancing participatory research approaches. Deliberate actions are needed to promote responsible scaling to understand and take the socially differentiated impacts of unintended consequences of scaling efforts.

Making farmer co-designers of their farming system would make agricultural development strategies relevant, desirable, and scalable and would result in resilient farming systems. (Meunier et al. 2024) This study provides valuable insights into the dynamics of Ethiopian mixed farming systems, contributing to more effective agricultural policies and interventions.

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Drivers for double cropping adoption in north-eastern Italy

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Keywords: soybean, territorial drivers, LPIS, GIS

Introduction

Climate change is a driver of cropping systems changes. Supporting them require knowledge of farmland dynamics for effective policies for farm resilience and sustainability. Diversification practices have been tested and proposed as adaptation (Hufnaghel et al., 2020), like extension of crop rotations, intercropping, cover crops or double crops (DC) (Messean et al., 2021). DC, which requires abundant water and long growing seasons, is constrained in Mediterranean areas by water scarcity. Nonetheless, DC offers benefits such as supplemental income, reduced fixed cost incidence, improved pest and weed control, and soil erosion prevention (Dou et al., 2023). In Friuli Venezia Giulia region (FVG), North-Eastern Italy, DC is a common technique (Estel et al., 2016) but very little is known about its spatial distribution and adoption drivers. In this context, our goal is to assess DC patterns via the Land Parcel Identification System (LPIS) database investigating the factors affecting DC in farms.

Material and methods

FVG, in North-Eastern Italy at the top of the Adriatic Sea, bordering with Austria and Slovenia, is suitable for DC thanks to June-August rainfall patterns (613 mm). Cropping systems are based on summer crops, mainly maize and soybean, in rotation with winter cereals. Since LPIS collects CAP subsidy applications, we used five LPIS layers (2019–2023) as spatially-explicit data for DC assessment. For each parcel we used information on the anonymized farm code, area, parcel id, crop code and use and irrigation availability (IrrA). From 2023 declaring all the crops in a parcel became compulsory before, the second crop declaration was voluntary. Thus, DC areas from 2019–2022 are likely underestimated, though the frequency of DC sequences remains comparable. Based on literature and local expert knowledge (5 farmers interviewed until March '25), we identified 3 potential factors affecting DC adoption: farm size, irrigation, location in relation to resurgences line (rl): soils with low water availability above, high below. Based on that we formulated three hypotheses. The first hypothesis is that DC is mainly used in medium-small and medium-sized farms to mitigate fixed costs and yield instability risks. We tested this by correlating farm UAA and DC ratio (DC_UAA/farm_UAA).

The second hypothesis is that DC is favoured by irrigation. This was tested using a Chi-squared test comparing DC and single cropping (SC) hectares with IrrA. The third hypothesis concerns the rl, where groundwaters emerges due to clay and silty layers of the alluvial plain, that is hypothesized affecting water availability for farms due to soil structure and depth. Thus, we tested for differences in DC adoption in the two sub-regions above and below the rl using a Chi-squared test. All statistical analysis were performed on RStudio-2024.12.1-563.

Results

DC area was 5% of LPIS UAA in 2019-2022. The most abundant spring crops were maize, soybean and sorghum, whereas the winter ones were wheat and barley. In 2023 the DC surface detected was 10% (21341 ha) with 171 unique first/second crop combinations. Soybean, maize and sorghum covered 98% of DC surface (tab.1). Farm size and DC intensity have a small positive relation. No positive association emerged between IrrA and DC adoption

but, soybean and sorghum as second crop are related to no IrrA. Farmers interviews validated DC identification through LPIS analysis.

	grain soybean	silage maize	forage sorghum	grain maize	grain sorghum	forage soybean	
grain soft wheat	26,0%	0,2%	0,7%	0,3%	0,5%	0,0%	28,4%
grain barley	36,6%	0,4%	0,5%	0,6%	0,3%	0,0%	39,0%
forage soft wheat	2,2%	2,7%	0,8%	0,1%	0,1%	0,0%	5,9%
rapeseed	4,6%	0,0%	0,1%	0,0%	0,0%	0,0%	4,7%
forage barley	1,5%	3,7%	0,2%	0,1%	0,0%	0,0%	5,6%
grassland	1,1%	1,2%	0,6%	0,2%	0,2%	0,0%	3,9%
forage triticale	2,0%	1,7%	0,4%	0,1%	0,1%	0,0%	4,4%
ryegrass	1,2%	0,5%	0,5%	0,2%	0,0%	0,0%	2,5%
grain pea	0,8%	0,0%	0,2%	0,0%	0,0%	0,0%	1,2%
grain triticale	0,8%	0,0%	0,0%	0,0%	0,1%	0,0%	0,9%
forage pea	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%
	78,2%	11,5%	4,7%	2,2%	1,3%	0,1%	

Table 1 : the most abundant crops in DC for 2023 (crop DC ha/total DC ha)

	DC	SC	chi ² -test
Average intensity per farm	9%	91%	***
IrrA average surface	13%	29%	***
	Above resurgence line	Below resurgence line	chi ² -test
Average DC intensity	8%	6%	p>0,05

Table 2 : main statistical analysis for 2023. First raw show the average intensity (farm DC or SC hectares/total farm UAA) per farm of DC and SC. The second raw shows the average of Irrigable area in DC and SC. The third the DC intensity in the two sub-regions

Discussions and perspective

DC covers barely 10% of farm surface, but DC intensity is not homogeneous among the different farm size classes. IrrA affects DC less than reported in literature when looking at the whole region (Lamichhane et al., 2023) probably due to the rainfall patterns in late spring. Water demand for DC adoption is thus supplied by rainfall; if they change, adjustments in DC will be needed. Soybean and sorghum are preferred over maize in non-irrigated areas due to their lower water demand (Pitchers et al., 2023). DC intensity is not affected by location; this was unexpected considering the differences in water availability. Farmer interviews suggest that maize is still perceived as a cash crop but, the low water availability (irrigation/soil) combined to changing rainfall patterns may make preferable DC to maize as main crop. This perception seems to be supported by the higher percentage of SC than DC with IrrA. In this sense, this study provides a preliminary regional-scale analysis of DC and its adoption drivers.

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Flexible crop rotation identification and classification: new tool and application to France

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Keywords: Cropping systems, Circular pattern matching, Land Parcel Identification System, Crop sequence

Introduction

Characterizing dominant crop rotations across spatial and temporal scales is essential for farming system design and modeling. Crop rotations influence key ecosystem services such as yield, nutrient cycling, and pest control (Sahajpal et al., 2014). They consist of recurrent crop successions on a field over time. In Europe, the Land Parcel Identification System (LPIS) is the most comprehensive source of field-level agricultural land-use data. In France, LPIS covers 94% of agricultural land, detailing crop successions for approximately nine million parcels in continuous sequences of increasing temporal depth (Girault and Martin, 2024). However, the very high diversity observed in crop sequences complicates identifying dominant rotations at territorial or higher levels.

Approaches identifying dominant crop rotations range from indirect statistical or machine learning-based reconstruction to direct rule-based or expert-based estimations (Leenhardt et al., 2012). Indirect methods often combine Markov chains with clustering techniques, generating artificial crop sequences that are statistically representative at the territorial level and further analyzed with agronomic expertise (e.g., average return time of starter crops, functional diversity; Nowak et al., 2022; Stein and Steinmann, 2018). Direct approaches identify existing recurrent patterns before assessing their representativeness. However, crop rotations are modified by climatic or socioeconomic factors, challenging algorithm convergence and reuse in cropping systems models (Bohan et al., 2021). The last large-scale attempt in France to identify field-level crop rotations using an ad-hoc direct approach (Leenhardt et al., 2012), identified predefined agronomically coherent rotations of up to three crops, aggregated into 13 classes.

Existing methods lack flexibility and reusability due to unavailable or case-specific code and reliance on expert calibration. A tool for systematically identifying and classifying crop rotations while maintaining adaptability for novel applications is needed.

Methods

Our approach generalizes the rule-based algorithms from Leenhardt et al., (2012) and Sahajpal et al., (2014). It requires a crop sequence dataset, a crop codes mapping table, and outputs dominant crop rotations with their spatially explicit coverage. The procedure consists of five steps: (i) crop codes aggregation, (ii) crop sequence preprocessing, (iii) flexible crop rotation matching, (iv) selection of dominant crop rotations, and (v) distance assessment between crop sequences and rotations.

First, crop codes are aggregated to a tunable granularity level to reduce crop and sequence diversity. Sequences with perennial or unknown crops are discarded. Recurrent patterns covering at least 60% of a crop sequence's length are identified iteratively (e.g., for an eight-

year dataset, patterns of up to four years are detected if covering at least five years). A unique terminology (*P_f_{non-P}_%seq) captures the pattern (P), its coverage ratio (%seq), and flexible crops (non-P). Among different potential matching patterns, one is retained, with hierarchical criteria: maximizing coverage and preferring shorter and recently observed patterns. Circularity checks ensure equivalent patterns (e.g., A-B-C, B-C-A and C-A-B) are unified. Patterns P without flexible crops are considered rotations.

Dominant crop rotations are identified based on customizable selection criteria, such as limiting the number of rotations or setting a minimum representativity threshold. Each crop sequence (including those without any matching pattern) is then assigned to the most similar selected rotation using custom distance metric, typically the Hamming distance, which measures substitution costs between sequences. Ties are solved through random sorting.

The procedure was applied to the 2015-2022 metropolitan France crop sequence dataset (Girault and Martin, 2024), after filtering fields below 0.5 ha. LPIS crop codes were aggregated into 50 classes, and rotations selected to represent at least 50% of total arable land.

Preliminary results

We illustrate results using two contrasting French regions: Meurthe & Moselle and Beauce. These regions include 66,900 and 45,900 crop sequences, but only 25,000 and 29,000 remain unique after crop code aggregation. Flexible crop rotations cover 85% and 87% of the selected area, with shorter %seq sequences predominant in Beauce. For instance, if the pattern-matching threshold were raised to 70% instead of 60%, flexible crop rotations would cover only 50% of Beauce's area. Identified flexible rotations (*P_f_{non-P}_%seq) maintain 80-90% uniqueness even after circular harmonization (15,400 and 19,800), but drops to 10-15% considering patterns P only (yielding 2300 and 3100 distinct rotations). The largest 11th and 80th crop rotations together cover 50% of the total area (Table 1) and represent 90% of crops and 70% of successive crop pairs observed at the territorial level. Full nationwide results, including sample size, calibration effects, and assessment of rotations' length and diversity, will be presented at the conference.

Meurthe & Moselle		Beauce	
Grassland_100	28%	BTH-BTH-CZH	4.0%
BTH-BTH-ORH-CZH	15%	BTH-MIS	3.5%
BTH-ORH-CZH	8.8%	BTH-ORH-CZH	3.5%
BTH-BTH-BTH-MIE	4.2%	BTH-CZH	2.5%
BTH-MIE	4.0%	BTH-BTH-ORH-CZH	2.5%
<i>BTH: soft winter wheat; ORH: winter barley; CZH: winter rape; MIE: silage maize; MIS: grain corn</i>			

Table 1. Top five dominant crop rotations and their total area coverage

Perspectives

Limited by data history availability, the proposed procedure missed here five-years and longer rotations. Comparing outputs with farmer decision-making and expert insights can enhance interpretability. Yet, the procedure identifies circular crop patterns from field data, simplifying complex crop successions into representative rotations, and can support scaling strategies for cropping and farming system models like STICS or MAELIA.

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Legume-based crop diversification in smallholder farming systems: insights from a farm-level analysis of crop allocation practices

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Keywords: crop rotation, cropping practices, legumes, maize-based systems

Introduction

Legume-based crop diversification is widely regarded as an agricultural development strategy for smallholder farmers in Africa, as it has the potential to diversify diets, improve soil fertility, and increase small-farm productivity. Farmers are generally aware of the benefits of legume integration and commonly cultivate them on small areas. Agriculture research has mostly focused on the development of innovations to intensify legume production at field-level, introducing higher yielding varieties, inoculants, fertiliser blends, as well as improved agronomic practices. The underpinning assumptions have often been that higher productivity makes legumes production more profitable, and that higher returns on investment increases farmer uptake.

The targeting of interventions has often been based on experimentally derived agronomic benefits and ex-ante modelling analyses rather than actual farmer practices, often limiting the local relevance and adoption of these technologies (Nord et al., 2021). Evaluating crop diversification strategies is crucial given rising fertiliser prices, on which maize cultivation heavily depends. This context reinforces the need to expand the area of crops like legumes, which can still yield with few inputs.

Constraints to legume expansion are often attributed to a combination of limited marketing opportunities, dysfunctional input and seed market, and resources endowment (Mhango et al., 2012). However, farm-scale studies on farmers' legume crop allocation practices remain scarce and our understand of locally relevant maize-legumes cropping systems remains limited. This study investigates, from a farm-scale perspective, how current maize-legume cropping systems are shaped through farmers' decisions on crop and resource allocation, with the aim of identifying key drivers of crop diversification practices.

Methods

The study was conducted in the Songwe Region, a major rainfed maize-producing area in Tanzania's Southern Highlands. The heterogeneity of agroclimatic conditions across the highlands results in highly localised cropping systems, where maize is consistently grown alongside one or more legumes, such as common beans, groundnuts, and soybeans.

The study draws on a farm characterization survey of 140 farms, which involved reconstructing field-level crop sequences for each field of the farms over the four preceding growing seasons (Figure 1), along with collecting detailed information on input use, labour, cropping calendar, and productions. Farmers' orientations and decision-making processes related to the observed cropping practices were further explored through follow-up semi-structured interviews.

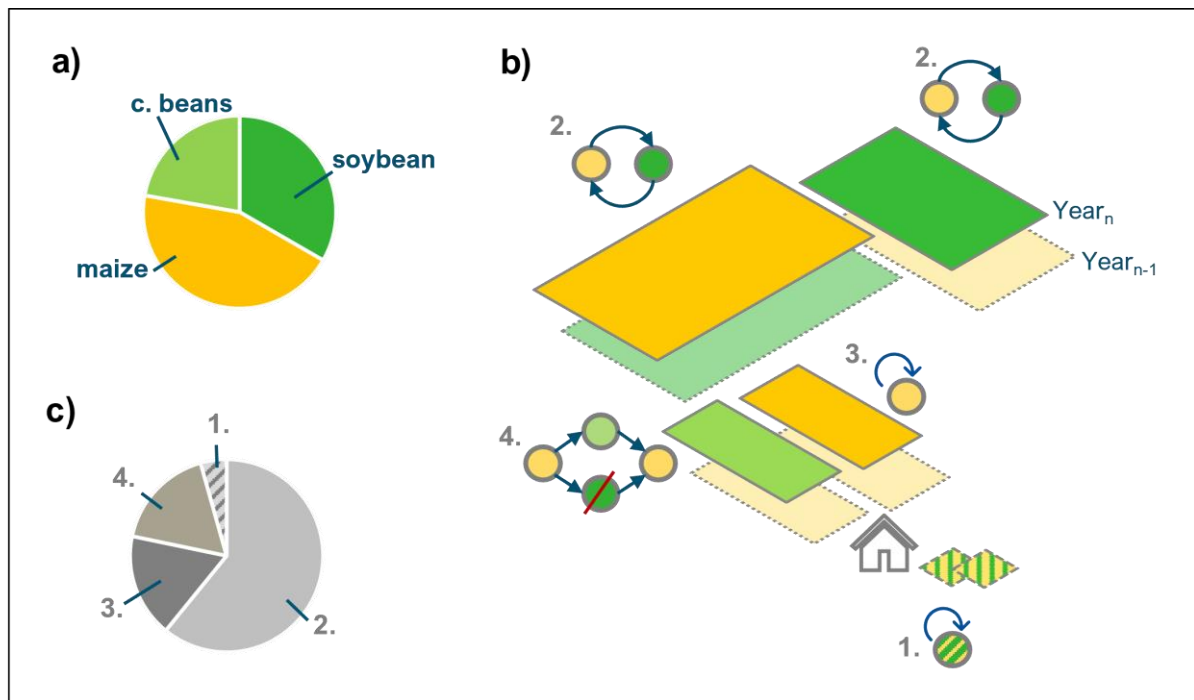


Figure 1. Farm-scale crop area distribution on an example farm for a given (n) season between maize, common beans, and soybean (a); field-based crop allocation (b) types of maize-legumes cropping systems: maize and common bean relay cropping (within season) repeated over multiple seasons (1), simple rotation between maize and a single legume species (2), flexible rotation between maize and multiple legumes species (4), and maize monocropping or maize-dominant rotation -maize cultivated 3 out of 4 years- (3). (c) Share of each cropping system over the total farm area.

Results and Discussion

Crop allocation practices result from farmers' decisions aimed at fulfilling production objectives while adapting to local constraints. Two interacting levels of decision-making can be distinguished. At the farm level, production orientation translates into a desired crop share (Fig. 1a), shaped by agroecological suitability of crops, marketing opportunities, and household's resource endowment. Maize area is typically determined first, based on food security needs and fertiliser expenditure capacity. Legume area is adjusted according to the land that remains, usually cultivated with no or minimal inputs. On average, farmers dedicated 53% of their farm area to maize and 33% to legumes (common beans, groundnuts, and soybean), with one to two legume species commonly grown on the same farm, typically one cultivated as a cash crop (soybean, groundnuts), and the other for both food and market purposes (common beans, groundnuts).

At the field level, adjustments in crop allocation were based on rotation considerations, field characteristics, and the availability of inputs and labour at the start of the season. Farmers relied heavily on maize-legume rotations (Fig. 2), with a range of cropping systems co-existing within farms (Figs. 1, 2). These systems were mostly characterised by the practices of rotating maize and legume(s) every season. These cropping systems were associated with specific functions (Dury et al., 2013). (i) Optimising input use efficiency: farmers prioritised fertiliser use on the most demanding crop and valued the reduced input requirements for maize when rotated annually with legumes. (ii) Leveraging heterogeneity of land and labour resources: legumes were often allocated to fields with declining productivity, or to plots managed by specific household members, reflecting intra-household division of labour. (iii) Providing stability within and between season: maize-common bean relay cropping enabled staggered harvests and income within a season, while flexible rotations with multiple legumes allowed

adjustments based on seasonal legume market prices and household needs. While not exhaustive, these crop allocation practices reflect diverse and increasingly complex strategies. Rotation patterns capture one important dimension, but others exist, such as dynamic land tenure arrangements, which offer additional options for crop allocation.

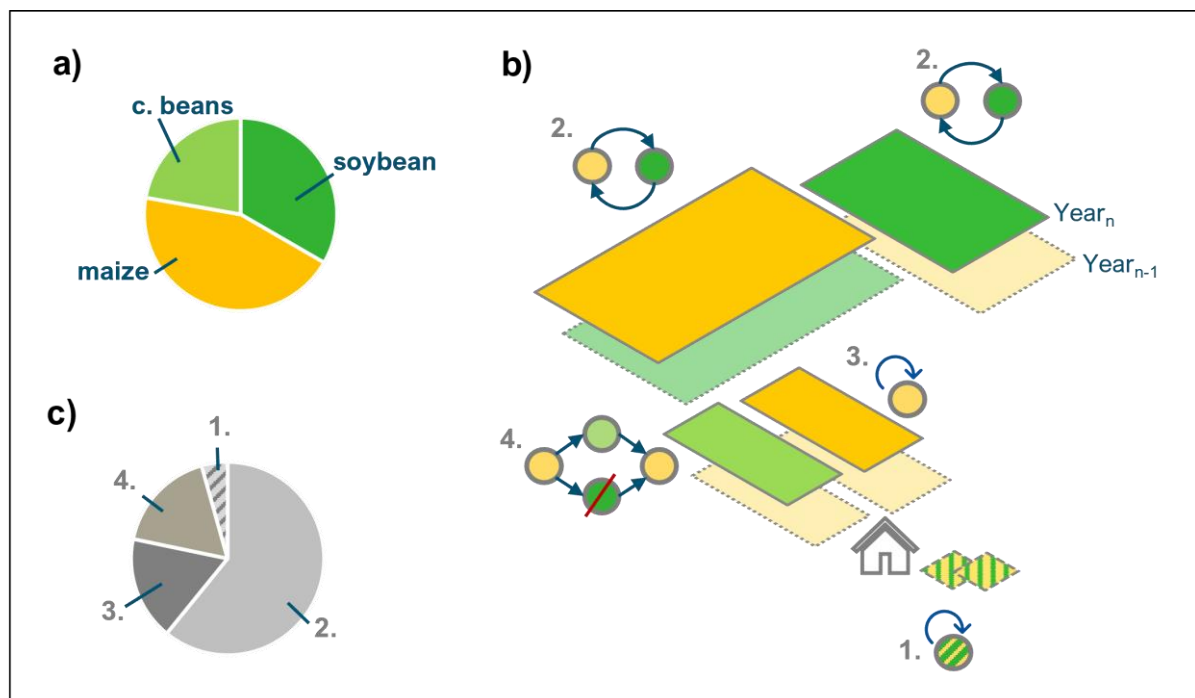


Figure 2. Cropping systems distribution over the total farm area for a sample of 63 farms. Farms are ordered in increasing order of total cultivated area during the 2023-2024 growing season and subdivided into the dedicated areas for each type of cropping systems.

Perspectives

Legume-based crop rotations are widespread in maize-dominated smallholder systems in Tanzania's Southern Highlands, primarily as a low-cost strategy to manage input use. Cost reduction remains the primary motivation for cultivating legumes. Given additional capital, most farmers would allocate resources to maize intensification, or farm expansion, rather than investing in technologies aimed at intensifying legumes production. Area and rotation frequency of legumes are shaped by the arbitration of resources at the farm level, highlighting the importance to assess and design diversification strategies from a whole-farm perspective.

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Intercropping and crop diversity: how farmers integrate species into arable systems

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Keywords: cropping system, legumes, DEPHY network, crop diversification

Introduction

Crop diversification is a promising approach to enhance ecosystem services in simplified cropping systems (Tamburini et al., 2020). Increasing plant species diversity, both spatially and temporally, has been shown to improve pest and disease control, water and soil quality, and crop production (Beillouin et al., 2021). One of the most studied diversification practices is intercropping, the simultaneous cultivation of two or more species in the same plot. This practice has been applied to a wide range of systems, particularly in arable crops, and has demonstrated positive effects on ecosystem services and input reduction (Yan et al. 2024). However, while intercropping is well-studied in research stations, its adoption by farmers remains poorly understood. There is limited knowledge on how farmers integrate intercropping into their cropping systems, which species they choose, and how intercropping affects overall crop diversity. Moreover, it remains unclear whether intercropping introduces new species into farming systems and whether these species persist once intercropping is discontinued.

In this study, we investigate how farmers in France implement intercropping in arable systems by looking at the plant species used in association. We also study how species diversity and composition change over time when intercropping is implemented by comparing cropping systems before the adoption, during its implementation, and post-abandonment.

Methods

We used data from the French national DEPHY network, which has monitored over 2,000 farmers implementing cropping systems that are less reliant on pesticides since 2010 (Lechenet et al., 2017). For this study, we analysed approximately 500 cropping systems that included intercropping in both conventional and organic systems, with data spanning multiple years (minimum 3 years, maximum 15 years) (Fig. 1). The dataset included different types of intercropping, such as combinations of cash crops, fodder mixtures, and cash crops with companion plants. Based on this dataset we characterised the intercrops used by farmers.

To assess the impact of intercropping, we identified 324 systems where intercropping was not practiced at some point during the recorded years. This allowed us to compare species composition before, during, and after the implementation of intercropping.

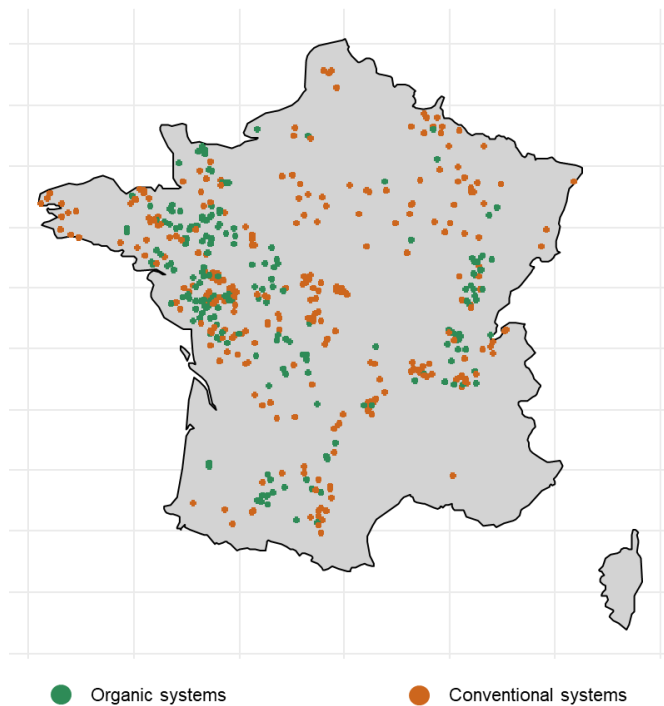


Figure 1, Location of the cropping systems (organic in green, conventional in orange) using intercropping in the DEPHY network.

Results

Our results indicate that farmers primarily intercrop cereals with legumes (approximately 80% of recorded intercrops), followed by brassicas with legumes (6%) and cereal mixtures (4%). We found that crop species richness, diversity, and evenness significantly increased during intercropping, independent of other baseline changes in the cropping system (Fig. 2). This increase in diversity led to a higher proportion of legumes and a lower proportion of cereals within the cropping system.

Additionally, we found that intercropping involved both previously cultivated species and newly introduced species in 40% of cases. In approximately 30% of cases, the intercrops consisted entirely of new species for the system, while in 10% of cases, all intercropped species had already been cultivated by the farmer before intercropping. Interestingly, after discontinuing intercropping, only 20% of farmers continued growing all the species they had previously intercropped, while 40% retained some of the species and another 40% abandoned them entirely. Legumes were the most commonly introduced species but also the most frequently abandoned. Interestingly we observed that species composition is more similar between years recorded before and after intercropping than when comparing these years to the composition while intercropping is implemented, showing that cropping systems tend to go back their initial state once intercropping is stopped.

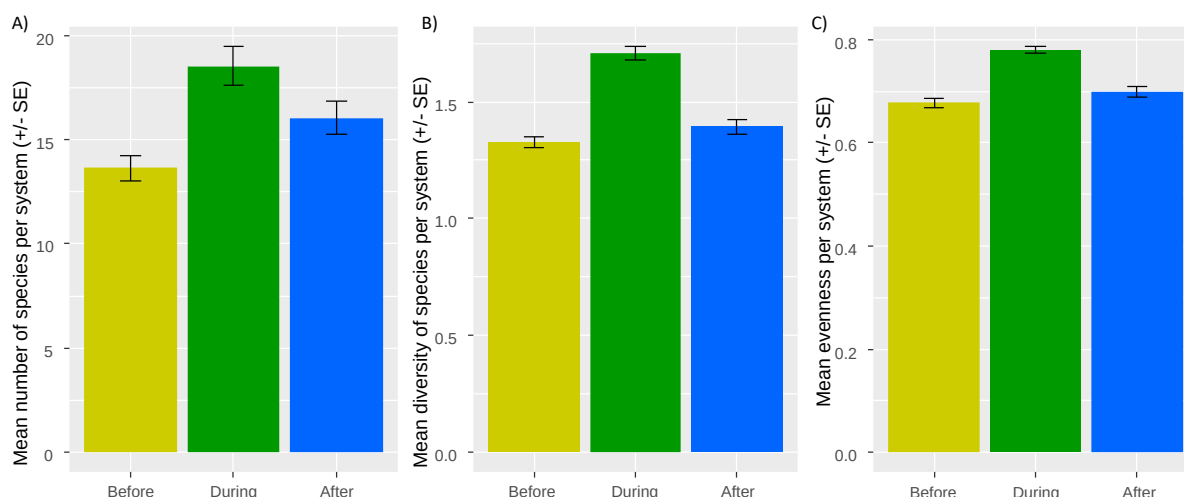


Figure 2, A) mean number of plant species per cropping system in three intercropping phases (before, during, and after using intercropping). B) Mean diversity (Shannon index) of plant species per system in three intercropping phases. C) Mean evenness (1-Simpson index) per cropping system in three intercropping phases.

Discussion and Perspectives

Our findings highlight that intercropping is an effective strategy for increasing crop diversity in cropping systems. It promotes the inclusion of legumes, which can reduce reliance on synthetic fertilisers and enhance cropping system sustainability. However, while intercropping introduces new species into farming systems, these species are often abandoned once the practice is discontinued. Additional species were often minor crops such as pea, faba bean, or triticale, and their discontinuation might be related to difficulties in finding appropriate markets for those crops, which is often a barrier to the implementation of intercropping (Mamine, 2020; Jensen 2020; Morel, 2020). However, specific reasons behind these changes could not be identified with the data available and direct interactions with farmers would be needed to uncover these reasons.

This study provides valuable insights into how intercropping influences cropping system composition. However, further research is needed to assess how these changes impact system performance, particularly regarding pesticide and fertiliser use.

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Exploring machinery management logics for implementing species mixtures: insights from agronomy

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Keywords: equipment, farmer's strategy, innovation tracking, intercrop

Introduction

Species mixtures are one of the key tools for agroecological transition, allowing for reduced environmental impacts while maintaining yields (Bedoussac et al., 2015). However, farmers often face difficulties when willing to implement this technique for the first time, particularly regarding their access to suited equipment for growing and sorting species mixtures (Bellon Maurel & Huyghe, 2017). Whereas various studies showed that farmers already develop species mixtures (Feike et al., 2010; Verret et al., 2020), we don't know how they manage their equipment consequently. This study explores farmers' logics for managing their equipment to grow and sort species mixtures.

Methods

The method is based on the on-farm innovation tracking approach (Salembier et al., 2021). We surveyed 14 farmers who cultivate species mixtures and modify their machinery accordingly. Drawing on concepts from system agronomy, we analyzed the data collected on each farm to explore: (i) how farmers manage species mixtures from an equipment perspective, (ii) the technical characteristics of the machinery used for implementing mixtures, including modifications, repurposing, and tinkering, and (iii) their machinery management logic to implement mixtures. Multi-thematic coding (Dumez, 2013) was used to group information according to different categories associated with actions, equipment and the farmers' logic of action.

Results

For all the farmers surveyed, sowing, harvesting and sorting are key moments during which they manage differently their equipment fleets, aligning with the ways they handle their species mixtures.

From the farmer's point of view, the spatial arrangement and seeding depth are two technical choices significantly interfering with the equipment management logic. Among the 20 species mixtures identified (Table 1), we distinguished six categories that differ on these two aspects. For instance, the Category 1 consists of species sown in the same row at the same depth, while the Category 2 features species sown in alternate rows and at different depths (Figure 1). A given mixture can be grown according to several categories, depending on the farmer. This is the case for the wheat-faba bean mixture, which is grown in all categories except Category 4 (same row but different depth). Similarly, a farmer may use different categories depending on the nature of the mixed species. Thus, of the nine farmers who cultivated at least two species mixtures, three used two different categories (Categories 1 and 6).

Among the mixtures practiced, various harvesting and sorting methods were observed, leading us to propose a second typology of species mixtures based on the number of species harvested and the market outlet for the harvested product, regardless of whether it requires sorting (Categories A to D). One case involves the cooperative for sorting the wheat-faba bean mixture preferring to outsource the sorting rather than taking on an additional task during harvest when species need to be delivered promptly. Another farmer harvests his wheat-pea mixture and sells it directly to a livestock farmer without prior sorting.

We identified and categorised a variety of equipments that has been repurposed, adapted, combined, and tinkered with for the sowing, harvesting, and sorting. Most of them concern the sowing and only one the harvest. For example, a farmer uses a seed drill with two distribution heads and partitions the hopper to sow a wheat-faba bean at two different depths. Another combines a precision seed drill for maize with a slug pellet spreader to sow clover, facilitating the sowing process in one pass (Figure 1).

Among the 14 farmers interviewed, we identified three management logics of equipment fleet to grow and sort species mixtures: (i) minimizing costs in mechanization by repurposing existing farm equipment, (ii) adapting equipment to sow mixtures based on species characteristics and physiology (e.g. seeding depth), and (iii) choosing mixtures and equipment in relation with the available resources locally (e.g. agricultural services, sorting platforms and cooperatives).

Discussion and Perspectives

This study proposes a novel perspective on species mixtures by considering equipment used in practice. This equipment-based approach enhances existing literature (e.g. Gardarin et al., 2022; Verret et al., 2020), which characterizes mixtures primarily by their sowing date, duration of species coexistence in the field, and intended outcome (cash vs. service), without considering the machinery involved. Our study reveals a more nuanced spectrum of equipment use than the conventional binary between "self-built tools" and "new or robotic equipment." Indeed, as shown in previous studies (Comi, 2023; Salembier et al., 2020), farmers adapt, repurpose, and deeply modify their equipment. This original approach yields results that could inform the design of species mixture, integrating equipment considerations across various situations.

Species mixtures (nb of farmers cultivating the mixture)	Category based on sowing						Category based on harvest and sorting			
	Same depth			Different depths			2 species harvested			
	Cat. 1 same row	Cat. 2 alternate rows	Cat. 3 broadcast	Cat. 4 sam row	Cat. 5 alternate rows	Cat. 6 row and broadcast	Cat. A no sorting	Cat. B easy sorting	Cat. C difficult sorting	Cat. D no sorting
Wheat - Faba bean (8)	3	1	1		1	2		2		2
Wheat - Clover* (1)							1		4	
Wheat - Pea (1)	1									1
Wheat - Faba bean - Pea (1)			1					1		
Wheat* - Lentil (1)	1						1			
Triticale - Pea (4)	3	1						1		2
Triticale - Faba bean (1)	1									1
Barley - Pea (2)	1	1								2
Barley - Faba bean (1)	1						1			
Barley - Lentil (2)	1							1		1
Barley - Clover* - Alfafa* (1)		1				1	1			
Rapeseed - Cover crops* (4)		1		1		2	4			
Spelt - Lentil (1)	1								1	
Oat - Vetch (1)						1				1
Buckwheat - Clover* (1)	1						1			
Rye - Faba bean (1)	1									1
Rye - Lentil (1)	1								1	
Khorasan wheat - Faba bean (1)	1							1		
Sunflower - Cover crop* (3)						3	3			
Maize - Soybean - Clover* (1)						1	1			
Number of species mixtures (out of 20)	14	5	2	1	1	7	8	5	4	9
Number of farmers (out of 13)	8	3	1	1	1	5	7	5	3	6

Table 1: Number of farmers growing the different species mixtures identified and categorisation of these mixtures according to spatial arrangement and sowing depth (Categories 1 to 6) and according to

categories of harvesting and sorting of the mixtures (Categories A to D). * indicates a service plant in some cases.

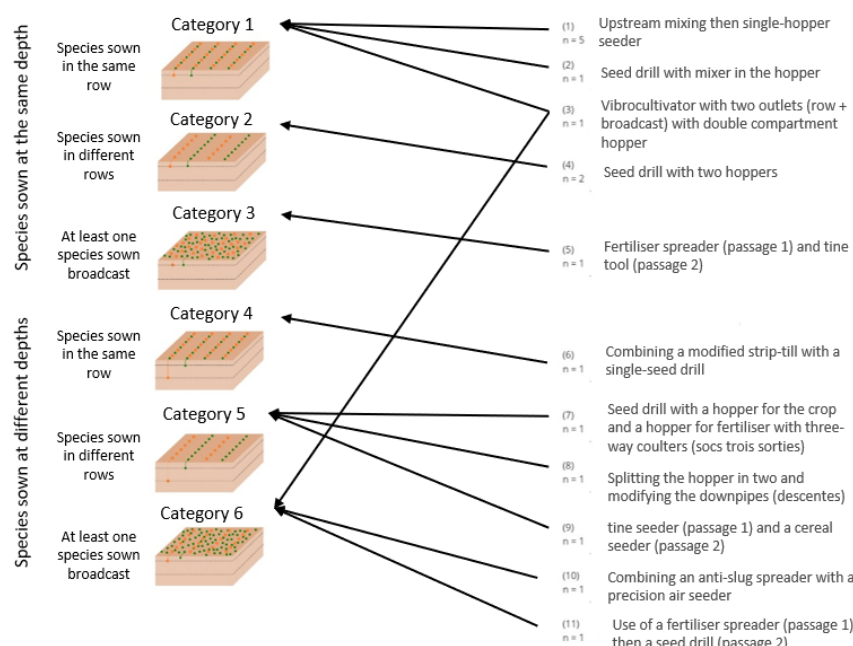


Figure 1: Schematic representation of the six categories of mixtures identified according to seeding depth and spatial arrangement of associated species (Left); Tools and number of farmers using them (n=) for the different mixture categories (Right).

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Agroforestry market gardening: lessons from farmers' practices in south-eastern France

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Keywords: trajectory, typology, design, Mediterranean area

Introduction

Over the past fifteen years, south-eastern France has seen a growing interest from both established and aspiring farmers in Agroforestry Market Gardening (AMG), cropping systems combining trees (mostly fruit trees) and market gardening on a plot. These systems promote biodiversity, diversify income and support agricultural adaptation to climate change. They are commonly found on small-scale organic farms relying on short supply chains (Léger et al., 2018). However, their structural complexity, mixing multiple annual and perennial species, makes them challenging to implement and manage. This paper explores farmers' experiences to identify obstacles and drivers influencing AMG sustainability.

Methods

In the French Mediterranean area, about 50 farms implementing AMG have been identified through previous research projects and local partners. All farms are organic, with most focusing on vegetables and/or fruits production, and AMG areas ranging from 0.1 to 3.5 hectares. Few farms are fully managed under AMG; most implement it partially. A sample of 20 farms has been selected for surveys based on the diversity of their histories and systems. Indicators for system characterization and insights into practices' evolution and their drivers over time were provided through semi-structured interviews and farm visits. An AMG cropping system is characterized by its spatial arrangement (alignment patterns and trees spacing), the number and types of species cultivated, along with management methods specific to its perennial (trees) and annual (market gardening) components, shaped by annual management routines. To account for and explain these practices' evolution, AMG cropping system trajectories were identified, drawing inspiration from Mawois et al. (2019). A trajectory is a succession of coherent phases (stable practices) interspersed with transition phases (driven by change processes). In this process, we primarily focused on design practices, as any change impacts the species components and their spatial arrangement within the system.

Results

Trajectories types are independent of AMG system design, which is mainly shaped by the plot's initial state. Each farm hosts one to two AMG systems; 28 were identified across the sample, aged 3 to 17 years. Based on the initial tree-vegetable intercropping and their evolution over time, four AMG trajectory types were defined (fig.1). Trajectory 1 involves introducing vegetable crops beneath already-established trees. Trajectory 2 involves planting trees on plots where market gardening is already established. Trajectory 3 describes the design of tree-vegetable association before any horticultural farming activity, on plots previously used for cereal cultivation or left as agricultural or forest fallow. Trajectory 4 refers to the temporary establishment of AMG favouring trees; market gardening is transitional.

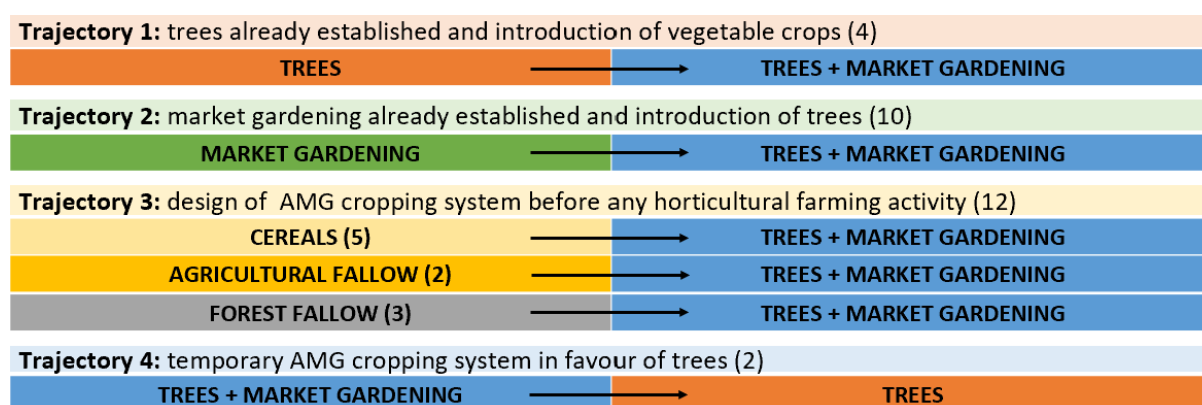


Figure 1: types of AMG cropping system trajectories within farms. Numbers in parentheses indicate the associated system count.

Within the same trajectory type, management changes differ over time. Figure 2 presents two examples of AMG cropping systems under trajectory 3. The first trajectory highlights numerous changes concerning tree component (fig.2A). Trees were planted gradually, starting with fruit trees to diversify income, followed by non-fruit trees to provide other services for vegetable crops. A lack of expertise in managing fruit trees and competition for water and light affecting vegetable crops, led to fruit trees partial removal, modifying the initial system design. Trees in the second trajectory were planted all at once, while vegetable areas expanded gradually as the farmer gains expertise (fig.2B). Training-led management changes mainly affected the tree layer, though adjustments in vegetable crops also occurred, seemingly unrelated to tree presence.

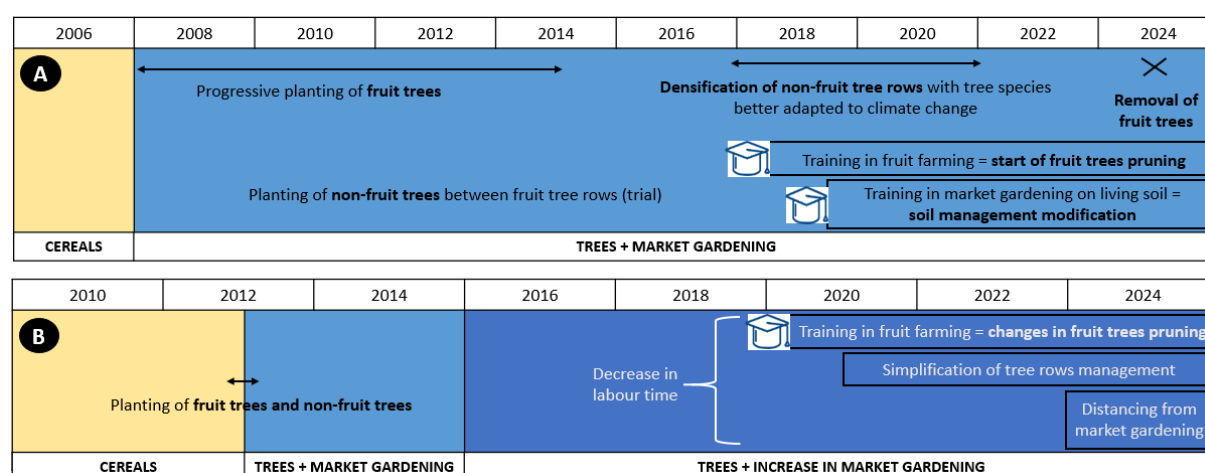


Figure 2: examples of two AMG cropping systems belonging to trajectory 3.

AMG cropping system design depends on the plot's initial state, meaning the presence or absence of prior horticultural farming activity and/or trees, as well as farmer profiles, including trainings, objectives and inspirations from other farms. Management changes during tree growth depend on AMG design, training received, and farmers' economic, organizational, and social constraints. In these systems, market gardening activity is mostly prioritized over fruit farming one, although a few farms focus more on fruit trees, leading the system to trajectory 4. This pattern is common among smallholder farms, where farmers shift to less time-consuming activities, such as processing, to offset income losses from market gardening. The overlap of market gardening and fruit farming inevitably requires work's reorganisation, and the need of dual expertise on the farm appears essential to prevent one activity from being side-lined.

Discussion and Perspectives

AMG cropping system trajectories highlight the need to adapt farm work to the contrasting temporal dynamics of horticultural activities (Paut et al., 2021) to improve both environmental (e.g., reducing soil tillage) and/or technical-economic performances (e.g., simplifying practices to reduce labour time) of the system. These systems evolve as farmers seek to achieve their objectives. Changes in agricultural practices resemble the design of a new working system shaped by a series of events and decisions (Chizallet et al., 2016). Most interviewed farmers have adjusted their AMG system through trials and failures and would take a different approach if starting over. These trajectories reveal patterns of tree-vegetable associations that correspond to different types of AMG cropping systems, some better suited to specific farm contexts based on their priorities, objectives and organization. Meanwhile, new AMG systems are emerging, trajectories have been described in detail in leaflets, offering valuable case-studies and lessons to inspire new project leaders.

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Analysing the activities of farmers in transition at different spatio-temporal scales to design training courses

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Keywords: Agroecology, course-of-action, learning, viticulture

Introduction

With the advent of agroecology, the challenge is to draw on the ecological services of the farming system to reduce the use of chemical inputs. This implies mobilizing a diversity of practices and plant and natural resources that interact in time and space. Given the complexity of the situations to be addressed, supporting the agro-ecological transition of farming systems is essential. One way of encouraging farmers to develop complex, systemic thinking is to enhance the value of peers' collective experience within these systems, particularly through training. Indeed, analysing the activities of those working within these farming systems in transition reveals the knowledge acquired during this process and the typical phases of development they encounter. Analysing the functioning of the farming system in relation to its environment must therefore take into account different levels of analysis. In this study, we examined the transition of vineyards adopting a new soil maintenance practice that incorporates horse-drawn service providers to preserve soil and vines. Our research question was: How is cooperation constructed between winegrowers and service providers working with horses for soil maintenance over different time scales? Little is known about the pair between service providers and their horses in the agroecological transition of vineyards. We studied this cooperation on different time scales, from the short time of service provider-horse-soil interaction to the long-time of cooperation between service provider and winegrower.

Among the various approaches analysing human activity, the course-of-action approach takes a holistic view of human activity, considering three levels of analysis (Poizat et al., 2023). The lower level considers the interaction between an actor and its environment at a given time *t*. In our case, it corresponds to the implementation of the practice of soil maintenance with a horse by the service provider at the plot level at a given time *t*. The middle level of analysis focuses on interactions within small collectives of actors "within narrow temporal, spatial and organizational boundaries" (Ibid., pp. 9-10). It corresponds to the farm level, which integrates the interactions and activities of several actors (winegrower, equine traction provider and horse) on a time scale of around ten years. The higher level of analysis extends temporal and spatial boundaries and is outside the scope of this research.

The course-of-action program provides conceptual and methodological tools for studying activity as an asymmetrical coupling between an actor (service provider or winegrower) and its environment, with two ontological postulates. The postulate of enaction implies that activity is fundamentally situated and, in part, invisible to an outside observer. The second postulate states that an actor can describe and comment on their lived, situated, embodied experience if the research conditions are optimal for facilitating the actor's explicitation of their lived experience.

Methods

Studying farmers' practices

The lower level of analysis provides a detailed description of the experiential knowledge and indicators mobilized to act in a given situation. Four professionals working with horses were filmed during two types of soil operations involving two to five plots. These professionals were interviewed in eight video-based interviews to identify the typical knowledge they mobilize in action (Bénézet et al., 2022).

Studying transitions in agricultural systems

The middle level of analysis relates to that of collective activity within a farming system evolving over a decade. We analysed the cooperative trajectories of three winegrower-provider pairs with a long history of cooperation (eight to twenty years) using six re-enactment interviews based on traces of their respective activities during the period in which the practice was implemented. These interviews revealed the significant events and learning experiences of each partner (winegrower and service provider) during this period. By comparing these elements, we identified what the partners shared during the process.

Results

A diversity of senses mobilized by the service provider when working on the soil

We show that providers employ multiple senses to observe the interaction between their plow, horse, and soil. In fact, they use sight, touch, hearing, and smell to adjust their practices during soil maintenance (Figure 1). These senses are also employed in their relationship with their horse. Their interpretation of their horse's behavior helps them assess the conditions in which they are working.

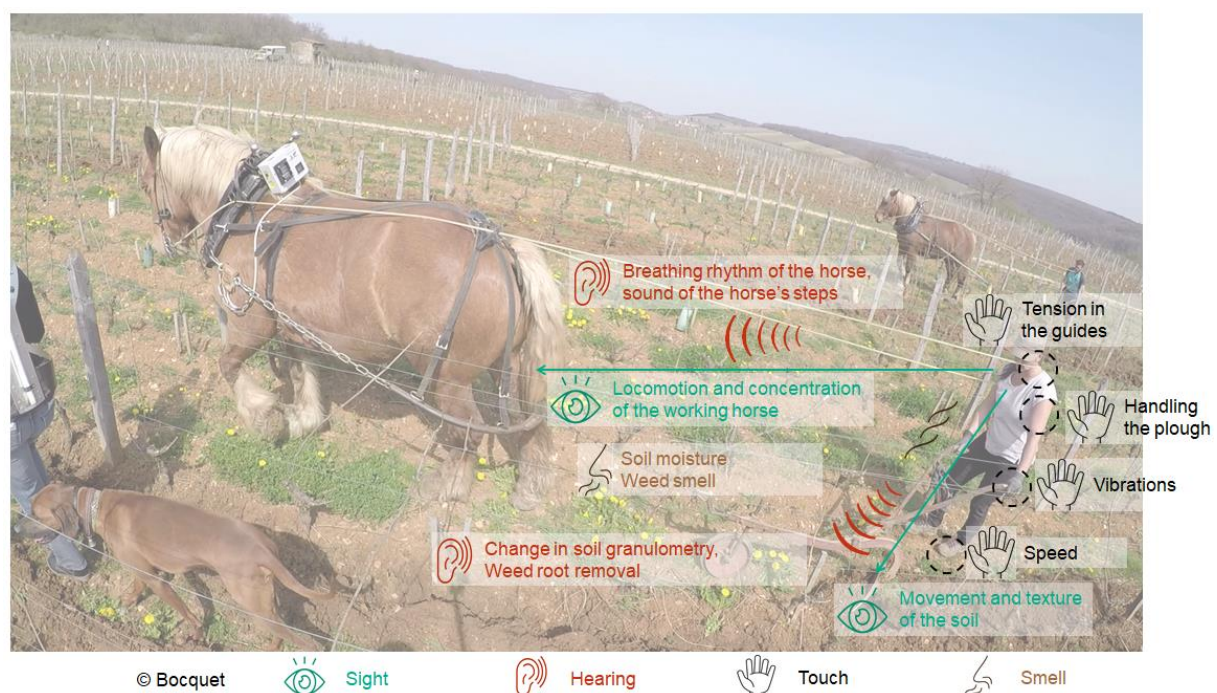


Figure 1. Examples of the senses that providers mobilize in a given situation.

Mutual appropriation of a practice for the design of a new farming system

Our research shows, within the collectives studied, a sharing of concerns and knowledge throughout the process of integrating practice on the vineyard between the winegrower and

the service provider. The physical and bodily nature of the practice, the numerous events (e.g. meteorological, sanitary) impacting the vineyard and the collaboration with the horse require regular exchanges between them. They help the practice to run smoothly and preserve the health of the various actors (horse, service provider and winegrower) as well as the environment with which they interact (soil and vines).

Discussion and Perspectives

Working with a horse-drawn service provider allows winegrowers to gain insight into how their soils will react to changes in technical itineraries during the transition, thanks to the increased sensitivity that comes with working with horses. To facilitate the projection of farmers into future situations on their own farming system, training systems can be designed. We built and tested a collective and inter-activity iterative design of a video-based resource platform highlighting the different activities, their sensitive dimension and their interaction on farm over different temporalities. Highlighting the typical situations that peers encounter aims to develop action possibilities and increase learners' ability to adapt to the unexpected (Leblanc, 2018).

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Combining technical and social localized knowledge to support the co-design of integrated crop-livestock systems between farms

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Keywords: Organisation, Agroecology, Collaboration, Crop-livestock integration

Introduction

Crop-livestock integration and crop diversification are major levers for the development of agroecology and for improving farming system resilience by e.g. limiting disease pressure, optimizing the use of nutrients and regulating the water cycle (Lin, 2011; Martin et al., 2016). However, their implementation by farmers is a challenge, as they require an increased workload (Navarrete et al., 2015) and more knowledge (Toffolini et al., 2017). Inter-farm collaborations involving the sharing of a crop rotation planning with pastures and crops to feed livestock, appear to be a lever for crop-livestock integration (Asai et al., 2018; Martin et al., 2016; Moraine et al., 2016). With a group of ten farmers next to Rennes (western France), the Corollaire project aims to co-design collaborations between neighbouring farms for a better integration of crops, grassland and livestock. The involved farms are covering a large diversity of productions, some are specialised in dairy farming, others in plant production.

However, these types of collaborations are poorly documented in the literature. Before getting to the co-design stage of the project, knowledge acquisition was needed to feed the participants, as raised by the farmers in a pre-project meeting and advised by standardized design methods such as KCP (Le Masson et al., 2009) and RIO approach (Elzen and Bos, 2019). We distinguished two types of useful knowledge:

- Knowledge about forms of organisation of inter-farm collaborations.
- Contextual knowledge about the farms and the farmers involved.

This paper presents the results of the design-oriented knowledge acquisition.

Methods

To enhance knowledge on the forms of organisation of inter-farm collaborations, we used the innovation tracking method (Salembier et al., 2021), with a snowball sampling and semi-structured face-to-face interviews with farmers already involved in collaborations. We aimed at understanding the context in which collaborations were set up, the forms of organisation (e.g. annual or long term, oral or written, including payments or not), the benefits for the farmers and the transaction costs (Asai et al., 2018).

The contextual knowledge was acquired by interviewing the ten farmers involved in the project. The farm diagnosis aimed at understanding the agronomic context of the farming system, the decision-making processes of the farmers and their motivations.

Results

The analysis of existing collaborations led to identify four types, along a gradient from complementarity to synergy:

- Joint selling: Coordination between farmers to offer a complete range of products for direct selling
- Planned sales between two farms: A farmer produces a crop on his/her own land and sells it to his/her neighbour on a regular basis. The neighbour commits to buying the crop each year.
- Exchange of raw materials: The two (or more) farmers produce a crop on his/her own land for his/her neighbour on a regular basis. Financial compensation can occur in case of unbalanced value.
- Shared crop rotation: Field exchange or sharing. Often formalised by an agreement as the operations are intertwined and require better guarantees (fig. 1).

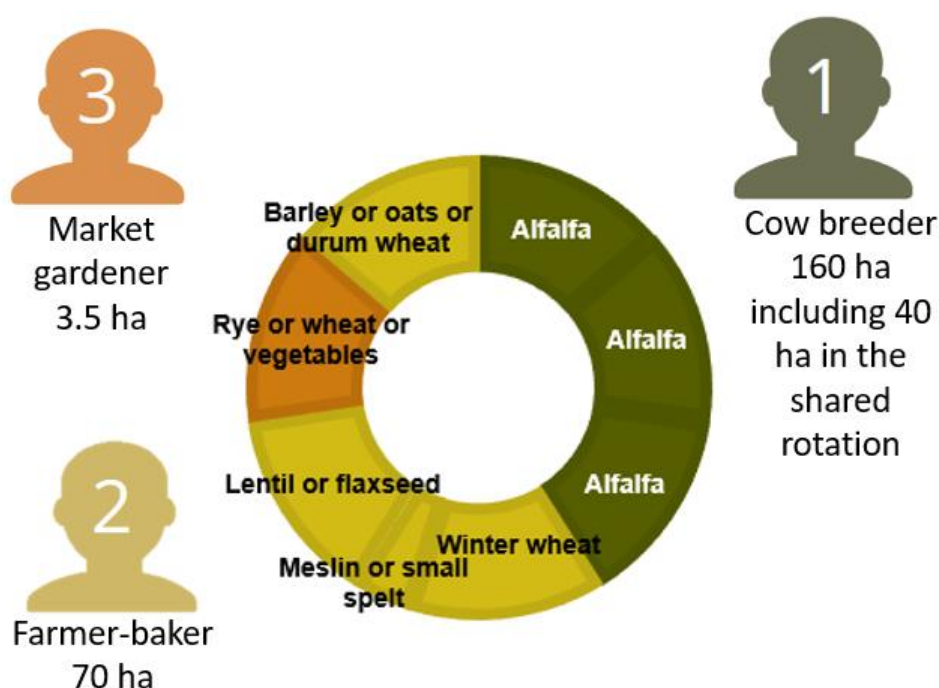


Figure 1. Case study of a shared crop rotation involving three farms located in Grand-Est region, France.

Combining the farm diagnosis with geographical data resulted in a representation of farms and fields location, the land-use and length of crop rotation, livestock density and flows of nutrients between farms. It allowed farmers to elicitate the issues encountered locally, collaborative scenarios to better manage them and mention neighbours or other local actors who could help unlock collaborative scenarios.

Discussion and Perspectives

This study focused on the pre-design step, which is often overlooked in co-design processes. Still, knowledge acquisition on actor motivations and flows has proved important in supporting co-design processes. The combination of generic knowledge, used as inspiring examples especially for innovative organisational forms of collaborations, with contextual knowledge is key to help the co-design stage. Contextual knowledge was spatially explicit mapped which proved useful to support farming system design especially considering beyond farm level approaches (Ryschawy et al., 2022).

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Integrating sheep into vineyards: diversity of farmers' agronomic logics and trajectories

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Keywords: Innovation, Transition, Agroecology, Integrated Crop-Livestock Systems

Introduction

Agriculture has increasingly shifted toward farm specialization to improve economic performance. However, this production model has significantly contributed to loss of biodiversity, climate change, soil erosion, and air and water pollution. Integrated Crop-Livestock Systems can help address some of these issues. In viticulture, Integrated Sheep-Vineyard Systems (ISVS) are nascent but quickly expanding. Some studies have highlighted the ecological and economic benefits of ISVS as well as their potential contribution to agroecological transitions (Brewer et al., 2023; Niles et al., 2017; Ryschawy et al., 2021; Schoof et al., 2021). However, farm practices of ISVS are highly diverse, and limited information exists on the link between farmers' objectives, implementation of ISVS and the observed results. Understanding the logic driving these actions enables the production of relevant knowledge that can be used to design new ISVS. Moreover, the evolution of these systems remains understudied. This study aims to analyze the diversity of ISVS systems based on winegrowers' objectives and to explore how they have designed and adapted grazing systems over time to reach targeted outcomes.

Material & methods

Eleven surveys were conducted in California, USA (in person), and four in Maryland/Vermont, USA (via Zoom). Additional surveys are planned in France, six in Provence and six in Aquitaine in spring 2025. The four regions were chosen to represent two main wine growing regions with different climates, Mediterranean with California and Provence, and temperate/oceanic with Maryland/Vermont and Aquitaine. The farms were chosen to encompass various types of ISVS. Five main themes were covered during the interviews:

- A description of current grazing practices
- The expected results of grazing
- The perceived impacts of the practice
- The influence of grazing on adaptation of other farming practices
- The evolution of grazing practices and objectives over time.

The interviews were recorded and transcribed. To analyze the diversity of grazing practices, we relied on the concept of agronomic logic (Quinio et al., 2022) that refers to the coherence between objectives, technical choices, observations, and constraints that guide farmers' decisions within a given context. The agronomic logic of each farm was described. To study the evolution of practices over time, we used the concept of trajectories (Chantre and Cardona, 2014), identifying coherent phases of objectives and practices. Finally, a cross-case analysis was conducted to identify recurring patterns or contrasting approaches in how farmers design and adjust their ISVS across different production contexts.

Results

A diversity of grazing agronomic logics

Several objectives and associated practices of grazing were identified among the farms surveyed. In California, grazing generally occurs between November and March (pre-budbreak) (Nb=12) in low-cordons vineyards, and year-round in high-wire vineyards (Nb=1 and two projects) (figure 1). In Vermont, due to winter snow, grazing begins later, typically in mid-April (Nb=1). The common objective across all vineyards is grazing on sown or spontaneous cover crops (Nb=14), sometimes linked to a desire to reduce or stop herbicide use (Nb=3). In addition to cover crop management, farmers also integrate grazing to help meet their objective of fertilization (Nb=1). This is not only seen as a benefit to offset inputs but also as a guide to manage grazing and calculate stocking rates and paddock rotations on small areas. Another objective is using grazing to stimulate cover crop growth to maintain alley cover as long as possible and maximize its benefits (Nb=1). On this farm, sheep graze for a short period on small areas, before bud-break. The final objective recorded is utilizing sheep for leaf plucking/thinning to reduce the pressure of fungal pathogens by increasing air flow and meet ripening objectives (Nb=1). This practice occurs in a low cordon California vineyard (post-flowering, pre-veraison) and requires intensive herd management. Further, this practice is linked with stopping copper use in the vineyard. These four types of ISVS contribute in various ways to advancing agroecological transitions, particularly through the reduction of tractor passes, the reduction of herbicides, and the complementarity with farming practices such as cover crop and ecological nutrient management.

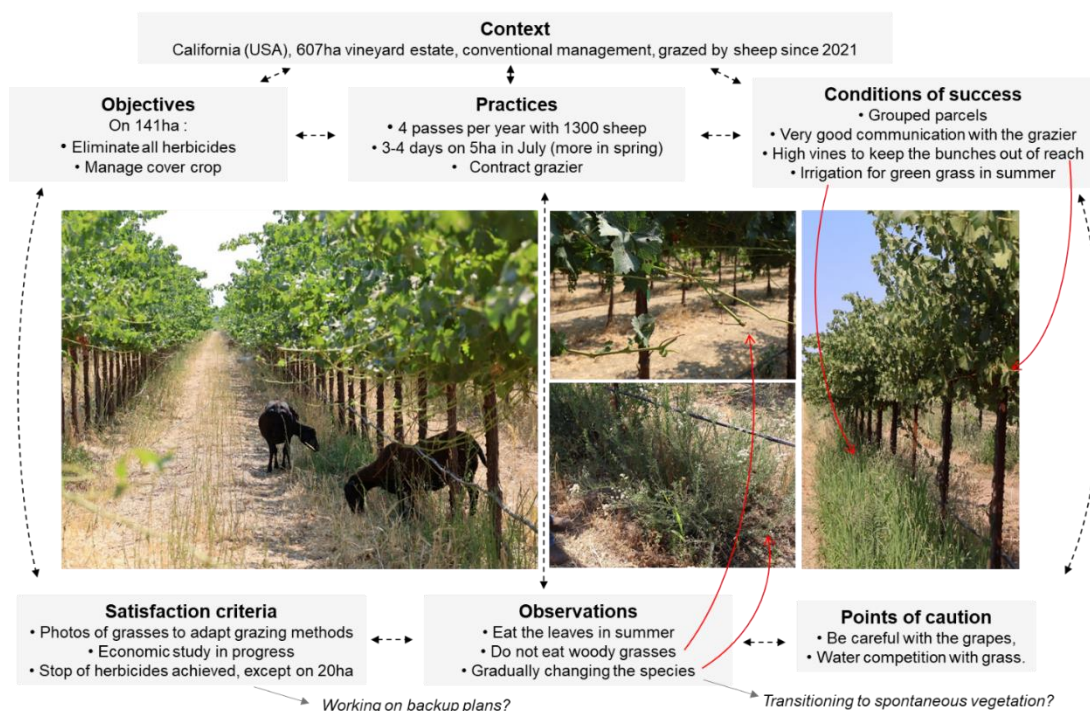


Figure 1. Key elements of the agronomic logic behind an example of ISVS in California. Black arrows indicate the links between the different components of agronomic logic (e.g., objectives, practices, and conditions of success depend on the farm context; satisfaction criteria are directly linked to the objectives and observations, etc.) In italic, the perspectives of change or adaptations

Different trajectories since the first implementation of grazing

Different trajectories of transitions were observed in the farms surveyed:

- Level 1: Unchanged grazing objectives and practices, with focus on adaptation of co-management practices (e.g., modification or elimination of technical operations, rescheduling or suppression of certain inputs) (N=3)
- Level 2: Fixed grazing objectives, with adjustments in grazing methods to better align with the initial goal and expected outcome (N=5)
- Level 3: Fixed grazing objectives, with co-evolution between grazing practices and other interventions to optimize outcomes (N=2)
- Level 4: Evolving grazing objectives, leading to changes in both grazing practices and other agricultural practices (N=2) (e.g, in figure 2)

	2021	2022	2023	2024	2025
Objectives	Clean the floor for better efficacy of pre-emergent herbicides		Reduce herbicides uses on low cordons vineyards Stop herbicides on high wire vineyards		Same objectives + reduce irrigation ? + reduce fertilization ?
Practices	Contract grazier, 1 pass in fall on 610ha		Same contract grazier Several passes during the year		Change of contract grazier • 480ha (low cordons) : 2 passes per year, in winter • 140ha (high wire) : 4 passes/year To be defined Estimations needed
Satisfaction	Satisfied, less grass debris Logistical issues with the grazier		Logistical issues with the grazier, size of flock not adapted → herbicides used on several blocks		Good collaboration with the new grazier Satisfied, no herbicides except on 120ha Need to be ajusted

Figure 2. Evolution of objectives, practices, and satisfaction for an ISVS level 4 case in California. Each grey box represents a time phase during which grazing objectives and practices remained stable. The grey boxes indicating satisfaction reflect the farmer's assessment of their practices during each respective period.

Discussion

This study provides new insights into the characterization of ISVS by exploring the underlying linkages between practices and objectives and by documenting the various transition pathways these systems undergo after initial adoption to maximize desired outcomes. These findings support the implementation of new ISVS in vineyard farms, emphasizing that such systems must be adapted to each specific context, with clearly defined objectives and production conditions. From a theoretical perspective, this study contributes to enriching the methodology for analyzing agronomic logics across diverse socio-ecological landscapes (Quinio et al., 2022).

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Trajectory of a dairy farm transformation to agroecology

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Keywords: coevolution, transformation, agroecology, dairy farm

Introduction

To date, agriculture contributes to 22 % of greenhouse gas emissions, with more than half that result from livestock. At the same time, livestock farms are impacted by global changes which compromise their productivity and resilience. In response to these challenges, innovative farming systems based on agroecological principles are being promoted (FAO, 2018). Implementing this agroecological model calls for a farming system redesign, i.e. a full transformation of farms (Hills, 1998; Altieri, 1989; Gliessman, 2016). However, agroecological transformations have not been documented extensively and this lack of knowledge may limit the adoption of agroecological systems. Since 2013, an agroecological dairy farming system has been implemented and monitored in an INRAE experimental farm in Lusignan, France (Novak et al., 2013). In this study, we investigate the coevolution of the dairy herd and its feed resources to understand the processes which operate during such a transformation.

Methods

Using qualitative and quantitative data, we analysed the changes in farming system components (herd, crops, grasslands and forage trees) and farming practices occurring throughout the transformation to agroecology. Thanks to files reporting details on the design plan, the farming system establishment and the managing team's discussions, we modelled trajectories for each component to identify phases marked by temporary alignments between objectives and practices (Chantre et al., 2014). We characterised the farming system and its components through their size (e.g. number of animals, land area), composition (e.g. number and type of crop species) and their spatial and temporal organisation for each phase. Finally, we assessed their technical performance over the different phases (average, variability and slope). Using this approach, we synthesised the trajectory of the farming system over a decade (2013-2023).

Results

Dynamics of practices and performance over time

The implementation of the new dairy farming system respected initial design choices stricto-sensu. In 2013, the herd was composed of 100% Holstein cows, three-way crossbreeding (practice (1), Fig.1) (Holstein (Ho), Jersey (Je) and Scandinavian Red cows (Rs)) was quickly implemented, followed by a switch to two calving periods (2) and the lengthening of cow lactation to 16 months (3). The willingness to set up quickly the crossbreeding led to an overstaff of heifers (+14 LU i.e. +31 heifers between 2013 and 2017). Simultaneously, three highly diversified crop rotations (4) were organised over the 90 ha with the aim to use the fewest possible pesticides and inorganic fertilisers. These changes in the farming system and the occurrence of hazards (weeds, pests, adverse weather conditions) degraded the self-sufficiency for forage. In response, new practices (tactical adjustments phase) were implemented: purchase of fodder (8); cover cropping (5); direct sowing (6); improved grazing management with earlier turnout and more frequent rotation (17). Due to the persistence of issues, the farming system entered a new phase with modifications of initial objectives and

practices: new crop rotations (9); allowance of herbicides and inorganic fertilisers for crops at risk (10); earlier culling of animals (12), etc. The components finally reached a "routine" regime when all the revised design choices had been implemented and the projected size of the components was respected. The last practices implemented during this phase were the production of on-farm concentrates (15) and the grazing of forage trees (16). Along with this transformation, the herd kept its milk production relatively constant with an average of 7424 ± 333 kg milk/year/cow and improved milk quality with +3.9 g/kg and +6.6 g/kg of protein and fat content respectively, over the 11 years. So did the reproduction performance with +20% of success rate at first artificial insemination between 2013 and 2023. Crops and grasslands kept their productivity levels with 349 ± 31 t DM harvested per year, allowing a self-sufficiency for forages in the range 73-10094.5% over the decade, well above the regional standards.

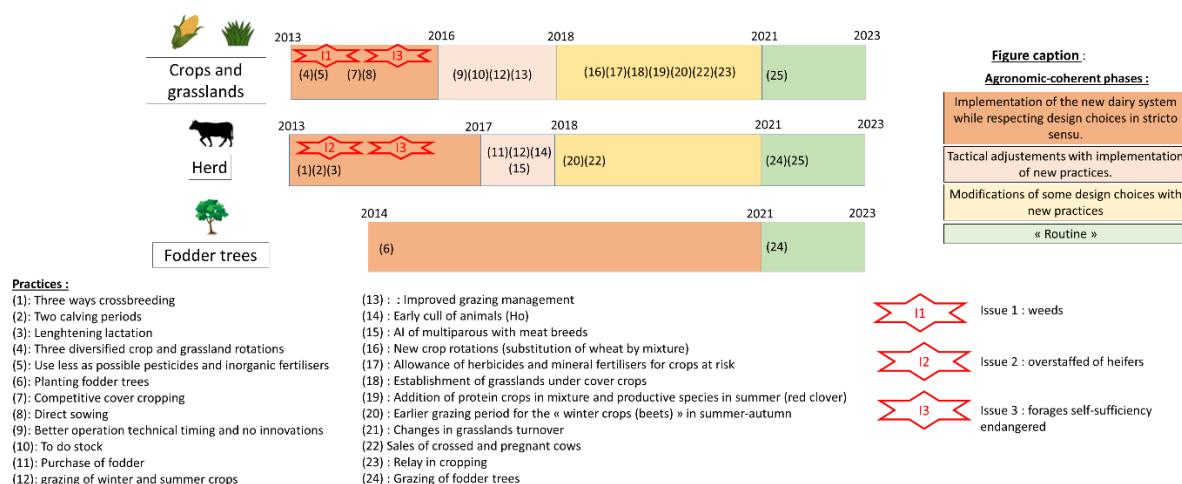


Figure 1. Trajectories of the farm components (crops and grasslands, herd, forage trees) as successions of phases characterised by the implementation of new farming practices

A reduction in the dependence on inputs and an improvement of circularity

Schemes synthesizing the composition, dimensioning, inflows and outflows (on a nitrogen basis) of each component show (Fig.2) that the new farming system has increased its biodiversity by diversifying the crops, the pastures and the herd, in addition to adding a tree component. In parallel, it has reduced its inputs thanks to a decrease of concentrates supplementation level and inorganic fertilisers use, while maintaining its outputs of milk and animals sold. Internal flows display the development of circularity due to enhanced biomass exchanges allowed by a larger diversity of flows between the farming system components and manure recycling on crops and grasslands. This allowed the farming system to improve its nitrogen use and remained its nitrogen efficiency.

Discussion and perspectives

As observed in previous studies (Chantre et al., 2014; Lamine et al., 2011), the trajectory analysis highlighted changes in objectives and practices before reaching a "routine" regime. As we focused on a transformation to agroecology, the process took time but led to an overall improvement of the farming system sustainability through, among others, reduced dependence on inputs and nitrogen use efficiency remained stable. In addition to establishing the feasibility of such a transformation, this assessment generated knowledge on a typical transformation pathway that can be re-used by farmers. To tackle the complexity induced by such a transformation, we proposed a new method to synthesise and represent the change process in the farming system, its components and their interactions (Fig.2). Future studies will explore the farm assistants' learnings allowed by such an agroecological transformation and will

compare the resilience of the farming system and its profitability to other commercial farms over pluriannual time series.

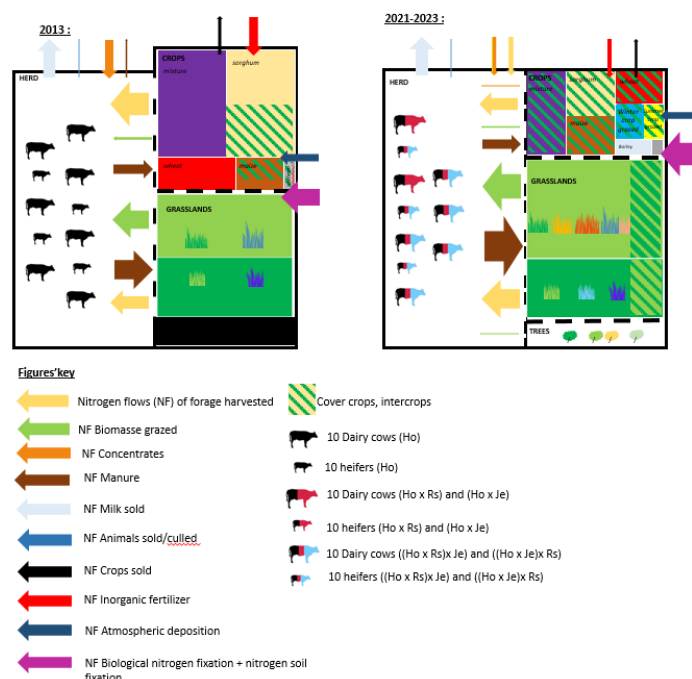


Figure 2. The dairy farming system before (left) and at the end (right) of the agroecological transformation. Each scheme represents the composition of the system components, their dimensioning and inflows, outflows and internal flows through arrows with their size varying according to the flow size on a nitrogen basis.

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Mobilising agroecological principles to analyse the transition pathway of a mixed crop-livestock system

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Keywords: assessment, agroecology, practices, transition pathway

Introduction

Considering the challenges facing agriculture today, scientists and society are calling attention to the need to produce differently. Agroecology (AE) is one of the most promising ways to meet this challenge. However, while there is an abundant literature on the principles and theoretical frameworks of agroecology, there seems to be a gap between these principles and frameworks and their application on farms. According to Thomas et al. (2014), there is no standard model in AE: it is a matter of working on principles which then need to be applied to concrete situations depending on the context and local conditions. The aim of this article is to present the method we used to analyse and keep track the evolution of uptake of AE practices associated on a research farm.

Methods

The case study: the Transi'marsh system experiment

Since 2009, the INRAE research farm of Saint-Laurent-de-la-Prée has been carrying out the Transi'marsh system experiment using a 'step-by-step' approach (Meynard et al., 2023). The aim is to become a demonstrator of agroecological transition (AET) in marshlands, with four particular objectives: to grow crops mainly for human consumption, to promote wild biodiversity, to be economically viable and to contribute to climate change mitigation. The 167-hectare organic mixed crop-livestock farming system comprises 114 hectares of permanent wet grasslands and 52 hectares of arable land. Grasslands are grazed and/or cut to produce hay for a herd of 45 local suckler cows.

The AET analysis

To analyse and monitor the stages of the agroecological transition, eight principles from the scientific literature were selected:

- Four principles derived from Dumont et al. (2013): (1) adopting management practices that aim to improve animal health, (2) decreasing the inputs needed for production, (3) decreasing pollution by optimizing the metabolic functioning of farming systems, (4) enhancing diversity within animal production systems to strengthen their resilience,
- Three principles developed by Duru et al. (2015) around the concept of multifunctional agriculture based on biodiversity at farm level: (5) increasing plant diversity and soil cover through adapted cropping sequences, (6) reducing disturbance to soil functioning, (7) organising the landscape matrix to increase biological regulation,
- (8) lastly, one principle derived from Théron et al. (2017) based on territorial embeddedness.

For each of the principles, we have inventoried the associated farming practices implemented in Transi'marsh since 2009. At the same time, we identified indicators to quantify the changes in each practice during the transition.

Results

The practices implemented in the system over the last 16 years have been presented in a time-line (Figure 1). It shows that i) some practices have been applied since the beginning of Transi'marsh (e.g. maintaining the hardy local breed); ii) others were introduced during the AET (e.g. planting hedges) and iii) many of the new practices were introduced after the switch to an organic system (e.g. burying straw in the soil).

As an example, for principle 7, we have identified 8 practices. Table 1 shows changes in the related indicators for 4 of them.

	2009	2014	2017	2020	2024
Area of vegetation strips (ha)	0	5	5	5	9
Ponds (cumulative number)	5	5	6	7	9
Mean size of cultivated fields	4.8	3.8	3.8	3.2	3.2
Hedge plantations (cumulative meters)	0	0	110	110	210

Table 1. Evolution of 4 indicators related to the "organisation of the landscape mosaic" principle.

Discussion

The study presents a visualization of the changes in practices on the experimental farm in its trajectory to become an agroecological farm. This tool, that could be collectively built, is very simple and practical to implement. It forces the collective -- composed of engineers and technicians - to question its AE transition and to identify the principles that are least applied. It also encourages to clarify and reconsider our decision-making process.

However, applying the principles of AE, and more specifically carrying out the practices associated with them, does not systematically imply the success of the practice. For example, vegetation strips can be planted around or within cultivated plots for the benefit of crops but they then have to be managed and their effectiveness assessed. This highlights the limitations of the approach if it is not complemented by an assessment of the performance and sustainability of the system.

Compared with the Agroecological Performance Assessment Diagnostic (TAPE) proposed by the FAO in 2019, our tool is less prescriptive. It focuses on the biophysical dimensions of the system, although it also addresses territorial anchoring. Its aim is not to produce grades, but rather to encourage open reflection on practices and how they fit in with the AE principles.

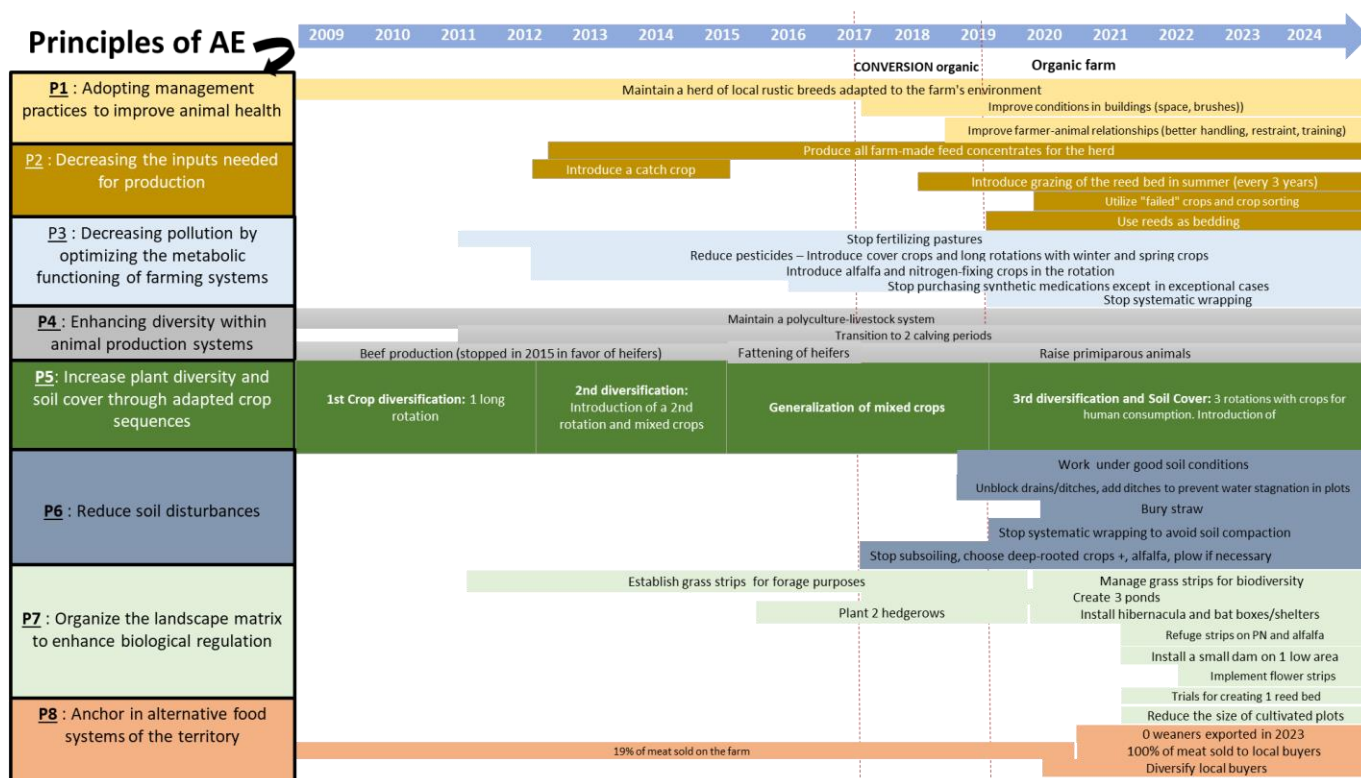


Figure 1. Transi'marsh AET time-line showing the eight principles (P) of agroecology. Each line represents a practice belonging to one of the principles. Its beginning indicates the start of its implementation.

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Figure 1. Transi'marsh AET time-line showing the eight principles (P) of agroecology. Each line represents a practice belonging to one of the principles. Its beginning indicates the start of its implementation.

Comparing agricultural typologies and nitrogen networks in Colombian agroecosystems: an agroecological and bioeconomic perspective

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Keywords: Farming systems, Classification, Sustainability, Colombia

Introduction

Understanding the diversity of agricultural systems is essential for designing sustainable agroecosystems that enhance resilience and efficiency. Typology construction allows for a structured characterization of farming systems, supporting decision-making for sustainable intensification and resource optimization (Tittonell, 2023). This study compares two typification methods: one based on archetypes and another using multivariate analysis (Berre et al., 2019), applied to family farming systems in Nariño, Colombia. Additionally, we explore nitrogen network structures in agroecosystems selected based on their typological classification. This approach allows us to assess integration, organization, and efficiency under different production models. Specifically, we aim to answer the research question: How do agroecological practices influence nitrogen flows across diverse farming systems in Nariño? By comparing nitrogen flows between conventional and agroecological systems, we seek to identify key leverage points for improving nutrient cycling and sustainability.

Method

The study was conducted in the municipality of La Cruz, Nariño, Colombia. A structured survey with 110 questions covering six dimensions (sociodemographic, agricultural practices, environmental aspects, commercialization, economics, and associativity) was administered to family farmers. Two typification approaches were used: (i) archetypal analysis using the convex hull algorithm to identify representative farm profiles, and (ii) mixed factorial analysis (FAMD) followed by hierarchical clustering to generate structural groupings. A probabilistic, stratified sampling strategy was employed, following the finite population method proposed by Mucha & Lora (2021), considering contextual limitations such as armed conflict, limited time, and resource constraints. The sample was calculated from a total population of 141 family farmers. Sustainable practices were defined as those promoting resource-use efficiency, internal nutrient recycling, biodiversity conservation, and reduced dependency on external inputs. These included organic fertilization, crop rotation, intercropping, rational grazing, integration of crops and livestock, and protection of water sources. Three representative farms from contrasting typologies were selected for nitrogen network analysis. Conceptual models were developed, and nitrogen flows were quantified across inputs (fertilizers, biological fixation), internal compartments (crops, animals, soil), and outputs (products, losses). The data were processed into flow matrices and analyzed using ENA metrics to assess system integration, efficiency, and functional diversity.

Results

The multivariate clustering identified three typologies: (1) conventional agriculture with limited diversification, (2) mixed crop-livestock systems with conventional management, and (3) diversified mixed systems with sustainable practices. The classification of producers was based on nine highly discriminative variables, including livestock ownership (QVI: 0.99), achira cultivation (QVI: 0.94), and membership in associative groups (QVI: 0.85). A Principal Component Analysis (PCA) was performed, and the PC1-PC2 biplot revealed that livestock ownership and achira cultivation were the most influential variables in differentiating producer groups. This analysis provided a clear statistical framework for defining typologies and understanding production system diversity (Figure 1).

The archetypal analysis revealed two predominant farm profiles: "traditional diversified farmers", characterized by high crop diversity and organic fertilization, and "modern intensive farmers", who optimize synthetic inputs and irrigation to enhance productivity. The number of archetypes was determined using the lowest Akaike Information Criterion (AIC = 111.55) value as the primary statistical parameter, ensuring the best statistical representation of variability in production systems. The comparison of methods demonstrated that the archetypal approach captures functional adaptation strategies, while the multivariate analysis provides a structural classification.

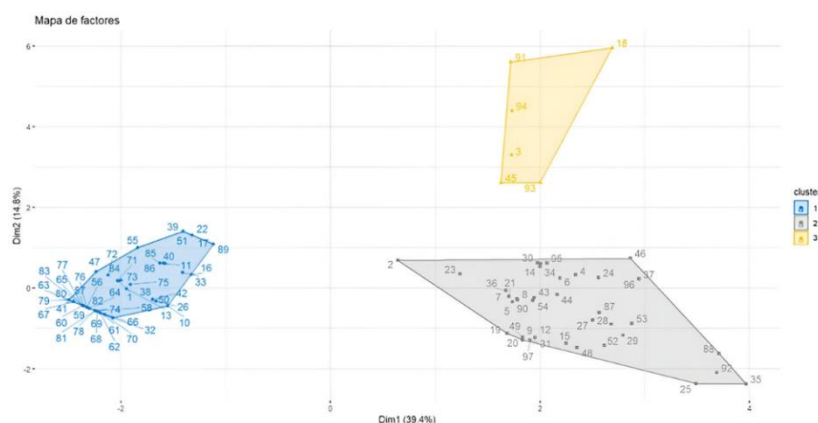


Figure 1. Typologies identified through multivariate clustering

Nitrogen flow conceptualizations were developed for three representative farms, allowing the quantification of inputs, internal transfers, and outputs. Preliminary results indicate that agroecological systems exhibit higher integration among components, improved nitrogen use efficiency, and greater internal recycling compared to conventional systems, which display predominantly unidirectional flows and a stronger reliance on external inputs. This analysis highlights the potential of circular practices to enhance nutrient cycling and reduce dependency through agroecological intensification (Figure 2).

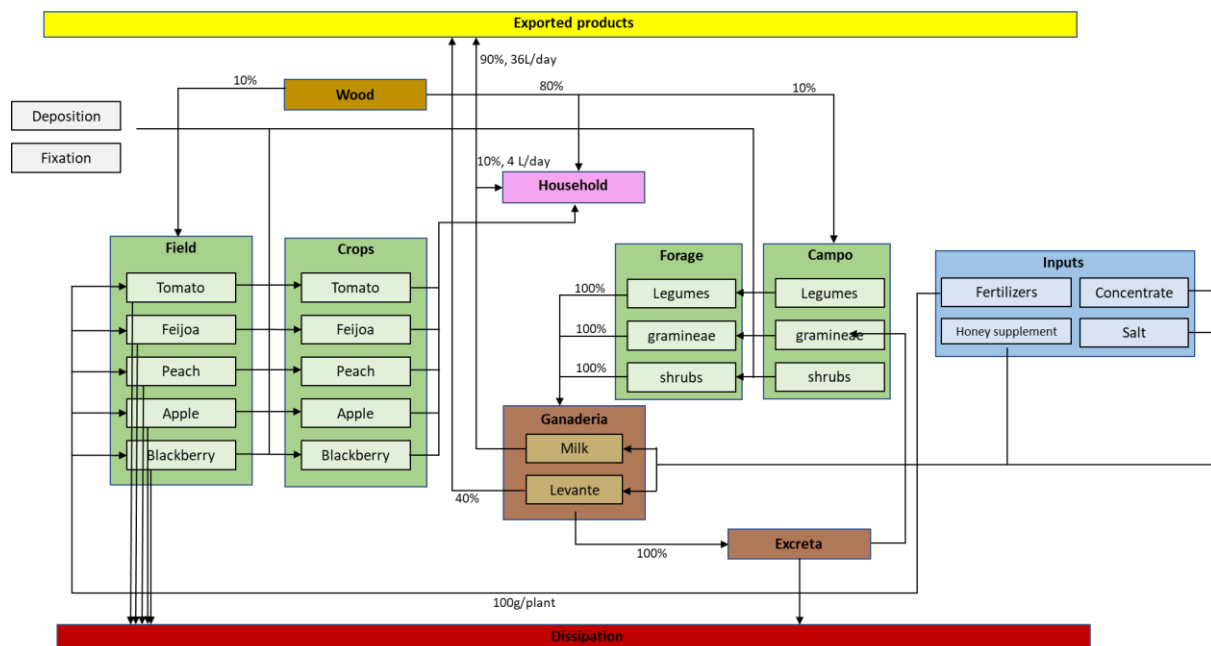


Figure 2. Conceptualization of nitrogen networks in Nariño, Colombia.

Perspectives/discussion

The integration of typological analysis with nitrogen network evaluation provides a comprehensive understanding of agroecosystem diversity and nutrient use efficiency. While archetypal analysis identifies real-world adaptation strategies, multivariate clustering offers structural groupings, together enhancing the design of targeted interventions. Agroecological practices emerged as promising alternatives for improving nitrogen cycling and sustainability in smallholder systems. This dual methodological approach supports the development of evidence-based recommendations and policy guidance. Future work will expand the analysis to a broader sample to validate findings and refine monitoring indicators.

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Functional classification and technical performance of cow-calf systems on campos grasslands

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Keywords: Livestock systems, Campos grasslands, Agroecology, Typology

Introduction

Cow-calf systems on native grasslands dominate South America's Pampas and Campos region. Their sustainability, however, is questionable because of their low productive and economic results and their negative environmental impacts (Modernel et al., 2018). Ecological intensification (Doré et al., 2011) aims to increase meat production per unit area without increasing costs while preserving and improving ecosystem services such as biodiversity, soil and water quality, and soil carbon stocks by promoting intelligent and intensive use of the ecosystem's natural support and regulation functions through managing biodiversity, solar energy capture, and biogeochemical cycles. Paparamborda et al., (2023) developed a conceptual model to support the ecological intensification of cow-calf systems, identifying key strategic, tactical, and decision-supporting techniques, concluding that their application by Uruguayan farmers is low. In this study, we used archetype analysis to construct functional farm typologies (Necula et al., 2024; Tiftonell et al., 2020) aiming to classify Uruguayan cow-calf farm systems based on distinct combinations of strategic, tactical, and decision-supporting techniques and exploring their relationship with resource endowment and farm results indicators.

Materials and methods

We used two datasets combined with archetype and discriminant analyses. The first, more general dataset contained results from a representative survey of Uruguayan livestock farms. The second, highly detailed dataset included information on 28 family farm participants in the "Climate-smart livestock production and land restoration in the Uruguayan rangelands" co-innovation project (GyC dataset). The first dataset was used to elucidate archetypes. Archetypes were created by iteratively applying the algorithm of Eugster & Leisch (2009) to the 109 farms x 9 techniques data matrix, increasing the number of archetypes starting from one. The number of archetypes most supported by the data was chosen based on the smallest relative residual sum of squares (RSS). The 28 farms of the GyC dataset were assigned to the archetypes using discriminant analysis. The archetypes were then compared in terms of structural and functional variables. Differences between the archetypes for these variables were tested with a Kruskal-Wallis test. Data analyses were performed using R 3.6.3 using the following R-packages: "archetypes" (Eugster and Leisch, 2009).

Results

Four archetypes (A1 to A4) of cow-calf systems emerged. A1 and A4 exhibited strongly contrasting levels of techniques implementation, while A2 and A3 were intermediate (Table 1). Our data showed that the archetype with the highest level of technique application (A1) achieved the best performance in meat production, weaning percentage, and weight of calves at weaning and in trophic (TEf) and conversion efficiency (CEf) but not in above-ground net primary productivity (ANPP) (Table 2). The difference in productive performance between the

archetypes represents a gap that can be closed by increasing the application of ecological intensification techniques.

Category	Technique	Score	Archetypes			
			A1	A2	A3	A4
Strategic	Selecting stocking rate	1 = until 0.6 AU ha ⁻¹ 2 = 0.6 - 0.8 AU ha ⁻¹ 3 = 0.8 - 1 AU ha ⁻¹	2.59	3.00	1	3.00
	Determining mating season starts and length	1 = Continuous 2 = Double 3 = Seasonal	3.00	2.98	2.88	1
	Weaning timing	1 Delayed 2 Others 3 March	3.00	2.98	2.74	1
Tactical	Applying temporary weaning, possibly combined with flushing	1 No 2 Temporary weaning 3 Temporary weaning + Flushing	2.00	1.62	1.34	1
Decision-making supporting	Monitoring Body Condition Score (BCS).	1 No 2 Yes	1.60	2.00	1	1
	Testing bulls' fertility before the mating season	1 No 2 Yes, by the farmer 3 Yes, by a vet	3.00	1.00	1.38	1.22
	Diagnosis of ovarian activity.	1 No 2 Yes	2.00	1	1	1
	Pregnancy diagnosis.	1 No 2 Yes	2.00	2.00	1.30	1
Other	Share of improved pastures in the total grazing area of the farm (%)	1 0% 2 1-5 % 3 5-10% 4 10-15 % 5 15-25 % 6 25-40 % 7 > 40%	5.21	4.64	2.96	1

Table 1. Scores of the strategic, tactical, and decision-supporting techniques for each of the four cow-calf farm archetypes based on a representative sample of 109 farms from the Cuesta Basáltica and Sierras del Este regions in Uruguay.

All farms from the GyC dataset could be assigned to the four archetypes by discriminant analysis. There were no significant differences (Table 2) in farm size (ha), percentage of land owned (%), total stocking rate (AU), and cattle and sheep stocking rates (AU) among the archetypes based on the GyC farm data. A1 and A2 had larger percentages of improved pasture areas than A3 and A4 ($p = 0.019$). A1 farms had the greatest weaning rate value, reaching 0.82 ± 0.08 ($p = 0.012$), while A1 and A3 farms tended to achieve higher calf weight at weaning than A2 and A4 ($p = 0.08$). Beef production was lower on A4 farms than in the other three groups ($p = 0.029$), mutton production and wool production were not different, and meat equivalent was the highest in A1 farms (108 ± 28.6 kg ha⁻¹; $p = 0.027$). There were no statistical differences in ANPP among the four groups, while TEf and CEf of A1 farms were the highest ($p = 0.017$). The ANPP differed between years ($p < 0.001$) and regions ($p = 0.0219$). There was a significant interaction between the archetype and month ($p < 0.001$). In November, the ANPP of A1 farms exceeded that of A3 and A4 farms.

Conclusions

There is a diversity of cow-calf production systems in Uruguay that we were able to capture from the construction of archetypes. These archetypes show diversity in implementing techniques and the productive results they obtain. The archetype with the greatest implementation of techniques is the most productive and energy efficient. In contrast, the archetype with the least implementation of techniques is the least productive and least energy efficient, with values below the averages reported for Uruguay. In addition, this last archetype is the most prevalent in Uruguay involving 40 or 50% of farms. Our findings reveal a significant potential for productivity improvement in Campos grasslands without reliance on additional

external inputs. Knowledge and application of ecologically intensive management, rather than farm resource endowment, is the primary factor enabling productivity and trophic efficiency increases.

			GyC dataset				
Dimension	Variables	Unit	Archetype 1 (7 Farms)	Archetype 2 (4 Farms)	Archetype 3 (7 Farms)	Archetype 4 (10 Farms)	p-value
Farm Structure	Farm size	Hectares (ha)	585 ± 651	699 ± 223	545 ± 499	592 ± 442	0.59
	Land owned	%	68.7 ± 37.1	91.5 ± 17.0	94.1 ± 15.5	79.4 ± 35.6	0.38
	Total stocking rate	AU ¹	0.84 ± 0.11	0.82 ± 0.07	0.68 ± 0.09	0.74 ± 0.13	0.061
	Cattle stocking rate	AU ¹	0.70 ± 0.20	0.68 ± 0.06	0.53 ± 0.19	0.55 ± 0.21	0.3
	Sheep stocking rate	AU ¹	0.08 ± 0.07	0.08 ± 0.01	0.10 ± 0.09	0.15 ± 0.1	0.61
	Percentage of the grazing area with improved pastures	%	17 ± 13 a	19 ± 8 a	9 ± 10 ab	3 ± 3 b	0.019
Farm results	Weaning rate	%	82 ± 8 a	69 ± 7 ab	72 ± 13 ab	60 ± 10 b	0.012
	Calf weight at weaning	Kg animal ⁻¹	162 ± 23	138 ± 21	159 ± 24	140 ± 15	0.087
	Beef production	Kg ha ⁻¹	89.9 ± 36.9 a	73.0 ± 17.5 a	71.8 ± 24.9 a	48.5 ± 14.1 b	0.029
	Sheep meat production	Kg ha ⁻¹	11.1 ± 9.1	6.2 ± 0.6	9.9 ± 10.0	12.5 ± 9.5	0.78
	Wool production	Kg ha ⁻¹	2.4 ± 1.8	1.4 ± 1.0	1.9 ± 2.0	3.9 ± 3.1	0.36
	Equivalent meat production (EMP)	Kg ha ⁻¹	108.0 ± 28.6 a	83.2 ± 16.2 ab	86.7 ± 16.9 ab	71.0 ± 17.4 b	0.027
	ANPP	Kg DM ha ⁻¹	5114 ± 451	5231 ± 1079	5064 ± 420	5211 ± 383	0.71
	Trophic efficiency (TEf)	MJ meat MJ ⁻¹ forage	0.012 ± 0.002 a	0.009 ± 0.001 ab	0.010 ± 0.002 ab	0.008 ± 0.002 b	0.017
	Forage to meat conversion efficiency (CEf)	kg meat Mg ⁻¹ forage DM	21.1 ± 4.5 a	16.0 ± 1.4 ab	17.1 ± 2.9 ab	13.7 ± 3.5 b	0.018

Table 2. Main farm structure and farm results (avg±sd) for the 28 farms from the GyC dataset, per archetype. Different letters indicate significant differences among archetypes

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Tracking on-farm innovations related to agroecological principles in French trout farming

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Keywords: aquaculture, practices, production system, territory

Introduction

Worldwide aquaculture production is increasing in volume and expected to contribute more to the production of human-edible food (FAO 2024). In France, trout (production of 35 000 t/yr) is the fish produced most in freshwater aquaculture. It is sustained by a dynamic national market, but the volume of production has remained stable over the last 20 years. To develop, fish farming faces several issues, such as decreasing waste emissions into the environment, accessing and using water sparingly (in quantity and quality), and feeding fish without using natural resources (e.g., fishmeal and fish oil) from wild-captured forage fish. Ultimately, fish farming needs to be redesigned in a sustainable way (Tacon et al. 2010; Diana et al. 2013). To this end, agroecological principles, defined for animal production, seem relevant. They consider specific characteristics of local conditions to decrease negative impacts, while promoting metabolic regulations of fish farms, depending upon the territory considered (Dumont et al. 2013). In this context, the aim of this study was to identify and characterize innovative practices already adopted by trout farmers and to relate them to agroecological principles.

Methods

The hypothesis formulated was that some trout farmers have already adopted one or more agroecological innovations. Tracking of on-farm innovation (Salembier et al. 2021) was the method used to detect these innovations in France. The method consisted of five stages:

- Formulating an innovation-tracking project: to define what is innovative, the dominant system(s) must first be defined. To this end, through semi-directed interviews, nine experts described their representation of the dominant system(s).
- Identifying on-farm innovations: the same nine experts were asked to identify trout farmers who performed practices that they considered innovative (i.e., different from those in the dominant system(s)) and agroecological. Based on their recommendations, 27 fish farmers were interviewed.
- Understanding the innovations: information was collected to help understand and describe the reasoning behind innovations away from the dominant system(s). This stage also characterized the goals, organization, strengths, and weakness of the fish farms, and assessed the fish farmers' satisfaction with their innovative practices.
- Assessing lessons learned from the innovations: this stage identified obstacles to innovations, mechanisms that promoted innovations, how fish farmers' practices evolved on their farms, and what they learned from it.
- Generating fish-farming knowledge: this stage generated and organized knowledge about the innovations identified in order to use it to help design innovative systems.

Results

The dominant systems

The experts described two dominant systems. In the first, the "mass-market" system (MMS), trout are produced to supply collective slaughtering-processing factories for human consumption. In the second, the "direct-sale" system (DSS), trout are produced for direct sale to consumers for human consumption, with or without processing, or for restocking rivers for angling. MMS uses trout monoculture, employs technical workers, reaches fish densities of up to 100 kg/m³, optimizes growth performance, and uses machines to control water quality (i.e., supply oxygen, filter water). In contrast, DSS produces several salmonid species, has fish farmers who work alone or with a family member, and reaches fish densities of up to 30 kg/m³.

Innovations identified

On the 27 trout farms surveyed, 4 innovative practices related to agroecology were identified. One of them aimed to limit negative effects of a fish parasite in river water by changing fish management at early stages of trout growth. Another aimed to decrease environmental impacts caused by using feed that contained fishmeal by replacing the latter with insects or processed animal protein. Another combined vegetable production with fish production in the same system to use fish waste as a nutrient source for the vegetables. The last one aimed to help preserve kingfisher (*Alcedo atthis*) populations by producing more trout fingerlings, which compensated for the amount of fish that the trout preyed upon on the fish farm.

Discussion and perspectives

To our knowledge, no previous studies have surveyed trout farms about agroecological innovations. The hypothesis that agroecological innovations already exist on trout farms was confirmed. Although most of the experts considered innovative practices to be new technologies, without considering agroecological aspects, the method of tracking on-farm innovations helped identify innovative practices and understand how they operated and evolved. The practices identified are expected to help design an agroecological trout farm in future workshops based on concept-knowledge theory (Hatchuel and Weil 2009), in particular by going beyond "design fixation", which could limit the resulting design. The subsequent goal will be to set up the agroecological trout farm to perform experiments with it.

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Tracking farmers' innovations to benefit from health service of grassland diversity

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Introduction

Livestock production is now controversial mainly for its ecological consequences. One way to achieve an agroecological transition in this sector is adopting integrated animal health management (Wezel et al., 2020). Feeding is one of the levers to integrate health management (Lamothe and Savietto, 2017). In ruminant production, grass, represents an important part of the diet. Interest of grasslands for agroecological transition has been proven (Millennium Ecosystem Assessment, 2005). However, the effects of some grassland species' secondary metabolites, which have antioxidant or anthelmintic properties (Poutaraud et al., 2017), on animal health remain unclear.

A study led in 2023 on 30 French livestock farmers identified four farmer profiles based on their knowledge of plant properties, their expectations of health services from grassland diversity and the mobilization of this service in their practices (Rose et al., 2025). This is an interesting step forward compared to the work of Petit et al. (2022) who did not highlight any farmers mentioning grassland management for animal health. As a part of a farmers' innovations tracking, this work can be considered as "unearthed" innovations (step 2) (Salembier et al., 2021). The next step of this methodology focuses on "getting to know" the practices behind these conceptions. Thus, we investigated this research question: How does animal physiological status influence grassland allocation by farmers?

Methods

To understand the trade-offs that these farmers made regarding the services expected from grasslands, we monitored their grassland management throughout the grazing season (March to June). Eight farmers were selected from the population studied in Rose et al. (2025) work, for saying they have a grassland management that allow them to benefit from health services. They were asked to complete a grazing schedule. Two meetings were planned. The first one aimed to explain farmers how to complete the grazing schedule by planning the grazing season. The second appointment aimed to review the grazing schedule and understand the reasons of each grassland allocation of animal batches.

The justifications were classified into 7 categories, based on what farmers said : "grass resource" corresponds to optimizing grass stock use, "grassland preservation" refers to preserving flora and production potential, "work organization" refers to facilitating farmers' work, "animal performance" corresponds to using protein and energy riche grass for milking or fattening, "animal behavior" refers to enabling certain animal behavior, "animal welfare" refers to facilitating animals' comfort and "animal health" corresponds to choosing grassland to treat a disease, preserve or strengthen animal health.

Since farmers have different numbers of animal batches, grassland plots and frequency of plots changes, they have a different number of allocations. Besides, farmers gave 1 or 2 justifications for an allocation. Thus, the number of justifications in each category was reported

as a percentage of to the total number of justifications given by farmers. A mean by category has been calculated.

Results

The most cited justification was the "grass resource" as farmers follow grass growth and rotational grazing. Second is "grassland preservation" which was particularly mentioned since it was a wet year. "Animal health" reason is one of the least mentioned justification with "animal behavior" and "animal welfare" (Table 1). Only 5 farmers gave it. For example:

E1 explains that suckler cows graze on temporary diversified grasslands for its "well-being", because flora allows growth and calves health.

E8 puts his dry cows on natural grasslands, poor in alfalfa, to prepare them for calving and to avoid metabolic disorders.

E17 explains that, after weaning the lambs, ewes graze on diversified natural grasslands, rich in aromatic plants which allow them to fill up on vitamins.

	E1	E8	E9	E13	E17	E26	E28	E30	Mean
Grass resource	60%	72%	70%	58%	46%	50%	85%	44%	61%
Grassland preservation	16%	18%	24%	0%	0%	33%	10%	23%	16%
Work organization	16%	7%	6%	19%	21%	7%	0%	17%	11%
Animal performance	0%	0%	0%	16%	25%	0%	4%	2%	6%
Animal behavior	0%	1%	0%	5%	0%	0%	0%	10%	2%
Animal welfare	4%	1%	0%	1%	0%	7%	0%	0%	2%
Animal health	4%	1%	0%	0%	8%	3%	0%	4%	3%

Table 1. Percentage of justification given by farmers for each category and category means

Discussion and perspectives

Despite farmers say they use grassland diversity for animal health, this poorly reflect in their daily grazing management. We hypothesize that farmers have a more systemic approach of health services of grassland diversity. Farmers seem to group similar grassland (flora composition, environment, expected services) and allocate animal batches to a type of grassland according to animals' physiological status. Once the batch is on its corresponding grassland type, farmers manage grazing according to grass growth. We propose analyzing how farmers plan their grazing season (first meeting) for each animal batch to identify the main management rules (Coléno, 2002).

Besides, to complete the track, health justifications must be analyzed to evaluate the effectiveness of these practices (Salembier et al., 2021). Agronomic content has been produced: farmers testified about their practices on camera for short videos.

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Trees for dairy farms' resilience to extreme weather events: first insights using a subjective approach

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Keywords: agroforestry, silvopastoral systems, farmers' perception, resilience assessment

Introduction

Extreme weather events (EWE), i.e., climatic stresses such as drought and heavy rainfalls, are expected to become major disturbances of agroecosystems. Increasing resilience of farming systems, i.e., the capacity to absorb disturbances and to reorganize (Holling, 1996), to such events is crucial for maintaining the provision of key ecosystem services. By integrating trees in plots with crops and/or livestock, agroforestry has gained attention as a way to increase the resilience of the farming systems. If ecological studies revealed resilience of soil processes near trees, improvement of the resilience at farm scale was less explored. Especially, temperate silvopastoral systems, that combine trees and pastures, have been neglected so far (Savajol et al., 2024).

Two approaches for measuring resilience co-exist: the objective and subjective ones (Jones, 2017). The latter finds its strength in recognizing farmers' experiences and motivations, and help integrate diverse knowledges to promote resilience. The aim of this study was to characterize to what extent trees contribute to dairy farming systems' strategies for resilience to EWE by using such an approach. We hypothesized that trees would be explicitly integrated as part of resilience strategies to EWE experienced on farms.

Material and methods

33 dairy farmers were interviewed in April-October 2023 within a gradient of farms going from highly extensive farming systems with high adoption of hedges and alley-cropping tree rows to intensive farming systems with maintenance of old hedges. During the interviews, open questions were asked about (i) the farmers' perception of climate change and related EWE, (ii) their strategies to cope with such events and (iii) the role trees play in these strategies. For each of these themes, data were encoded manually to list and count the concepts raised across the farmers' discourse.

Results

Climatic stresses mentioned by farmers were droughts (n = 18), increasing temperatures (n = 11), modifications of the seasons (n = 10) and of the wind regimes (n = 4), heat waves (n = 9), extreme precipitations (n = 7), storms (n = 5) and frost events (n = 1), and water overflows (n = 1); two farmers declared not to observe EWE related to climate change.

Farmers mostly mentioned strategies to cope with droughts (Fig. 1). Among these, plantation of trees was explicitly mentioned by eight farmers, while some others mentioned cutting tree branches (n = 1) and allowing cows to graze near pounds or hedges (n = 13).

When asked to what extent trees would contribute to increasing resilience to EWE, most farmers mentioned the creation of a favorable microclimate (n = 26). Other mentioned the regulation of water fluxes and quality (n = 8), the decrease in soil erosion (n = 4), the mitigation

of climate change ($n = 3$), the maintenance of soil nutrients ($n = 2$), the provision of additional fodder resource ($n = 2$) and the maintenance of biodiversity ($n = 1$). Three farmers declared they did not think planting trees was a solution to cope with EWE.

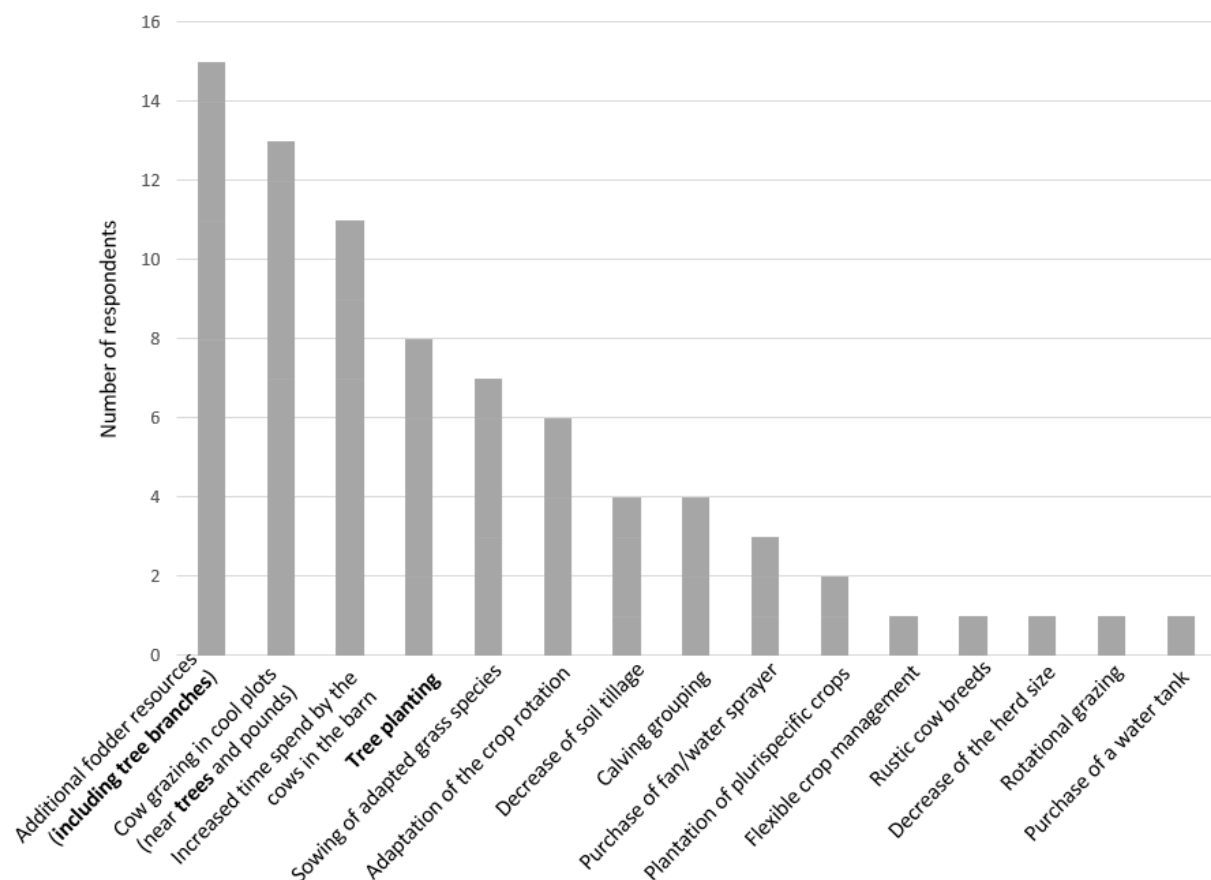


Figure 1. Strategies of resilience mentioned by the farmers ($n = 33$). Strategies in bold consider the integration of trees on the farms.

Discussion

Contrary to expectations, tree planting was not one of the main strategies adopted to face EWE. As observed by Blanco et al. (2020), tree planting was mostly seen as a way to improve plots' microclimate and to provide ecological regulations, rather than being integrated into farming practices and strategies.

When crossing these results with a preliminary study on the farming systems associated with the development of agroforestry (Mettauer et al., submitted), we observed that the intensive farming systems did not take advantage of the presence of trees and relied more on the use of external inputs (e.g., purchase of fodder and of equipment) to increase resilience (Rist et al., 2014). On the contrary, the extensive farming systems considered more trees and ecological regulations in their strategies for resilience. However, only few of these farmers deliberately used the products of trees within their strategies for resilience. Especially, branches can be used as an additional fodder resource when coping with forage shortage or fruits can contribute to product diversification (Quandt et al., 2019).

Perspectives

Our study invites future participative research to further explore and quantify the agronomical, socio-technical and political conditions to extend the use of trees in the strategies for resilience

in dairy farms. Such effort needs to consider methodological challenges on how combining objective and subjective assessment of resilience of the farming systems to EWE in the long term.

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Urban agriculture as a stepping-stone to rural farming: trajectories of new farmers

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Keywords: urban farming, trajectories, farmer training, generational renewal

Introduction

French agriculture is facing an intense demographic decrease with a loss of 100 000 farms and 11% of the agricultural workforce between 2010 and 2020 (Agreste, 2022). This phenomenon is expected to continue with a loss of 35 000 to 72 000 jobs out of 660 000 before 2030. Many farmers are near retiring age and 1/3 are uncertain about the future of their land. Only two new establishments are expected for three retirements (Purseigle & Hervieu, 2022).

At the same time, 35% of young farmers receiving state subsidies do not inherit their farm from close relatives. This suggests a dynamic similar to that observed in Canada, where many new farmers come from diverse, often urban, backgrounds (Laforge et al., 2018). With approximately 80% of the French population living in urban areas (INSEE, 2020), these spaces have become key sites for the emergence of various forms of Urban Agriculture (UA) (Aubry et al., 2022). Over 4 100 projects have been recorded in France (AFAUP, 2024). UA is also recognized for raising awareness among city dwellers, and is increasingly seen as a possible entry point into agriculture, helping newcomers gain basic skills—one of the main challenges identified for new farmers (Laforge & McLachlan, 2018). This supports the idea that UA may contribute to reversing the demographic decline in agriculture by attracting new entrants (Brossard, 2024).

The aim of this study is to investigate the role of urban agriculture in the professional trajectories of new farmers in France, particularly how an initial UA experience has influenced their training and farm models. To our knowledge, this is the first research in France to focus specifically on farmers who transitioned from UA to peri-urban or rural farming. While international research has documented UA's social and educational roles—such as addressing food insecurity (Poulsen et al., 2015; Siegner et al., 2018; Warren et al., 2015) and strengthening community ties (Boukharta et al., 2024; Orsini et al., 2013)—its potential role as a bridge toward rural farming remains underexplored. This study contributes to filling that gap by examining how UA might foster new farming vocations in France.

Method

Through network of urban farms, UA associations (AFAUP...) and agricultural stakeholders (Chambres d'Agriculture...), we identified farmers who settled in rural or peri-urban areas after a first experience in UA. Around fifteen semi-structured interviews will be conducted between March and July 2025 across selected French regions with active UA ecosystems.

We apply the life story method proposed by Bertaux (2006), which is effective for reconstructing individual trajectories and is already used by both researchers and farm establishment advisors (Fiorelli et al., 2014). These interviews will allow us to observe the determinants of farm establishment, particularly regarding the transition from urban to rural areas and the forms that these new farms take. Interviews with stakeholders in UA and agricultural transition will also be conducted to enrich the analysis.

These interviews will be analyzed using comparative analysis methods. The farmers' trajectories will be reconstructed, with a focus on biographical turning points (Abbott, 2001)s . A typology will be developed based on motivations, training paths, farm models, challenges, social conditions and resources mobilized—offering insights into how UA facilitates access to farming for those outside the traditional agricultural world.

Results

We expect to conduct around 15 interviews with farmers who transitioned from an experience in UA to rural or peri-urban farming since 2010. Preliminary results from four interviews reveal a variety of profiles in terms of age, education, UA experience and social background. Some are young graduates with no prior connection to farming, while others are older with vocational training or previous exposure to farming. UA experiences ranged from volunteering to professional management or formal training. For all, UA provided an opportunity to engage with agricultural work, but was not sufficient in itself, all participants sought additional hands-on learning, such as internships or WWOOFing. The typology will highlight this diversity, examining the role of UA as an entry point and the personal and structural factors shaping each path.

Discussion and perspectives

UA has been shown to influence perceptions of agricultural careers (Unay-Gailhard et al., 2025b) and to reinforce connections between agriculture and society (Unay-Gailhard et al., 2025a). However, scientific research has not yet addressed UA's potential as a pathway into rural farming, despite claims by stakeholders. Our research addresses this gap and contributes to broader studies on the urban–rural link in agriculture.

We aim to shed light on how UA experience influences farming models adopted by new entrants—for instance, their preferences for short supply chains (Dolci, 2021), organic practices (Samak, 2021), or collective structures (Cretin et al., 2023). Our study is a first basis for a longer-term project that is being submitted on the role of UA, professional or not, in the generational renewal of farmers in France.

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Unveiling on-farm anaerobic digestion systems diversity: a typology analysis of northern French farms

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Keywords: Anaerobic Digestion, Typology Analysis, Farming systems, Practices modification

Introduction

Anaerobic digestion (AD) is a biological process that converts organic matter such as manure and crop residues into biogas and digestate in oxygen-free conditions. On farms, it serves as a systemic innovation linking energy, nutrient cycling, and management, supporting the shift toward sustainable agrifood systems. Farmers increasingly adopt AD to improve resilience and long-term viability amid sector-wide financial pressures (O'Connor et al., 2020 ; McCabe et al., 2020). Across Europe, the growing integration of AD into farming systems has reshaped agricultural practices, leading to significant structural and operational changes within farms. To the best of the author's knowledge, comprehensive studies describing on-farm anaerobic digestion systems explicitly based on their structural and functional characteristics are largely absent from international literature. Existing research, predominantly conducted within France, has primarily explored agronomic and biogeochemical impacts (e.g., mixed crop-livestock systems (Moinard, 2021), livestock systems (Espagnol et al., 2021), or socio-economic and organizational dimensions (Cadiou, 2023), without holistically addressing diverse system configurations and their operational dynamics. Methodologically, (ADEME & Solagro, 2018) developed a socio-economic typology to classify on-farm AD systems based on legal frameworks, capital assets, and labor management linkages; however, such typologies remain limited in scope and do not fully capture the multifaceted nature of AD integration. These gaps limit our understanding of how farm systems evolve after AD adoption and how configurations affect sustainability. This study therefore analyzes the technical, agronomic, and socio-economic dimensions of AD integration across diverse farms, asking: How do variations in practices, farm characteristics, and socio-economic contexts explain the diversity of on-farm AD systems?

Materials and methods

Based on 40 semi-structured interviews with farmers in the Hauts-de-France region (northern France), we constructed a dataset of 67 qualitative and quantitative variables. These were grouped into three dimensions: (i) agronomic aspects (e.g., farm size, production systems, land use), (ii) AD system characteristics (e.g., substrates, energy output, digestate management), and (iii) socio-economic variables (e.g., funding, labor, strategic goals). Using Factorial Analysis of Mixed Data (FAMD) followed by Hierarchical Clustering on Principal Components (HCPC), we developed a singular typology of on-farm AD systems, identifying key configurations based on relevant criteria.

Results

The results of the analysis identified that the sampled farms can be categorized into 6 types (Figure 1).

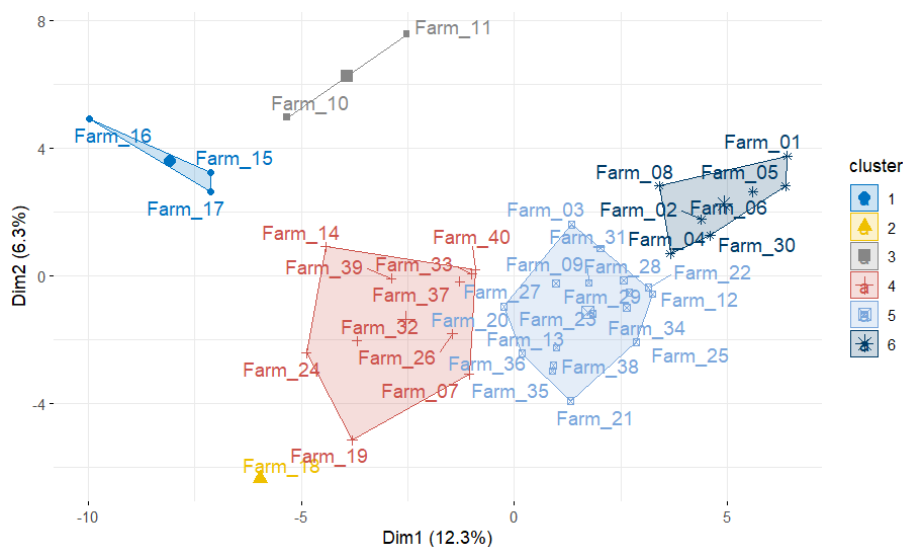


Figure 1. Factor Map of the surveyed farms derived from FAMD along the first two dimensions.

Each cluster is defined by a unique combination of variables. Key indicators were used to separate clusters, by quantifying the proportion of farms within each cluster that shared specific traits, to statistically assess the significance of these associations, and to provide an insight into the variability within a cluster and across all surveyed farms.

- Cluster1: Predominantly mixed crop–livestock systems with on-farm substrate self-sufficiency for electricity production only.
- Cluster2: On-farm AD systems specialized in industrial cropping.
- Cluster3: Mixed crop-livestock farming with local energy recovery.
- Cluster4: Mixed Crop-livestock farming with territorial AD systems and biomethane injection.
- Cluster5: Cropping system and mixed crop-livestock farms with territorial AD systems and biomethane injection.
- Cluster6: Territorial innovative on-farm AD system in extensive cropping systems.

Discussion and perspectives

This study examines how on-farm AD varies by scale, balancing trade-offs between efficiency and sustainability. Micro-scale systems emphasize on-farm waste management with limited energy recovery and modest economic benefits, while mid- and large-scale clusters enhance biogas output and revenue through biomethane injection, co-digestion, and extended retention times, though they face feedstock supply and regulatory challenges. Digestate use reduces synthetic fertilizer reliance but is constrained by nitrogen loss and strict application limits. While injection systems and seasonal spreading improve nutrient efficiency, high costs limit their adoption. Small-scale AD aligns with existing practices, whereas larger systems often intensify cropping, increasing nitrate leaching and soil imbalance risks. These dynamics align with international trends: in Germany, strong policy support and alignment with energy cropping have enabled widespread AD adoption, whereas in Australia and the UK, uptake remains limited due to weak incentives, regulatory barriers, and high investment demands (Wilkinson, 2011; Tidy et al., 2015). The effectiveness of AD integration depends not only on technological scale but also on national policies and farming structures. More than waste treatment, AD is a multi-dimensional innovation that reshapes inputs, farm organization, and farmer practices in response to environmental, economic, and regulatory pressures. It offers a clear example of systemic innovation and supports the analysis of transition pathways. Further research is needed to assess long-term impacts on land use, particularly the risks linked to energy cover crops and socio-economic trade-offs. These challenges highlight the need to view AD as a recalibration of energy, nutrient, and governance systems within agriculture.

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Drivers, barriers, and typologies of adoption of agroecological practices in northern Ghana

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Keywords: agroecology, sustainability, transition, assessment

Introduction

Despite technological advances in the agri-food systems since the Green Revolution, the current production pathway is faced with many challenges in the context of sustainability. While agroecology presents a viable alternative towards sustainable agri-food system, transition is hindered by challenges including institutional and contextual factors (HLPE, 2019). In Sub-Saharan Africa (SSA), these challenges are further complicated by perceptions (Marfurt et al., 2023). This study investigates perceive drivers and barriers of agroecological transitions in Northern Ghana, allowing for an analysis of innovative practices and transition pathways.

Methods

The study employed a participatory approach, combining a household survey, qualitative interviews, and field observations. The sample size was set to 95 farm households based on the available resources. Systematic random sampling was used for household selection for the survey, while stratified and simple random sampling guided participant selection for interviews. The study was guided by the 10 elements of agroecology (Mottet et al., 2020), and the categorization framework of the key drivers and barriers of agroecological transition (Souissi et al., 2024). We used percentage frequency to understand general overview of respondents' perception of agroecology. Principal Component Analysis (PCA) was conducted to understand the main perceived drivers and barriers of agroecology. Bartlett's, Kaiser-Meyer-Olkin, and Cronbach's Alpha tests were done to determined suitability and reliability. Factors were retained based on eigenvalues >1 (Costello & Osborne, 2005). To further explore how farmers perceive agroecology, we applied three additional analyses: Cluster Analysis (CA), ANOVA F-test and t-tests. For the CA we applied two-step clustering approach, first Ward's hierarchical clustering method was applied to the PCA component scores, followed by a partitioning step using K-means. Finally, the cluster profiles were compared by examining both the PCA component scores and relevant socioeconomic variables using ANOVA F-tests and t-tests.

Results

The PCA identified nine components that together explain 70% of the total variance, six of these components detailed in Table 1. Variables with loadings of 0.4 or higher were considered significant contributors. The CA revealed four optimal clusters. An ANOVA F-test confirmed significant differences among the clusters ($p < 0.05$). Cluster (C) 2 and 4 respectively captured 28% and 32% responses and presented the profile of agroecology enthusiasts. C3 was associated with barrier-focused components and captured 8% of responses. C1 reflected a moderate perspective and captured 32% households. ANOVA and t-test analyses indicated that socioeconomic factors including age, education, training, sex, and road quality, significantly contributed to the observed differences between clusters at significance levels ranging from 1% to 5%.

Drivers	Variables	Loading

Resource Compatibility (C1)	Compatible with my farm resources	0.861
	Compatible with my economic capabilities	0.865
	Compatible with my knowledge and experience	0.802
Pest and Resilience Benefits (C2)	Reduced pest and disease	0.783
	Improved resilience to climate change	0.809
	Improve soil fertility	0.422
Food Quality & Critique of Conventional Farming (C4)	Improve food quality and safety	0.696
	Preference for agroecological practices	0.763
Barriers		
Institutional Barriers (C3)	Lack of government support	0.792
	Lack of technical support & training	0.422
Market and High-Risk Perception (C5)	Lack of specific market	0.495
	Short-term risk	0.671
	Lower yields	0.501
Uncertainty and Training (C9)	Uncertain of future gains	0.704
	Lack of technical support & training	0.468

Table 1. Key drivers and barriers components identified through PCA

Discussion and Perspectives

The results show that farmers perceive agroecological practices as well-suited to their existing resources, making it a strong driver of agroecological transition. Our results also show that farmers perceived agroecology as essential for improving soil fertility and building resilience, while preserving traditional knowledge, and reducing dependency on chemical inputs. Unlike findings from Castellanos-Navarrete & Jansen, (2018), where conventional agriculture was preferred, farmers in our study were critical of industrial farming and perceive agroecology as a means of improving food quality and safety.

Despite these positive perceptions, several barriers hinder agroecological transition. Institutional constraints, such as lack of government and technical support, emerged as significant challenges. While agroecology is gaining recognition in Sub Sahara Africa (SSA), limited policy backing and insufficient training slow its adoption (Sinyangwe et al., 2023). Another major concern is the perceived financial risk and uncertainty. Farmers associate agroecology with short-term yield reductions and an absence of dedicated markets. The debate over whether agroecology can match conventional agriculture's productivity is particularly pressing in SSA, where food insecurity remains high, and population growth exceeds the global average. While farmers in the study region hold a positive attitude toward agroecology, concerns about production gaps and weak institutional support could temper transition.

Conclusion

On the basis of sustainability, transition to agroecology is increasingly advocated for, yet challenges persist, particularly in SSA. This study explored agroecological transition in Ghana and presents that farmers view agroecology as compatible with their resources and culture, while offering resilience benefits and reducing input dependency. However, scepticism remains regarding agroecology's production capacity. Other key barriers include lack of policy support, specific market, training, and information. The findings suggest that farmers' perceptions of agroecology are multifaceted and distinctly clustered. Overall, these results highlight the need for tailored interventions that address the specific concerns of each group, potentially enhancing the adoption of agroecological practices.

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Uncovering the diversity of farmers' practices to organise the redesign of a crisis-stricken sector: the case of French cherries

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Keywords: emergency situation, design for transitions, archetypes, design support method

Introduction

How can we prioritize what needs to be redesigned in an agricultural sector in crisis? The French cherry sector has been facing this question since the arrival of an invasive pest -- *Drosophila Suzukii* (DS), in 2010. The economic, environmental, and social impacts associated with managing this pest (mental burden, intensive use of pesticide, economic loss, etc.) are jeopardizing the short-term future of the sector (Ros et al., 2021). This 'emergency situation' sparks controversies around the management strategies to prioritize (e.g., pesticide use exemptions vs. redesign) as the national and regional players involved in the management of DS lack knowledge of the current farmers' practices and the concrete problems they face in their day-to-day work. While extensive research has focused on the biology of DS (e.g. Tonina et al., 2018), this study aims to uncover the diversity of farmers' cherry practices to bring reflexivity to collectively discuss priorities for redesigning the sociotechnical cherry system, considering emergencies.

Methods

The method builds on three fields of research: approaches to analysing farmers' practices within their sociotechnical environments (Gras et al., 1989; Meynard et al., 2018), methods to support collective design processes (Le Masson et al., 2017), and researches on innovation in time of crisis (e.g. Dumez et al., 2022). Data collection and analysis followed two steps: i) interviews with experts to characterize, from their perspective, the diversity of farmers' practices in their area of intervention, and ii) interviews with 45 farmers, chosen to represent this diversity in the five main cherry production areas in France. The cross-analysis of the cases aimed to qualitatively build archetypes of management logics for flies at the orchard and at the farm scale. It also aimed to specify the concrete problems met by farmers in their situation. The results will be discussed in the coming months with players engaged in the redesign of the cherry sociotechnical system (e.g. researchers, politics, marketers, farmers).

Results

Five management logics for flies at the orchard scale and situated problems met by farmers

Among the farmers interviewed, our results reveal five contrasted management logics for flies at the orchard scale, as well as problems farmers meet when trying to manage DS. These different logics and problems are rarely mentioned by the regional and national players involved in the redesign of the sector. These five logics are:

1. Systematic application of pesticides to produce high quality cherries in large quantities for mass distribution,

2. Systematic application of organic products and repellents for the low-cost management of pests to produce cherries for high added-value markets,
3. Cultivation of early varieties and use of biological control products for direct sale,
4. Physical protection (e.g. nets) and intensive orcharding with low pesticide use to produce high quality cherries in large quantities for mass distribution,
5. Physical protection and intensive orcharding over small areas for short distribution channels.

For example, concerning logic 4 the farmers chose to install insect-proof netting on their orchard. This choice involved adapting the shape of the trees, and they did it to ensure getting both quantitative (yield per hectare) and qualitative (size, fruit damage, etc.) cherry production. The farmers concerned often opt for this technic in situations conducive to the development of DS (e.g. humidity area, near forests etc.), and for ethical and cognitive reasons (e.g. overuse of pesticides, mental load). This management logic raises other issues, particularly in terms of investment, maintenance and work organisation (e.g. picking fruits under nets, using adapted machinery).

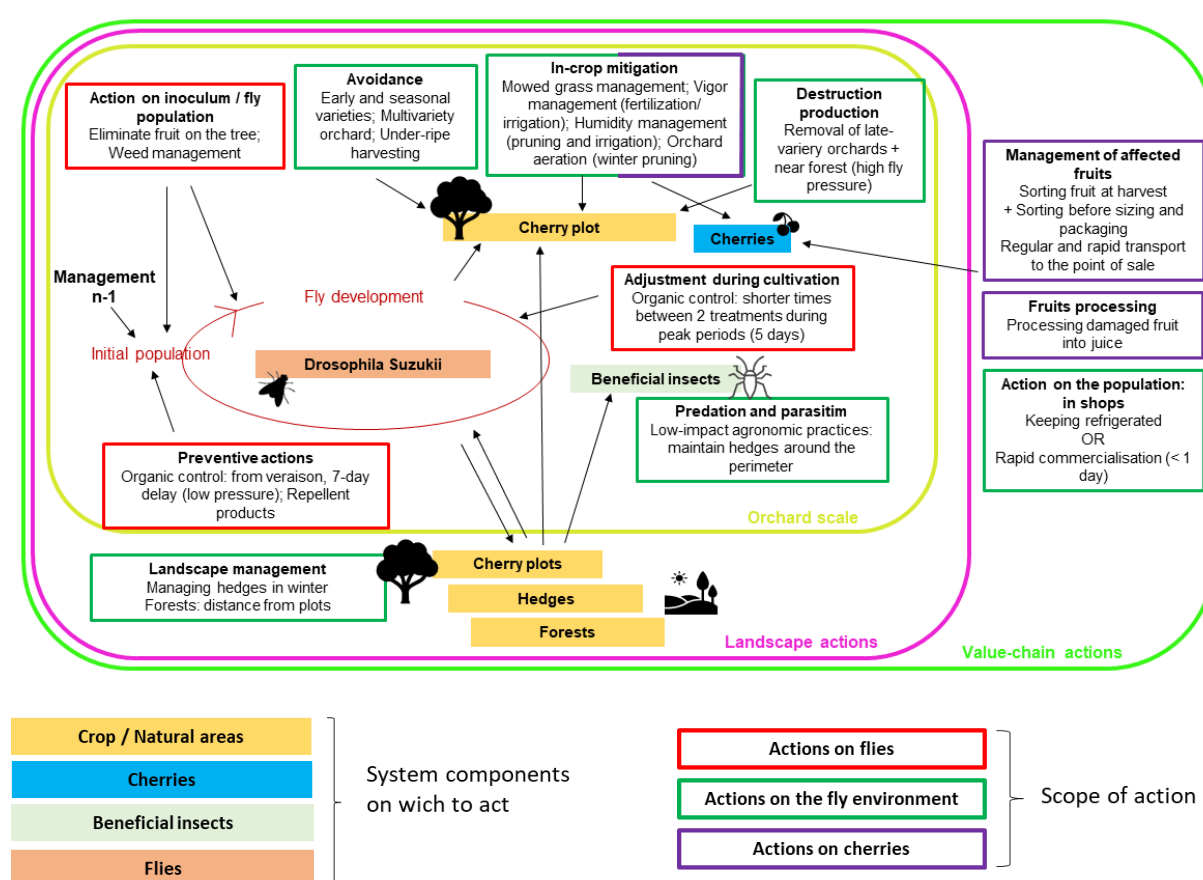


Figure 1. Actions involved in the management logic of a farmer (logic 2)

Six contrasted ways to manage flies at the farm scale

At the farm scale, we distinguished six archetypes for managing flies, that differ in relation with the economic role of cherries in the overall profitability of the farm, the work organization at the farm scale, the history of the farm and commercial opportunities.

For instance, on several farms (archetype 1), the cherry is a secondary production that farmers maintain on a small surface to diversify their activities. They look for simple DS management and install insect-proof nets and produce under organic certification.

Conversely, on several large farms (archetype 2) cherry is the central production, and the farmers diversify their crop management logics in different orchards in the aim to optimize their production, to spread risks, and get cherries in high quantity for mass distribution.

Discussion and perspective

The study highlights different farmers' flies management logics and ways to address the DS issue in different situations (e.g. a highly diversified farm on a plain vs. a specialised farm on slopes). It also shed light on situated problems encountered by farmers when managing DS (e.g. work organisation, ethical issues, investment), which contrasts with the way in which national players tackle this issue. These results aim to be used in a near future to support the redesign of the sector, considering emergencies, in different design spaces involving actors engaged in the management of DS. Our results also contribute to the development of methods to support collective reflexivity in design processes in emergency situations.

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How can winegrowers' decision-making lead to a fungicide-saving management?

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Keywords: Pesticides, Viticulture, Management Strategies, Diagnosis of uses

Introduction

Pesticides are largely used in viticulture, resulting in water and soil pollutions, and toxicity for living organisms (Winter et al., 2018). Solutions to reduce fungicides (that represent 69-82% of applications) in viticulture exist, such as optimizing the timing, frequency or dose of the application, substituting synthetic products by biocontrol, planting resistant varieties (Mailly et al., 2017; Pertot et al., 2017). However, these solutions are still under-mobilized as they often do not meet winegrower's needs (Pedneault and Provost, 2016; Pertot et al., 2017). One solution is to consider the diversity of situations in which those solutions will be used (Cerf et al., 2012), by characterizing winegrowers decision-making for fungi management. In this communication, we aim to analyze decision-making processes of winegrowers from two regions of France, with a focus on the individual and collective information they use. To our knowledge, this is the 1st diagnosis of use considering the role of several sources of information in the diversity of winegrower's fungal disease management.

Methods

We performed a diagnostic of uses (Cerf et al., 2012) to analyze the diversity of current winegrowers' decision-making for fungal disease management. We conducted 40 semi-structured interviews, 17 in Languedoc (South-East of France) and 23 in Alsace (North-East of France). Languedoc and Alsace are associated to a gradient of pesticide use (Mailly et al., 2017) and respectively located in a semi-arid Köppen-type Csa climate characterised by a temperate climate with dry and hot summers and in a temperate cold Köppen-type Cfb climate zone, with continental climate with no dry season and a warm summer (Beck, 2018). Here, we present a preliminary study illustrating two contrasting cases winegrowers A and B.

We collected 5 categories of variables: farm characteristics, fungal disease management objectives and expected results, fungal diseases' management practices, information used to decide to implement these practices and associated difficulties. We distinguished individual sources of information (e.g., climatic information, observations of symptoms or vine development), and those considered as collective since they involved at least another person (e.g., prescriptions made by an advisor, subscription to a technical journal, exchanges with peers). We then described the main types of decision-making that could lead to a reduction in fungicide use. For each decision we identified if it led to save fungicide, and the information used (Figure 1).

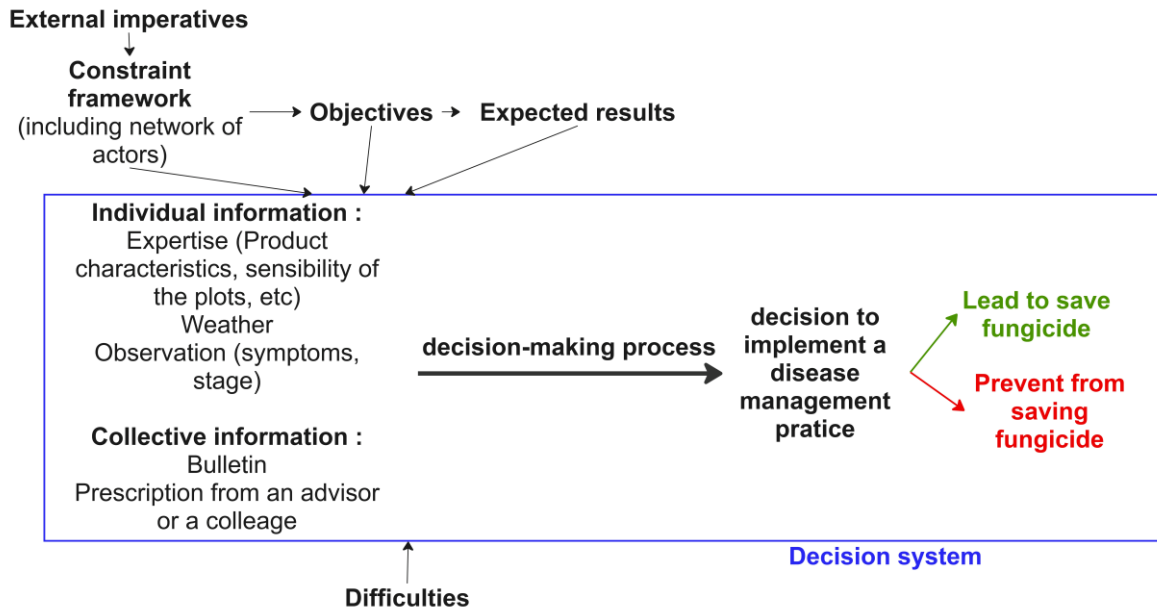


Figure 1. Analytical framework used

Results

We identified seven types of decision that could lead to a pesticide-saving management. Those decisions operated at different time scales a) at wine plantation (e.g. choice of grape varieties (>15 years); b) for multi-years (e.g. implementation of prophylactic measures); c) during the season, i.e. for the first treatment or treatment renewals. The decisions also operated at different spatial scales, concerning all or parts of farm plots.

	Information used	Decision-making processes	Decision
WG. A	Decision 1 : systematic Observation : Vegetative stage Expertise : Sensibility of the plot Expertise : powdery mildew occurs every year	— Treat the entire farm against powdery mildew when the carignan are at an early stage (2-3 leaves) —>	First treatment against powdery mildew on the whole farm the 21/04/2024
	Decision 2 : systematic Expertise : Risk of black rot	— Even if there's no risk of downy mildew, treat with copper against black rot at the first treatment —>	First treatment against black-rot on the whole farm the 21/04/2024
	Decision 3 : adaptive Collective information : Information bulletin Observation : symptoms of downy mildew Expertise : powdery mildew doesn't occur every year, appear all of a sudden	— If symptoms of downy mildew on the farm, do the first treatment. —>	First treatment against downy mildew on the whole farm the 09/05/2024
WG. B	Decision 1 : systematic Expertise : sensibility of the plots	— Treat only the 0.5 hectare of carignan, and only against powdery mildew —>	First treatment on 0.5 hectare the 01/05/2024 First treatment on the whole farm the 09/05/2024
	Decision 2 : adaptive Collective information : advisor and colleagues Observation : symptoms of downy mildew on the young vines	— If symptoms of downy mildew on the young vines or if the advisor or colleagues launch the alert of the first symptoms, do the first treatment —>	First treatment on 0.5 hectare the 01/05/2024 First treatment on the whole farm the 09/05/2024

Figure 2. Decision-making processes of two winegrowers (WG A & B) concerning the 1st treatment. In green: decision leading to save fungicide, in red: decision preventing saving fungicide

We distinguished systematic and adaptive decision-making process. Contrary to systematic processes, adaptive ones were « if... then » rules and depended on changing parameters, such as the weather or the presence of symptoms. According to these parameters, adaptive processes could lead to save fungicide or not. For example, renewing a treatment if it rains could lead to save pesticide on a very dry year only.

A winegrower could adopt several different decision-making processes and decisions, e.g., concerning the target, timing and localization of the first fungicide-treatment (Figure 2).

Discussion and Perspectives

Although winegrower A had an adaptive decision-making process targeting downy mildew that could delay the first application of copper, the systematic one targeting black-rot prevented saving this application. It shown the importance of specifying the link between decision and fungicide-saving management. Also, it was important to both understand each decision and the whole process (e.g., delaying the first treatment does not inform on the total number of treatments during the season), as well as to test those results on a larger sample of winegrowers. Our results are consistent with Chen et al. (2022), on the role of extension service and weather information on pesticide use. We however highlight other type of important information mobilized by winegrowers, e.g., symptoms' observations, exchanges with colleagues. The next step is to apply this analysis to our entire sample and to include other factors considered in decision-making (Figure 1), e.g., objectives, expected results, constraints, network of actors. This will enable us to identify common or divergent decisions within and between the two regions studied, as well as the information used to make them. Characterizing decision making of winegrowers and the role of different information is a necessary step before co-designing fungicide-saving strategies.

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Phytos-Explorer: supporting data-driven decision-making to reduce pesticide use at the territorial scale

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Keywords: Pesticide monitoring, Decision-making, Land use data, Spatial disaggregation

Introduction

The widespread use of pesticides in agriculture raises significant concerns about environmental pollution, human health risks, and biodiversity loss. While regulatory frameworks and local initiatives aim to reduce pesticide usage without compromising agricultural productivity, monitoring pesticide use at a territorial scale remains challenging due to data limitations, spatial heterogeneity, and the complexity of farming practices.

Quantifying pesticide application at the territorial scale is crucial for assessing the effectiveness of local plans and environmental policies, tracking changes in agricultural practices (Martin et al., 2023), and identifying pollutants which can be transferred to air and water bodies. However, when comprehensive ground-level data on pesticides use, or direct pollutant measurements are difficult to collect, the use of relevant indicators with appropriate spatial and temporal resolutions becomes essential.

Methods

We introduce *Phytos-Explorer*, a tool designed to monitor the annual use of plant protection product over time at territorial scale, helping to improve management, and tracking progress in reducing their application. It is based on a method for disaggregating sales data of pesticides, which also integrates highly detailed information on land use at the territorial level and the approved uses of these products. *Phytos-Explorer* can also integrate local agricultural practices and expert knowledge -- either through table input or direct collaboration with researcher -- to enhance prediction accuracy. The aim is to assist stakeholders, researchers, and policymakers in evaluating regulatory impacts, identifying high-risk applications, and propose targeted mitigation strategies.

The tool combines national pesticide sales records at the postal code level (BNVD in France) with high-resolution land use datasets, including the Land Parcel Identification System (LPIS) for agricultural parcel identification -- covering more than 300 crop types (Sagris et al., 2013) - - and land use data from the French National Institute for Geography (IGN) for non-agricultural areas. The tool also incorporates detailed information on product usage, such as approved reference doses and target crop associations, along with the location of organic parcels and expert insights.

A spatial disaggregation model is applied since sales data do not provide direct information on pesticide application locations. The tool assigns sold pesticides to different land uses, e.g., crop types and specific parcels based on allocation rules which, in turn, are based on product specification, and eventually with local expert validation. To date, available data range from 2015 to 2023, with a gap of two years. The tool was compared to ground-truth over a two-year period on a single watershed. Here are reported four case study areas representing diverse agricultural and environmental contexts:

(A) a large territory (60,000 ha) facing the substitution of multiple herbicide active substances by a single molecule, raising concerns about resistance and environmental load; (B) a small catchment (3,620 ha) facing a serious water pollution related to a single substance used on a single crop; (C) a watershed where recent expansion of sugar beet cultivation has triggered environmental concerns due to potential increases in phytosanitary inputs; (D) a watershed characterised by strong farmer engagement towards the complete elimination of pesticides use.

Results

Phytos-Explorer demonstrated overall good agreement with ground-trough data, particularly for fungicides ($R^2=0.84$, RMSE = 58.3 kg), growth regulators ($R^2=1.00$, RMSE = 15.1 kg) and herbicides ($R^2=0.66$, RMSE = 65.9 kg). Performance was lower for insecticides ($R^2=0.3$, RMSE = 3.4 kg).

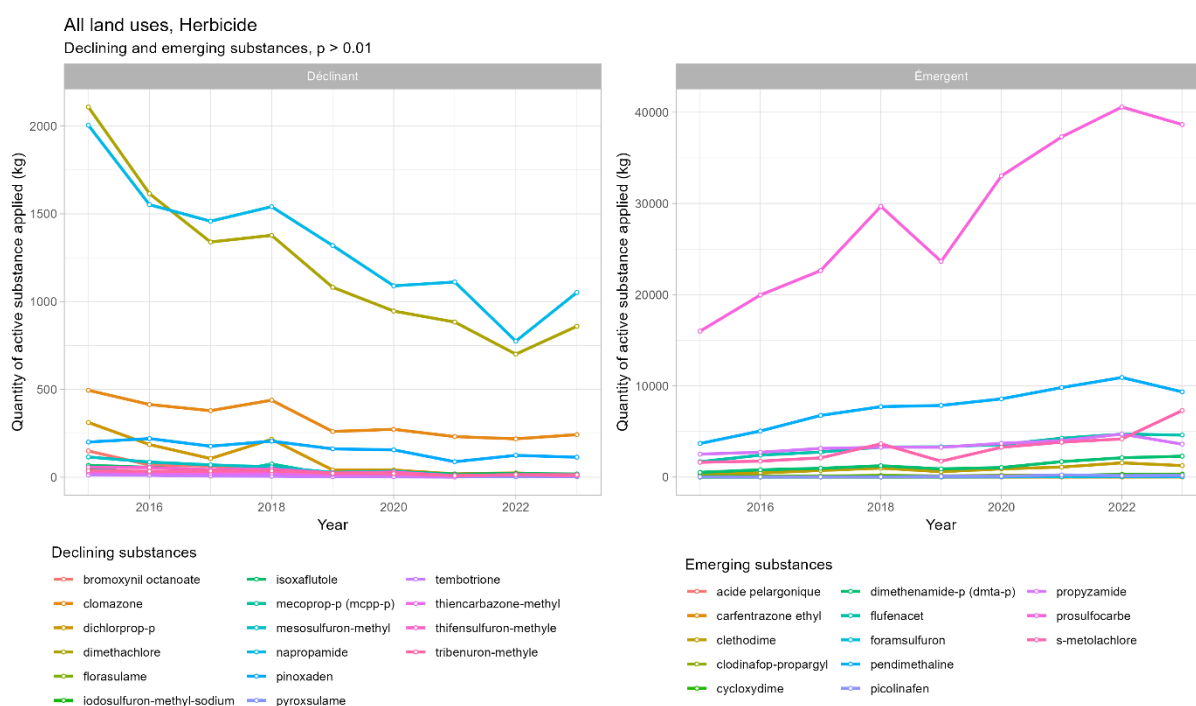


Figure 1. Declining and emerging substances in the watershed of 60,000 ha (case A) over time.

The tool produced estimates of pesticide use across diverse land use types, capturing inter-annual trends in application, integrating land use dynamics, and enabling the analysis of active substance substitution patterns and stock evolution over time. An example of a targeted analysis on emerging and declining substances at the landscape level (case A) is presented in Figure 2, illustrating the tool's utility in supporting local intervention monitoring and issuing warning on specific compounds. In this case study, particular attention is given to prosulfocarb, which appears to have substituted several other active substances, raising concerns regarding its increasing use and potential implications for water resource protection. A further example of inter-annual trends for the 10 most-used substances on sugar beet (case C) -- relevant for tracking shifts in usage patterns -- is presented in Figure 2. In this case study, the cultivated area of sugar beet as well as the estimated applied quantity of metamiltron increased by over 150% between 2015 and 2023, highlighting a significant upward trend in both crop extent and herbicide use over the study period.

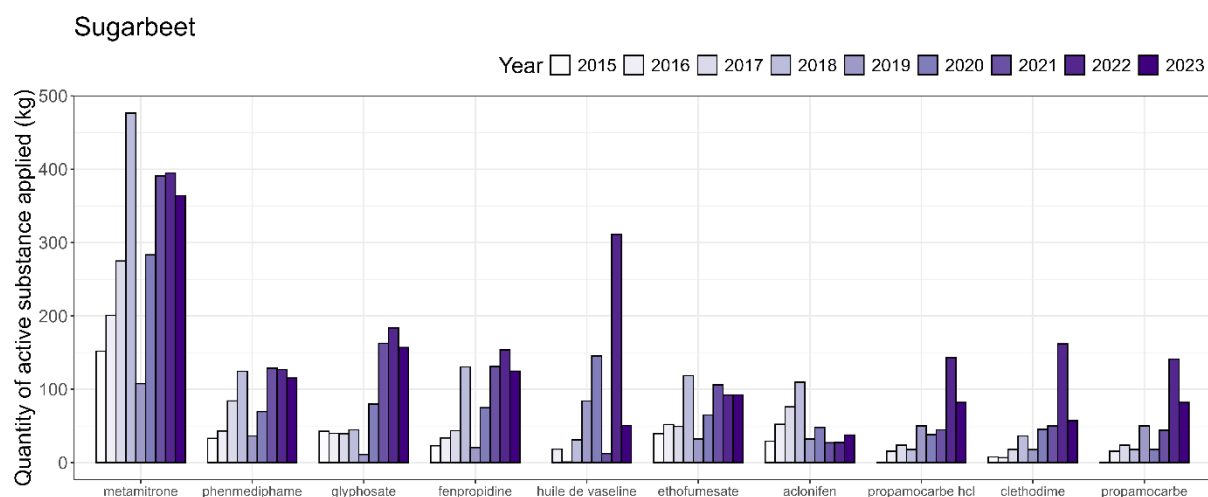


Figure 2. Inter-annual trends for the 10 most-used substances on sugar beet in case C.

Results also indicate that the integration of local expertise (cases B and D) significantly enhances estimation accuracy, particularly in regions with diversified cropping systems. Specifically, the tool was able to distinguish the application of certain products to specific land uses by leveraging local knowledge (e.g., the spatial distribution of target crops), thereby enabling the monitoring of actions implemented to reduce the use of pesticides over time.

Discussion and Perspectives

Phytos-Explorer proves to be a valuable tool for monitoring pesticide use at the territorial scale, helping to track temporal trends, assess management practices, and identify areas for intervention. By integrating local expertise and detailed data on land use and product applications, the tool provides more accurate predictions. Its emerging role in supporting evidence-based decision-making for a range of local stakeholders -- including land managers and policymakers -- position it as promising tool. Although *Phytos-Explorer* is still in early stages of application, the insight it generated show great potential for enhancing pesticide management at landscape level.

However, the tool's effectiveness depends on the availability and quality of input data. Key limitations include the reporting delays in land use and pesticide sales data -- typically with a two-year lag -- as well as uncertainties related to on-farm stockpiling, which may lead to discrepancies between recorded sales and actual application timing. Improving the collection and sharing of phytosanitary practices at territorial scale, particularly through farmer engagement, could significantly enhance the accuracy and timeliness of model predictions.

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Classifying farming practices for a conceptual model of their impact on biodiversity

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Keywords: field, landscape, ecological processes, ecosystem components

Introduction

Agriculture is involved in the five drivers of biodiversity erosion at the global level identified by IPBES (2019), and as such plays a major role in overshooting one of the nine planetary boundaries (Campbell, et al. 2017). Recent studies show that research into how farming practices affect biodiversity is accelerating (e.g. Bonfanti et al., 2023; Cozim-Melges et al., 2024; Schievano et al., 2024). However, their vision of practices remains traditional: a list of management actions that contribute to production objectives. There is no ecological approach that considers practices in terms of their impact on ecosystems and biodiversity. We believe that this conceptual renewal is necessary in order to address the issue of the impact of agricultural practices on biodiversity. Here we present a framework for classifying these practices, alongside an associated conceptual model that illustrates their impact on biodiversity through the states and processes of the agroecosystem.

A framework for farming practices in relation to their impact on biodiversity

The framework is based on a hierarchical classification to help control the complexity of farming practices at landscape and field scales. It consists of three levels:

- The practices family level concerns generic actions of farmer. These generic categories are:
 - Space-time allocation of land
 - Addition of living organisms
 - Addition of physical and chemical factors
 - Removal and destruction of biomass and living organisms;
- Each family is divided into several subfamilies, which describe each generic action in more detail, e.g. space-time allocation of land includes, among others, allocation of cropped area in the landscape, field configuration, allocation of semi natural elements;
- Finally, the practice category gives further precision to the subfamily, e.g. the type of crop covered, the input category, etc.

Overall, the framework includes 4 families, 17 subfamilies and 31 practices. The family "Addition of physical and chemical factors" has the most categories with 6 subfamilies and 14 practices.

A conceptual model of the relationships between farming practices and biodiversity

Using the family level, it was possible to design a conceptual model relating farming practices to biodiversity through the state of ecosystem components and several processes, both impacting the final drivers of biodiversity, the ecosystem quality and the trophic networks (Figure 1). The 5 drivers of biodiversity loss identified by IPBES (2019) can be placed on the

states and processes (Figure 1), which allows a link to be made between these very global drivers and specific practices.

- "Space-time allocation of land" influences the availability and connectivity of habitats, ("a" in Figure 1), and the abiotic components of the agroecosystem through the creation of microclimate, change in light and water availability, ("b" in Figure 1).
- "Addition of physical and chemical factors" modifies the abiotic component of the agroecosystem, ("c" in Figure 1), and the fate of living organisms, ("d" in Figure 1).
- "Removal and destruction of biomass and living organisms" influences the same components as the previous one ("e" and "f" in Figure 1)
- "Addition of living organisms" impacts the physical-chemical state, and especially the soil if these organisms are cultivated plants ("g" in Figure 1). By nature, it has an effect on the trophic relationships ("h" in Figure 1) and may influence the fate of organisms ("i" in Figure 1).
- Finally, emissions of greenhouse gases depend on all farming practices and affect the state of all components and processes of the agroecosystem, ("j" in Figure 1).

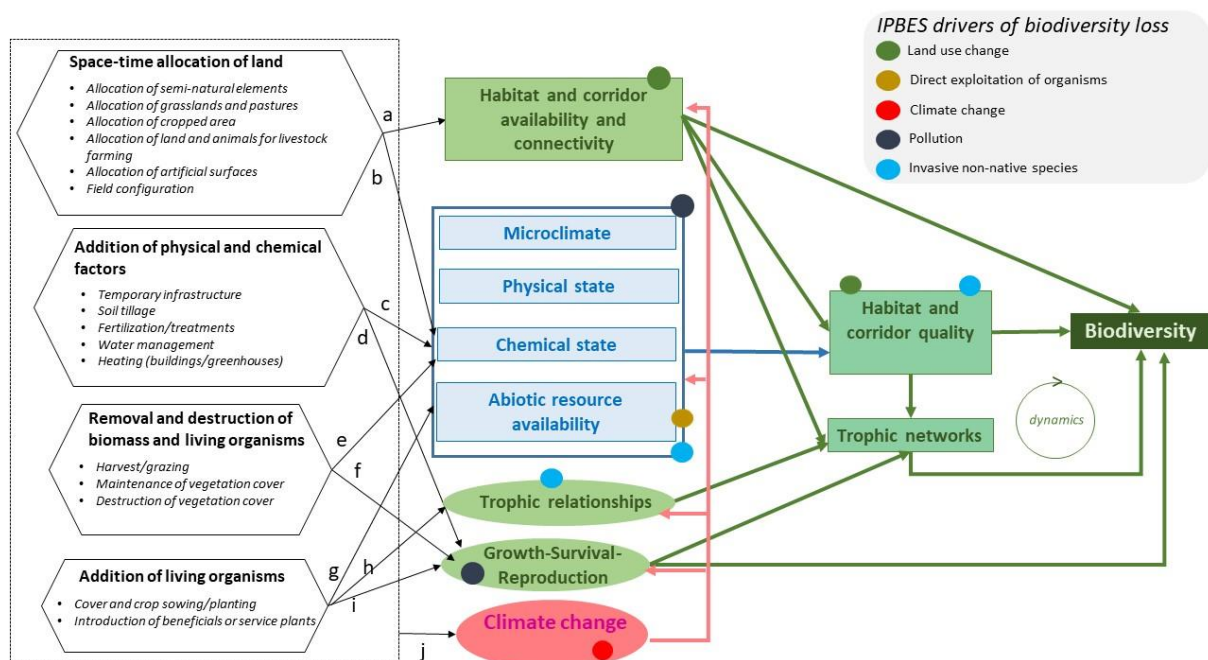


Figure 1. Conceptual diagram of the relationship between agricultural practices (families and sub-families of practices, in black on the left) and biodiversity (on the right). Ellipses represent processes, rectangles states. Green shapes represent biotic effects, blue shapes represent abiotic effects and red shapes represent indirect effects via climate. For the meaning of arrows, a to j, see text. The global drivers of biodiversity decline according to IPBES are shown.

Discussion

Each arrow in the conceptual model is well documented in the scientific literature, and it would be impossible to summarize all of this information here. What is original is the combination of these existing elements within a vision of practices and their impact pathways, guided by ecological principles. This vision was developed through collaboration between agronomists and ecologists. The model's complexity highlights the fact that it is impossible to derive a linear function that adds up the effect of each practice on biodiversity. The same is true at a higher level for the five drivers of IPBES. The value of agroecosystem conceptual models for data acquisition and analysis is widely recognized (Lamanda et al., 2012). Our model will be useful in guiding research questions on the impact of agricultural practices on biodiversity and in addressing knowledge gaps, such as those concerning the interactions between practices at

different scales, e.g. landscape and field (Martin et al., 2021). The model could be developed in qualitative and quantitative forms, considering not only the general concept of biodiversity, but also its many dimensions and levels, as set out in the Essential Biodiversity Variables framework (Pereira et al., 2013), or within a given taxonomic or functional group.

Acknowledgments

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Watershed-based climate resilience strategies: enhancing water security for sustainable agrifood systems

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Keywords: Watershed-based resilience, Climate-adaptive agrifood systems, Water security and sustainability, Integrated watershed management

Introduction

Climate change-induced rainfall variability, declining groundwater levels, and soil degradation pose significant threats to agrifood systems, particularly in water-stressed tropical regions. These factors reduce agricultural productivity, exacerbate rural poverty, and undermine food security. Watershed-based climate resilience strategies offer an integrated approach to mitigating these risks by improving water security, enhancing ecosystem health and sustaining farming system output. Integrated watershed management approaches, including diversified cropping, agroforestry, soil-water conservation, and livestock integration, have proven effective in optimizing resource use and enhancing resilience (Kumar et al., 2014). Importantly, these strategies also encompass social dimensions, such as stakeholder negotiation, community organization, and transaction costs related to participatory decision making and resource governance. Effective implementation requires institutional coordination and collective action.

Empirical evidence from India and global experiences suggests that watershed interventions significantly improve hydrological balance, increase land productivity, and promote economic sustainability and mitigate agrarian distress (Pande et al., 2014; Joshi et al., 2004). Studies in Ethiopia have demonstrated the role of integrated watershed management in reducing crop and livestock losses by 50% while improving soil fertility and farmer incomes (Wolka et al., 2023). Similarly, climate-water governance frameworks in the South Asian region highlight the need for river basin-scale interventions to strengthen water security and agricultural sustainability (Yasin et al., 2021). This study evaluates the effectiveness of watershed-based climate resilience strategies for enhancing farming system, drawing insights from micro-watershed projects in India and global case studies.

Methods

This study employs a mixed-methods approach, integrating empirical data from watershed management projects across India with a systematic literature review and comparative global case studies. A total of 18 micro watersheds were evaluated, including those under the National Watershed Development Project for Rainfed Areas (NWDPA) (2008–2014) and the Integrated Water Management Project (2015–2021). Impact assessments were conducted using hydrological, agronomic and socioeconomic indicators. The watershed interventions analysed included in situ moisture conservation, contour bunding, farm ponds, recharge structures, agroforestry, and climate adaptive cropping systems in a participatory approach. Long-term case studies from semi-arid central India were analysed using geospatial tools, statistical modelling, and field measurements to assess trends in crop productivity, agrobiodiversity, soil health improvement, surface water storage, groundwater recharge and water-use efficiency. Global watershed-based climate resilience initiatives, particularly from Ethiopia and South Asia, were compared to assess institutional mechanisms, governance frameworks, and adaptation strategies. Socioeconomic indicators such as rural employment (man days), income diversification, fodder availability, and benefit cost ratio (BCR) were assessed using household surveys and field level productivity data. Additionally, the study

examined carbon sequestration potential through soil organic carbon (SOC) stock assessments and biomass estimations, integrating remote sensing and allometric models. A multi-disciplinary analytical approach combining geospatial analysis, hydrological modelling, and climate impact assessment was used to understand the role of watershed management in strengthening water security, agricultural sustainability, and climate adaptation.

Results

The study demonstrates that watershed-based interventions significantly enhance agricultural productivity, agrobiodiversity, water security, and climate resilience. Micro-watershed interventions led to an 8–170% increase in crop yields, a 34–55% improvement in water-use efficiency, groundwater level increase by 0.12 to 4.4 meters. Various agronomic and bioengineering soil and water conservation and recharge measures in a typical micro watershed in semiarid regions of India resulted in average ground water rise of 0.84 meters, surface storage of about 5000 m³ in a typical watershed that helped enhancing cropping system performance (Singh et al., 2023). Soil conservation measures such as contour bunding and agroforestry resulted in about 45% reduction in runoff and about 1.1 t ha⁻¹ yr⁻¹ in soil erosion (Joshi et al., 2004), enhancing soil fertility and crop productivity by 11–23% besides increasing green cover (Fig.1) (Kumar et al., 2014). Watershed interventions also contributed to livestock productivity, with milk production increasing by 8–46% in integrated farming systems having increased fodder availability. Socio-economically, these interventions generated 85–220 man-days of green employment per hectare, reinforcing income diversification and rural livelihood security. This employment reflects both short-term labor demand for implementing conservation measures and longer-term opportunities generated through intensified farming, crop diversification, agroforestry, residue and compost management, improved livestock practices and other associated activities specially during lean agricultural period.

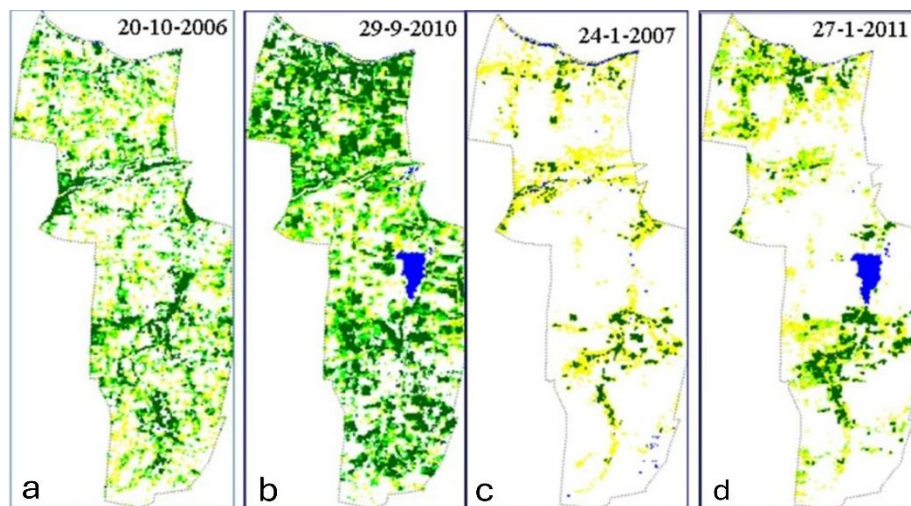


Figure 1. Spatio temporal variation in green cover (mainly crop area) across Dharampur Amravati watershed cluster, Central India. Panels (a) and (b) depict change in Rainy (end) season and (c) and (d) represent post rainy season

Economic evaluations indicate a benefit-cost ratio (BCR) of 2:1, factoring in project investment, and in-kind farmer contributions. Support included input subsidies, technical training, and in some cases labor incentives under employment schemes. Additionally, agroforestry and soil conservation measures contributed to 210–1400 tons of carbon stock accumulation, with 760 tons of additional SOC recorded in model watershed of about 750ha, highlighting the climate mitigation benefits of watershed-based interventions. The performance of interventions varied

significantly across sites, influenced by differences in climate, soil type, project focus, scale of community participation, institutional capacity, fund release patterns, and available resources.

Discussion and Perspectives

The findings confirm that watershed-based climate resilience strategies play a vital role in ensuring sustainable agrifood systems by resource integration, water conservation, soil health improvement leading to livelihood enhancement. Global comparisons validate these results. In Ethiopia, integrated watershed management has effectively mitigated drought-induced losses and improved farm productivity (Wolka et al., 2023). In South Asia, river basin-scale interventions emphasize the importance of institutional coordination in ensuring long-term water security (Yasin et al., 2021). The results from India align with these global trends, showing that participatory watershed management improves resilience to climate variability and strengthens agrifood systems. The Antisar and Vejalpur–Rampura watersheds in Gujarat improved water security, land productivity, livelihoods, and gender equity, serving as models for the state's watershed agency. Similarly, the Jigna watershed in the Bundelkhand region of Madhya Pradesh has been a focal point for several watershed development efforts aimed at enhancing water availability and agricultural productivity in this drought-prone area. Given the increasing pressures of climate change, scaling up watershed-based resilience strategies requires multi-sectoral coordination, policy integration, and technological innovation. Strengthening institutional mechanisms, promoting climate-smart agricultural practices, and integrating advanced geospatial monitoring tools can enhance the effectiveness of watershed interventions. Participatory governance models involving local communities, researchers, and policymakers are essential for ensuring long-term sustainability. Future research should focus on developing digital water management tools, incorporating remote sensing and GIS-based hydrological modelling, to optimize water use and enhance resilience to climate variability. Strengthening the link between climate adaptation policies and watershed-based farming systems will be crucial for achieving long-term water security, agricultural sustainability, and climate resilience.

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Applying ecosystem-based geodesign approach to support sustainable agricultural landscapes management

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Keywords: landscape ecology, ecosystem services, sustainable farming, New Zealand

Introduction

Ecosystem services-based management (EBM) is an interdisciplinary approach that integrates multiple ecosystem services covering ecological, socio-cultural, and economic factors to develop a comprehensive management strategy for protecting and enhancing sustainable use of land resources (Delacámara et al., 2020). To date the relevance of applying this approach to exploring future land use and sustainable development of agricultural landscapes in New Zealand has not been fully explored (Pearson, 2020). The incorporation of the ecosystem services into agricultural land use decision-making, especially at the farm scale, is limited (Dominati et al., 2021). There is also little evidence of the application of a design-driven perspective to land use planning which considers the participation and contribution of farmers as a key factor in the planning process (Eastwood et al., 2022). Therefore, the use of EBM within a design framework that incorporates participatory planning could enable the creation of a useful decision support system for sustainable land use planning and environmental management at the farm scale.

Methods

We utilised an ecosystem-based geodesign approach to design different land use scenarios for the future farmed landscape (Figure 1).

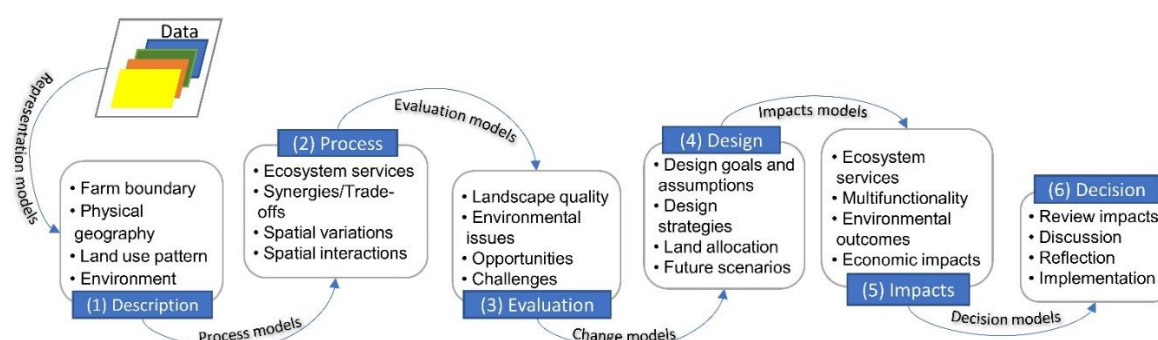


Figure 1. Conceptual framework of the ecosystem services-based geodesign process for creating future landscapes (Tran et al., 2023).

Six land use scenarios were developed through participatory mapping with farmers and field experts, GIS-based multi-criteria land suitability modeling, and hybrid optimisation incorporating both qualitative (farmer input) and quantitative (spatial data) approaches (Tran et al., 2023). The impacts of future land use changes on ecosystem services, environmental footprint, and economic output were evaluated by comparing baseline (current land use) and future land use scenarios. Ecosystem services and associated environmental indicators were mapped using Integrated Valuation of Ecosystem Services and Trade-Offs (i.e., InVEST) models (Natural Capital Project, 2025), and economic outcome was quantified using farm

system model (i.e., AgInform) (Dominati et al., 2021). A hill country sheep and beef farm in North Island, New Zealand was selected to test the proposed approach.

Results

Multiple land use scenarios were created for the case study farm using the framework demonstrated in Figure 1. Here we selected three contrasting land use scenarios to demonstrate how land use changes influence the provision of ecosystem services, environmental performance, and economic output (Table 1). These are the current land use, the environmentally friendly land use changes proposed by the farmers (Scenario 1), and the landscape conservation-based scenario developed using a hybrid approach (i.e., modelling and participatory mapping) (Scenario 2).

Indicators		Current	Scenario 1	Scenario 2
Ecosystem services*	Stock feed production	0.61	0.58	0.53
	Provision of timber	0.02	0.01	0.05
	Provision of Manuka honey	0.07	0.14	0.12
	Carbon sequestration	0.17	0.23	0.33
	Freshwater purification	0.89	0.9	0.92
	Provision of natural habitat	0.14	0.18	0.23
	Landscape diversity	0.12	0.12	0.14
	Landscape naturalness	0.14	0.22	0.28
Environment	Annual soil loss (tonnes/ha/yr)	4.10	3.59	2.78
	Sediment export (tonnes/ha/yr)	0.26	0.23	0.16
	Nutrient loss (kg N/ha/yr)	7.62	7.06	6.22
	Net GHGs emission (tonnes/ha/yr)	1.42	0.03	-4.90
Economic	Stock units at opening (1st April)	3116	3067	2861
	Stocking rate (SU/ha)	9.5	10.1	9.9
	Average EBITDA** from pasture (NZ\$/yr)	102,466	113,207	101,726
	Average EBITDA (NZ\$/ha/yr)	313	374	353

Table 1. Impacts of future land use changes on ecosystem services, environmental footprint, and economic output

(*) *Ecosystem services are normalized values; (**) Earnings before interest, taxation, depreciation and amortization.*

Both S1 and S2 present an increase in overall multifunctionality and ecosystem services provision (except stock feed production) as well as a decrease in environmental issues in comparison to the current land use. The positive impacts in environment and improvement in ecosystem services supply has resulted from a conversion of pasture to woody vegetation

cover, including indigenous forest, indigenous Manuka, space-planted poplars, and exotic forest. The economic assessment illustrates that overall profit per hectare for Scenario 1 and 2 could be higher than the current land use due to having various sources of income in addition to stock grazing, including timber, carbon farming, and manuka honey production. It is also demonstrated that land use changes proposed by the farmer (Scenario 1) could achieve the highest economic return whereas Scenario 2 show better performance in ecosystem services and environmental outcomes.

Discussion and Perspectives

The development of multifunctional agricultural landscapes offers a pathway to innovative and resilient farming systems capable of addressing emerging environmental challenges and ensuring long-term sustainable farm management. By integrating ecosystem services with a geodesign framework, the EBM approach can be comprehensively applied to agricultural land use planning to inform the creation of multifunctional farmed landscapes where multiple land use types co-exist. Such landscapes can deliver a broad range of ecosystem services, balancing economic and environmental needs, whilst increasing landscape diversity and complexity identified as critical to achieving sustainability. The collaboration with landowners (i.e., farmers) is a key to the success of designing feasible land use scenarios that reflect their preferences and support their well-being.

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Trade-offs among ecosystem services in diversified agricultural landscape designs for the North China Plain

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Keywords: Multi-objective optimization, Stakeholder engagement, Landscape Planning, Preferences

Introduction

Ecosystem services (ESs) supply is central to multifunctional agricultural landscapes. Since the Green Revolution, crop production has intensified, leading to landscapes dominated by a few cereal species and reliant on high chemical inputs to meet growing demands for provisioning services (Tilman et al., 2002). While these landscapes emphasize provisioning services, they often undermine non-provisioning ESs and aggravate disservices, such as greenhouse gas emissions and biodiversity loss (Foley, 2005). Addressing diverse ESs at the landscape scale is vital to satisfy stakeholder needs (de Groot et al., 2010). Landscapes with smaller fields and denser edges can enhance multifunctionality and boost regulating services like pest control (Landis, 2017). However, trade-offs between ESs and divergent stakeholder interests make planning complex (Wilhelm et al., 2020). Redesigning landscapes to be multifunctional and sustainable is thus challenging. The North China Plain, a major maize, wheat, and cotton production area, faces sustainability issues from intensive practices like wheat-maize double cropping (Cheng et al., 2023). Recent policies call for more balanced ESs via "Agriculture Green Development" (Shen et al., 2020). This region serves as a case study for redesigning landscapes to balance ESs and stakeholder priorities. This study presents a model-based framework to redesign multifunctional landscapes that address ESs supply issues. Applied to two Quzhou landscapes, it aims to: 1) Redesign landscapes with improved crop management and diversification across multiple ESs; 2) Explore ES trade-offs and synergies. The case studies illustrate the method's relevance for broader use in specialized cropping areas.

Methods

We followed five steps to explore alternative agricultural landscapes and their performance using the Landscape IMAGES model, which highlights ES trade-offs and synergies while integrating stakeholder preferences. Step 1: Two case study landscapes in Quzhou were selected. One is intensively cropped with wheat-maize double cropping; the other is more extensive with cotton monoculture. Step 2: Optimization objectives were defined based on stakeholder priorities, focusing on ESs with low supply or high importance (Cheng et al., 2023; 2025). A literature review and local survey identified key ESs. These indicators served as redesign objectives and were modeled in Landscape IMAGES. Step 3: Candidate land uses (cropping systems and management) were selected based on farmer surveys, including semi-natural habitats. Land-use rules followed local policies and ecological principles. ES

performance was evaluated using survey data. Step 4: A multi-objective optimization examined ES trade-offs and synergies. Improved designs were generated with the Differential Evolution algorithm, and optimal designs were selected based on Pareto efficiency. These Pareto-optimal landscapes were analyzed for trade-offs and synergies.

Results

We observed trade-offs between gross margin and non-provisioning ESs. Nonetheless, gross margin, biocontrol potential, and crop diversity could be substantially improved in both landscapes (Figures 1 and 2).

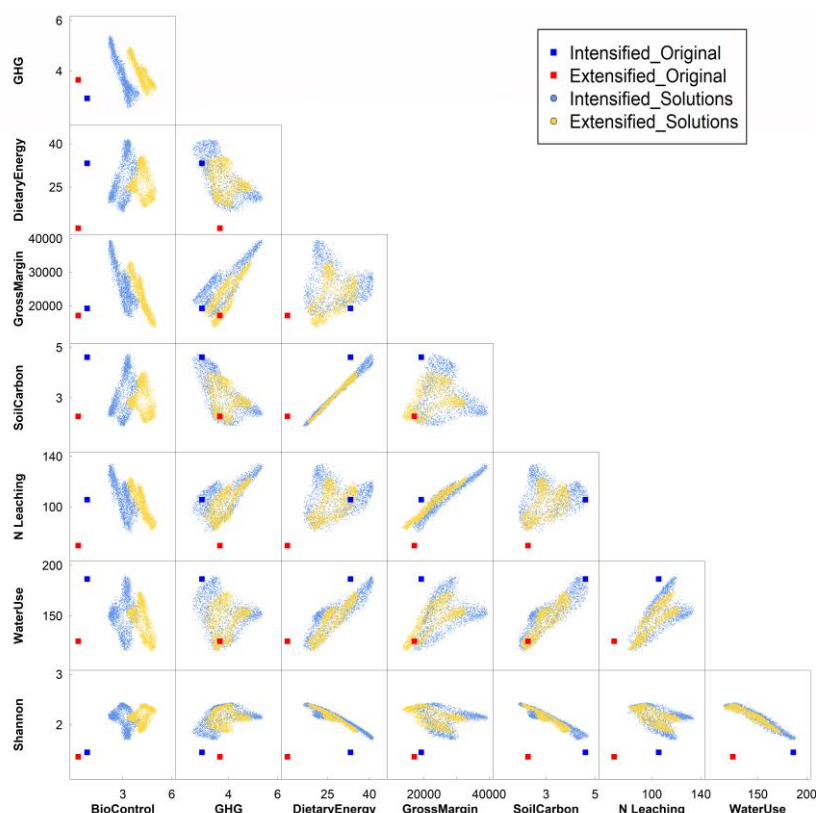


Figure 1. Relationships among ES indicators in Pareto-optimal landscape alternatives for an intensified (blue) and a relatively extensive (yellow) landscape. Red and blue squares indicate original landscape ES performance. The units of indicators: BioControl (% of maximum); GHG ($\text{Mg CO}_2 \text{ eq. ha}^{-1} \text{ year}^{-1}$); DietaryEnergy (persons $\text{ha}^{-1} \text{ year}^{-1}$); GrossMargin (CNY $\text{ha}^{-1} \text{ year}^{-1}$); SoilCarbon ($\text{Mg CO}_2 \text{ eq. ha}^{-1} \text{ year}^{-1}$); N Leaching ($\text{kg ha}^{-1} \text{ year}^{-1}$); WaterUse (mm year^{-1}); ShannonIndex (unitless).

Discussion

The multi-objective optimization modeling approach in this study addresses trade-offs between provisioning and non-provisioning ecosystem services (ESs). Diversification of the landscapes shows the potential to improve multiple ESs like biological control and reduce the dis-services. This framework optimizes landscapes by incorporating diverse cropping systems and semi-natural habitats, alongside agronomic management improvements, to improve ES delivery. This model uses survey data on ESs delivery in relation to cropping systems and have the potential to include stakeholder-informed weights on the preference of different ESs. Despite strengths, limitations exist, such as reliance on one year of crop data and empirical equations that may not fully capture dynamic interactions. For example, while the model assumes that flower strips support natural enemies, it does not account for pest and natural enemy species-

specific dynamics or pest-natural enemy interactions over time. In the current study it was not possible to engage stakeholders in indicator selection and assessment of the generated solution. Future efforts may include interactive tools, like virtual reality, to allow stakeholders to visualize and provide feedback on landscape changes.

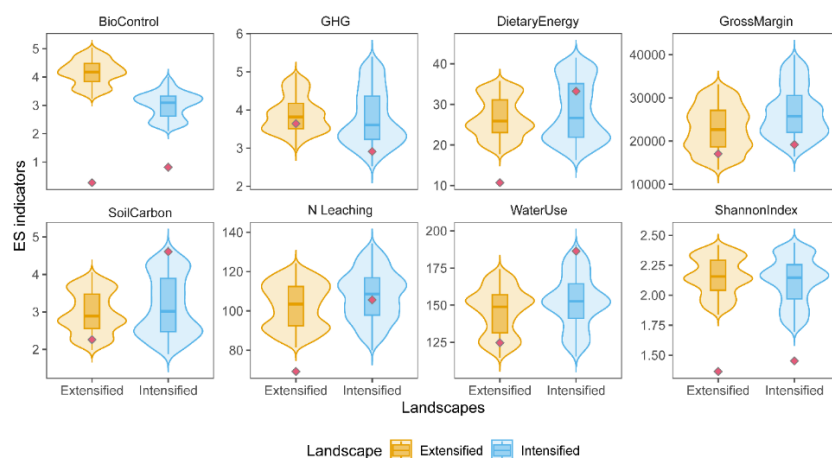


Figure 2. Distribution of ES indicator values in Pareto-optimal alternatives for both landscapes. Red dots indicate baseline ES values (Units as in Figure 1).

Perspectives

This flexible modeling framework can be applied at multiple spatial scales. It helps explore landscape alternatives, manage trade-offs among ESs, and support participatory planning to enhance multifunctionality.

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Mapping agricultural land use dynamics through integrated biophysical analysis for Mediterranean farming systems

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Keywords: Agricultural land use, biophysical drivers, multi-annual mapping, pixel-based

Introduction

Mediterranean agriculture has evolved over millennia under distinctive climate and terrain constraints (Zeder, 2008). The region's fragmented systems---marked by diverse management intensities, cultivation strategies, and socio-environmental disparities (Scorsino and Debolini, 2020)---exhibit notable spatial heterogeneity (Biarnès et al., 2021). This heterogeneity is expected to increase as Mediterranean systems face accelerated vulnerability to global changes (Malek and Verburg, 2017). Matching this increasing heterogeneity with the management of resources like soil and water is a wicked problem of increasing complexity (Esgalhado et al. 2021). Addressing such complexity requires analytical approaches calibrated to the spatial level at which environmental processes occur to better inform the decision-making of the concerned socio-technical systems (Rizzo et al., 2013). However, current regional mapping and modelling approaches inadequately integrate biophysical and socio-technical drivers of farmers' decision-making in a spatially explicit way, limiting the reliability of land use trajectory analyses for informing farming system design. This is partly due to the lack of land use mapping series consistent with the high fragmentation, particularly outside Europe (Biarnès et al. 2021). This study presents a multi-annual mapping method for Mediterranean rainfed agricultural systems contributing to broader research on farmer decision-making and the co-design of farming scenarios with local stakeholders, based on land use spatial-temporal dynamics.

Methods

The method uses multi-annual biophysical data to generate annual, detailed land use maps. Due to the absence of plot boundary datasets and the fragmented nature of Mediterranean agriculture, a pixel-based approach was adopted to capture land use dynamics from 2015 to 2024. While each pixel reflects local cropping decisions, the resulting maps will enable subsequent analysis of land use spatial configuration and connectivity. Moreover, the result helps to analyze farming system and landscape dynamics, linking biophysical drivers to spatial configurations and climate adaptation trends.

The study focuses on a typical fragmented rainfed agricultural area located in the Lebna watershed (210 km², northeastern Tunisia) with approximately 80% of agricultural plots <1 ha. The framework (Figure 1) integrates spatial metrics (terrain morphology and soil characteristics) and temporal metrics (meteorological conditions and phenological responses of the cultivated crops). We used five datasets: (1) land use field observations as described in (Biarnès et al., 2021); (2) a 1-meter digital surface model (Durand, 2019) to compute terrain metrics; (3) precipitation and temperature daily records collected by the OMERE observatory; (4) a digitized agricultural map of Nabeul Governorate to derive soil characteristics; (5) Sentinel-2 imagery (2015-2024) to calculate phenological metrics based on NDVI time series.

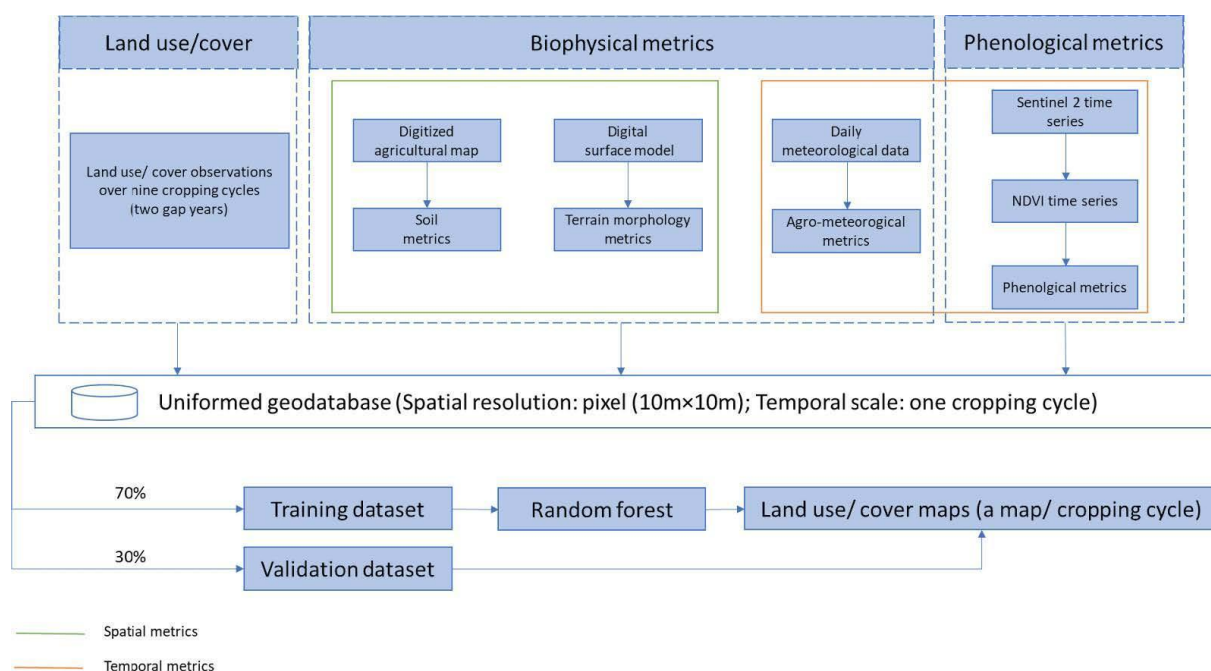


Figure 1. General workflow

Results

Preliminary results are a series of nine historical land use maps, one per cropping season. The multi-annual, context-sensitive method mitigates training data availability limitations, enabling robust class differentiation even for cropping cycles with sparse ground-truth information. Such detailed mapping facilitates the detection of recurrent patterns in agricultural land uses, thereby revealing land management strategies and providing insights into the complex interplay between environmental constraints and farmers' crop choice.

Discussion and Perspectives

This framework bridges a key methodological gap by integrating spatial configuration and temporal dynamics---often treated separately in spatial models and time-series analyses. While multi-temporal phenological analysis (Liu et al., 2018) and biophysical drivers' integration (Pacheco de Castro Flores Ribeiro et al., 2021; Zabel et al., 2025) have been applied in agricultural studies, their combined application for mapping land uses from field observations to watershed extent in fragmented Mediterranean systems remains, to our knowledge, unexplored. The framework's contribution lies in systematically merging spatial and temporal metrics to tackle the challenges of mapping fragmented Mediterranean farming systems under high climatic variability.

Future work could consolidate this framework by integrating socio-technical variables to capture farmer decision-making and coupling it with watershed agro-hydrological models to assess climate-driven impacts on productivity and resource availability.

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MAELIA for large-scale farming systems design: methodological approach

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Keywords: Scaling methods, Agent-based models, Integrated assessment, Agriculture

Introduction

Integrated Assessment and Modeling (IAM) approaches aim to account for the complexity of agricultural systems (Ewert et al., 2011), and are recognized for their ability to assist stakeholders in shaping organizations of human activities, such as those within biomass-based chains of the bioeconomy. IAM combines multidisciplinary knowledge with local actors' empirical expertise to create models that simulate and evaluate the consequences of various organizations under endogenous or exogenous changes (Hamilton et al., 2015). MAELIA is a high-resolution, agent-based IAM platform designed for multi-criteria analysis of territorial farming and bioeconomy systems (Therond et al., 2014). It simulates daily spatiotemporal dynamics of agricultural operations at the field level considering the diversity of farming strategies, soils and weather variability, and ecological processes. Currently, the largest MAELIA case study covers 40,000 ha and 1,150 farms (Tribouillois et al., 2022), with larger-scale assessments constrained by data availability and computational resources.

This study aims to develop a scaling strategy for applying MAELIA at the whole France scale to assess the sustainability of scalable solutions for producing, mobilizing and utilizing agricultural biomass while sequestering carbon in soils. The goal is to move beyond averaging approaches typically used at France (e.g., Afterres scenario) or regional scales (Billen et al., 2021). Previous bottom-up simulations, such as those using the STICS cropping systems model (Launay et al., 2021; Tibi and Therond, 2024) have been applied to a pedoclimatic unit mapping of metropolitan France (average 18 km² grid). However, MAELIA operates at the field level considering farm level constraints (e.g., work load for farming operations), posing additional scaling challenges. This work presents a methodological approach for applying MAELIA at the France level and discusses the implications and limitations.

Methods

The scaling strategy aims to maintain computational costs at levels comparable to existing case studies, as new functionalities continue to be integrated to MAELIA. It also seeks to preserve the existing modelling algorithm by implementing a flexible scale change treatment on top of MAELIA. The proposed method involves selecting representative production situations and farming systems for simulation (preprocessing), assessing dynamics of these entities with MAELIA, and upscaling results to the local, regional up to national scales.

The approach is rooted in an information system and a configurable data treatment that manages nationwide inputs data to characterize and select entities to be simulated (Figure 1). First, France is partitioned into relatively homogenous agro-environmental zones. Within each zone, farming systems are clustered based on field-level (e.g., pedoclimatic and crop sequences) and farm-level variables (e.g., area, production orientation). The resulting farm typology highlights key differentiation criteria relevant to MAELIA simulations, such as the presence of irrigation or organic farming. Simulated farming systems are selected from each typological pool using modal values for each variable to ensure coherent farm simulation unit

that integrates representative combinations of climate, soil, crop sequence and management, and irrigation.

Crop management for each production situation are modelled by identifying first the primary drivers of spatial differentiation. A procedure is developed to convert crop operations recorded in date-dose format into rule-based models (IF-THEN conditions) that trigger farming operations as needed by MAELIA. It requires characterizing machinery performances (e.g., tillage depth) and enabling conditions for operations (e.g., soil water content). Once simulations are performed for the selected entities, results are upscaled to larger levels (Ewert et al., 2011), with a quantitative assessment of embedded biases and uncertainties, and validation against historical data. Once calibrated, the approach can be used to evaluate the sustainability of nationwide alternative farming or bioeconomy system trajectories under various scenarios, incorporating reference case variations and alternative climate projections.

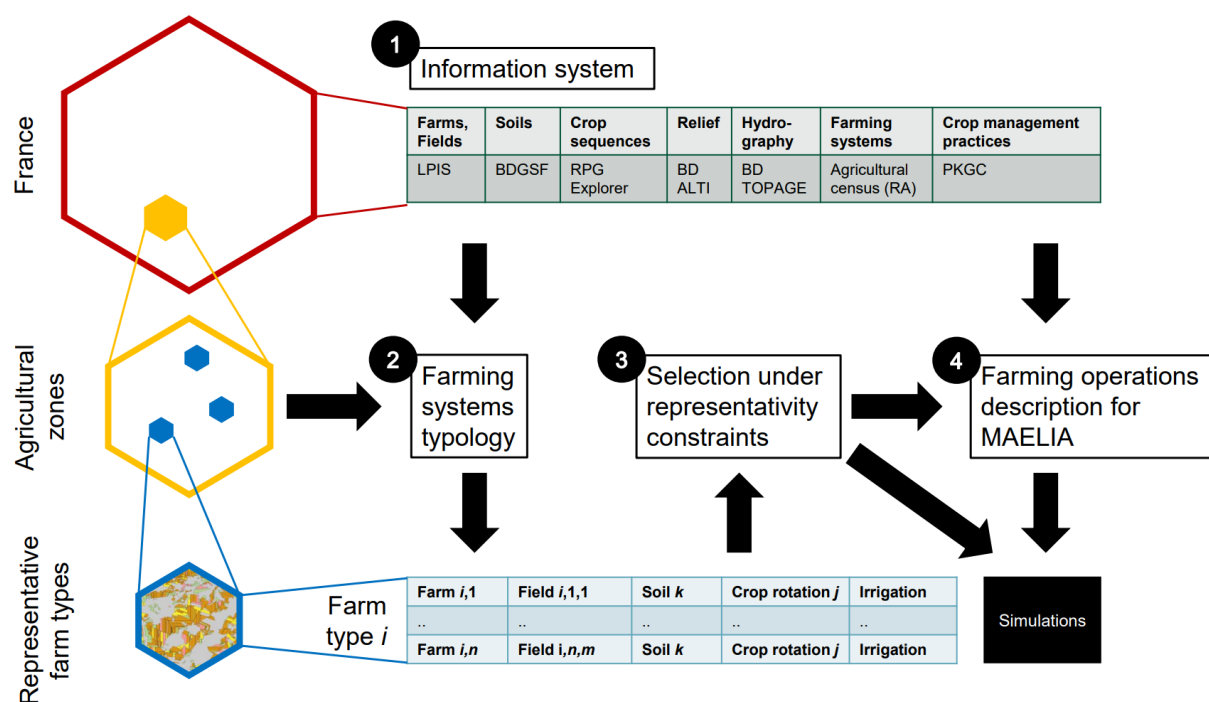


Figure 1. Key preprocessing steps of the MAELIA scaling strategy

Perspective

A major part of the procedure depends on consolidating the information system, with restricted data access currently under review. At the conference, we will demonstrate the country-scale feasibility of our approach by applying MAELIA to a representative sample of the 432 historical French agricultural zones (average area: 1,300 km²), using simplified crop practices and farm types. This work advances a tunable upscaling strategy for the agent-based MAELIA platform, designed to progressively relax selection constraints as computational barriers diminish. The strategy aims to represent French farming systems at scales ranging from approximately 50,000 fields and 1,000 farms upwards, unlocking flexible assessment of prospective agricultural scenarios through scales.

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Synergizing agroecological transition and the WEFE nexus: a farm-level modeling approach for sustainable agri-food systems in Morocco

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Keywords: Agroecological transition, WEFE Nexus, Farm typology, Resilience

Introduction

In Morocco, where agriculture accounts for 15% of GDP and supports rural livelihoods across 30 million hectares of land (World Bank, 2021; U.S. Department of Commerce, 2024), the sector faces rising challenges due to climate change, water scarcity, and food insecurity (WFP, 2019; WFP, 2023). Agroecological approaches---promoted by initiatives like the NATAE project---offer pathways to resilience and sustainability by enhancing resource use efficiency and ecological balance (Altieri et al., 2017; Wezel et al., 2020). In semi-arid regions such as Skoura Mdaz, drip irrigation and intercropping, supported by cooperatives, are emphasized as key agroecological practices to improve drought resilience and farm profitability (NATAE, 2023). By integrating participatory modeling and scenario analysis, this research examines the impact of these practices at the farm level within the framework of agroecological transition and its intersection with the Water-Energy-Food-Ecosystem (WEFE) Nexus in order to enhance resilience and resource efficiency.

Methodology

Farm Typology Development: Structural and functional criteria (land size, water access, market orientation, and others) were derived from interviews with 30 farmers and expert consultations, categorizing farms into three typologies: (1) Intensive Cash Crop-Oriented, (2) Intensive Livestock Diversified, and (3) Extensive Cereal-Livestock.

Bioeconomic Model Design: A linear programming model was developed to optimize production decisions at the farm level, with the objective of maximizing net returns while accounting for household-level auto-consumption and resource limitations. The model integrates key constraints including total land area, monthly labor availability, capital access, and minimum food needs. It covers major farm activities observed in Skoura Mdaz---such as rainfed and irrigated crop production (e.g., wheat, chickpeas, olives...), and livestock systems, reflecting the three dominant farm typologies. Agroecological practices such as drip irrigation and intercropping are modeled as alternative activities, allowing evaluation of their impact on income, food security, and resource efficiency. The model captures elements of the Water-Energy-Food-Ecosystem (WEFE) Nexus by quantifying trade-offs between water use, diversified ecosystem, and economic performance under different scenarios.

Scenario Co-Design: Stakeholder workshops defined scenarios combining agroecological practices (e.g., drip irrigation, intercropping) and organizational innovations (e.g., cooperatives).

Preliminary results

The identification of dominant farm typologies and the elaboration of the bioeconomic-Nexus model have been completed. However, the modelling results for agroecological scenarios are pending finalization.

Farm Typology Analysis Three typologies were identified, each presenting unique challenges for agroecological transition:

- Type 1 (Intensive Cash Crop-Oriented): Market-driven farms, especially for crop production, with high irrigation dependency are resistant to agroecological practices due to entrenched water-intensive systems and profit-focused mindsets.
- Type 2 (Intensive Livestock Diversified): Medium-scale farms with mixed rainfed-livestock systems show moderate agroecological adoption but face low crop productivity and market barriers.
- Type 3 (Extensive Cereal-Livestock): While already aligned with agroecological principles (low inputs, mixed systems), these farms remain unsustainable due to poverty-driven reliance on rainfed cereals and unmet household food needs.

Bioeconomic-Nexus Model Innovation The model integrates different components to quantify trade-offs between profitability, auto consumption, and sustainability. Key innovations include:

- Modeling effects on household-level food security by assessing effects of water supply variability on household food supply from self-produced and bought food.
- Addressing data gaps in resource-use strategies (e.g., farmers lack clear plans for water/energy efficiency).
- Managing variability in annual food production.

Scenario Definition Scenarios were developed through a participatory process combining farmer interviews, expert consultations, and a review of agroecological innovations considered within the NATAE project. While agroecology includes a broad suite of technologies, only a subset was deemed context-appropriate and feasible for farms in Skoura Mdaz. Among these, drip irrigation was identified by farmers as the most desirable option to improve water use efficiency and enable diversification under water-scarce conditions. Experts prioritized cooperative structures as essential for reducing transaction costs and enhancing market access.

Intercropping---in this case combining cereals or legumes with olive trees or agave---is modeled for its potential agroecological benefits, such as enhancing soil cover, promoting biodiversity, and stabilizing yields under drought conditions. These practices support both ecological and economic resilience. Four scenarios are to be tested:

- Baseline Practices: Current systems without agroecological interventions.
- Technological Adoption: Mandated drip irrigation and intercropping.
- Organizational Shift: Cooperative-led market access and resource-sharing.
- Integrated Approach: Synergy of drip irrigation and cooperatives.

Discussion and perspectives

While the model is still under refinement, preliminary results from the base scenario (current practices) highlight critical trade-offs between water use, profitability, and climate resilience. For instance, Type 1 farms' heavy reliance on crop activities with high water requirements underscores their vulnerability to drought, while Type 3 farms' dependence on rainfed cereals limits income stability.

Once finalized, the model will test alternative scenarios --- such as drip irrigation adoption, and intercropping --- to identify optimal resource-use pathways that balance farmer priorities with NATAE and WEFE Nexus goals. These scenarios will serve as a motivation for farmers to adopt more profitable yet resilient systems as well as a foundation for policy recommendations.

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Wheat redistribution in Huang-Huai-Hai, China, could reduce groundwater depletion and environmental footprints without compromising production

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Keywords: Huang-Huai-Hai region, Resource environmental impacts, Groundwater level, Crop redistribution

Introduction

Agricultural irrigation drives ~70% of global water withdrawals and 40% of food production, boosting yields (especially for rice and wheat) but at high environmental costs. It accelerates groundwater depletion (GWD) in critical regions like the North China Plain (Huang et al., 2015), Northwest India (Rodell et al., 2009), and California's Central Valley (Famiglietti et al., 2011), while worsening fertilizer surplus (Ren et al., 2023), greenhouse gas (GHG) emissions (Cui et al., 2021), and water pollution (Mekonnen et al., 2011). Despite productivity gains, irrigation often suffers from low nitrogen use efficiency (NUE) and irrigation water productivity (IWP), intensifying resource pressures. Balancing food security, sustainability, and groundwater conservation in GWD hotspots remains a key challenge, demanding integrated policies to reconcile these trade-offs.

The objectives of this study are to propose a gridded crop redistribution framework used in GWD regions for optimizing wheat distribution to reduce groundwater depletion and environmental footprints without compromising production.

Methods

We conducted a series of spatial optimizations for wheat redistribution to evaluate its potential in mitigating groundwater depletion while simultaneously enhancing food security, conserving resources, and reducing environmental footprint. Specifically, the following were considered: Wheat water requirements: (1) Quantified wheat blue water demand using a dynamic water balance model. (2) Assessed irrigation water efficiency changes via IWP. (3) Calculated the grey water footprint (GWF) by quantifying the volume of water required to assimilate the nutrients that reach groundwater or surface water. N resource utilization: A mass-balance model was applied to estimate NUE and N surplus. GHG emissions: GHG emissions from N fertilizer and manure inputs were quantified using IPCC emission factors and empirical models. To predict groundwater depth changes in 2030, we analyzed the relationship between groundwater depths and meteorological variables (including temperature, precipitation, and evapotranspiration) as well as cumulative net irrigation water demand for wheat using a multiple linear regression model. Next, we used spatialization parameters to predict groundwater depth changes in 2030 under three scenarios (S1, S2, S3) compared to the baseline, based on the regression model. Spatial optimization: Wheat redistribution was

optimized using the General Algebraic Modeling System (GAMS). Three scenarios are explored: (i) minimizing irrigation water demand for wheat without compromising production (S1), (ii) maximizing wheat production while ensuring sustainable groundwater use (S2), and (iii) maximizing both wheat production and NUE while ensuring sustainable groundwater use (S3).

Results

Our results show that environmental footprints can be reduced---blue water by 16%, grey water by 21%, and GHG emissions by 19%---while enhancing resource use efficiency, with IWP improving by 21% and NUE by 11% (Fig. 1). Maintaining current production levels is achievable with these adjustments. Furthermore, allowing a 17--18% decrease in wheat production could result in a groundwater depth increase of 9.03--9.38m by 2030, ensuring sustainable groundwater use. In the regions experiencing groundwater depletion, blue water, grey water and GHG emissions could decrease by over one third of the current levels.

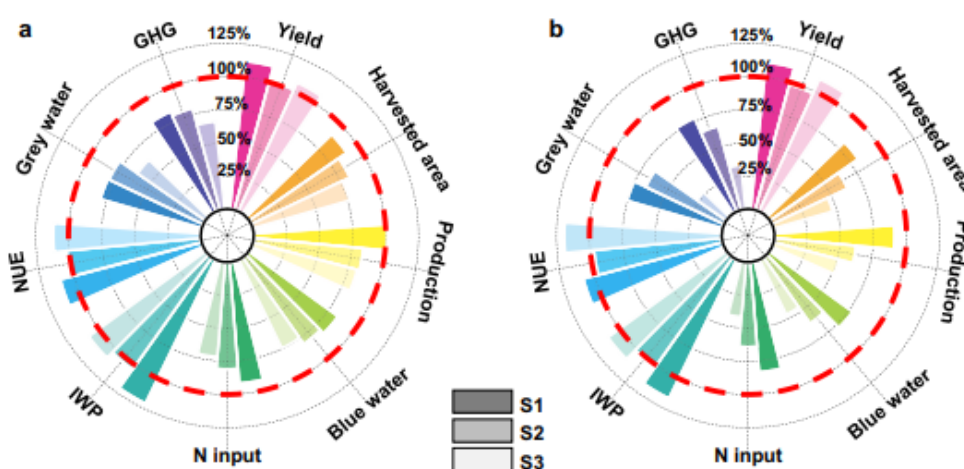


Figure 1. Multi-benefits of wheat redistribution. Relative changes in wheat production, resource use, and environmental impacts due to wheat redistribution under three scenarios in the a HHH and b GWD regions. The red dotted circle represents the current level. Bars in dark, medium, and light colors represent the relative percentage changes of the indicators compared to the current level under the scenarios of minimizing irrigation water demand for wheat without compromising production (S1), maximizing wheat production while ensuring sustainable groundwater use (S2), and maximizing both wheat production and NUE while ensuring sustainable groundwater use (S3), respectively.

Discussion, limitation and implications

Maximizing synergies through optimized wheat redistribution

Firstly, our optimized wheat redistribution maintains current production while reducing irrigation demand, enhancing food security stability. With a 17% yield reduction, it achieves sustainable groundwater use while meeting ~70% of China's projected 2030 wheat demand (Wang et al., 2022). Secondly, our findings align with the demand to decrease the distribution of crops with higher water demand as part of China's policy to reduce groundwater use since 2014 (Yuan et al., 2021). Finally, Wheat redistribution also yields additional benefits such as labor savings, enhanced resilience of climate extremes, increased agricultural biodiversity, reduced economic costs, and improved farmer adaption.

The costs and policies associated with the practical implementation of wheat redistribution

We can maximize synergies through optimized wheat redistribution without altering local planting, irrigation, and fertilizer application practices, demonstrating the feasibility of wheat redistribution. To ensure feasibility, the government should establish irrigation pricing, provide income subsidies, and guide adjustments in planting and fallow systems. Innovative mechanisms linking subsidies to groundwater recovery should also be explored. Our analysis offers a guide for the government to allocate agricultural subsidies in GWD regions.

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Satellite-derived yield estimation for multispecies cropping in a regenerative agriculture system

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Keywords: Multispecies cropping, Net primary production, Yield, MODIS

Introduction

Regenerative agriculture (RA) aims to restore soil health, enhance biodiversity, and improve agroecosystem resilience. Multispecies cropping (MSC) contributes to these outcomes by incorporating diverse crop species within the same field, promoting nutrient cycling, carbon sequestration, and natural pest suppression, while reducing reliance on synthetic inputs (Jayasinghe et al., 2023). The higher plant diversity is thought to improve resource efficiency and potentially increase the overall productivity of the land compared to monocultures. However, MSC adoption in broadacre farming is constrained by economic uncertainty, partly due to complexity of predicting in MSC yields.

Traditional yield estimation methods are labour-intensive, time-consuming, and limited in scale (Lobell et al., 2015). While remote sensing (RS) and machine learning (ML) have improved yield prediction in monocultures, application to MSC remains underdeveloped due to species-specific growth patterns, mixed-canopy effects, and variable biomass allocation (Han et al., 2024). Existing models often fail to capture interspecies interactions and resource partitioning, reducing their accuracy in MSC environments. This study aimed to develop a scalable yield estimation framework for MSC systems by integrating MODIS-derived Net Primary Productivity (NPP). Unlike conventional models, it uses high-resolution land cover classification to differentiate crop mixtures, improving biomass allocation estimates. This approach supports data-driven farm management and sustainability assessments in RA systems.

Methodology

A case study was conducted in 2024 on a commercial farm practising RA near Lake King, Western Australia, in a semi-arid Mediterranean climate (annual rainfall: 307 mm; temperature range: -0.1°C to 46°C). Soils vary from acid sands to heavy friable sodic soils. The study evaluated a MSC system including lupins, cereal rye, barley, faba beans, wheat, field pea, and vetch. Field data from 24 quadrats (triplicated), were used to calibrate satellite-derived NPP to estimate yield. The workflow (Figure 1) integrated MODIS-derived annual NPP, Sentinel-2-based land cover classification, and ground-truth data. MODIS 8-day NPP composites were aggregated to 427 grid cells and overlaid with crop-type maps generated using Random Forest classification in Google Earth Engine.

Grain yield was estimated using: $\text{Yield} = (\text{NPP} \times C \times \rho \times \text{HI}) / (1 - \omega)$, where the biomass conversion factor (C) was set at 2.0-2.22 (Counce et al., 2000), the aboveground biomass fraction (ρ) and harvest index (HI) were 0.72 and 0.26, respectively, for MSC. Post-harvest grain moisture content (ω) was 0.125. Model validation compared field-measured and NPP-derived yields. Biomass and grain samples were collected oven-dried at physiological maturity. Model accuracy was assessed using root mean squared error (RMSE), mean squared error (MSE), and the coefficient of determination (R^2).

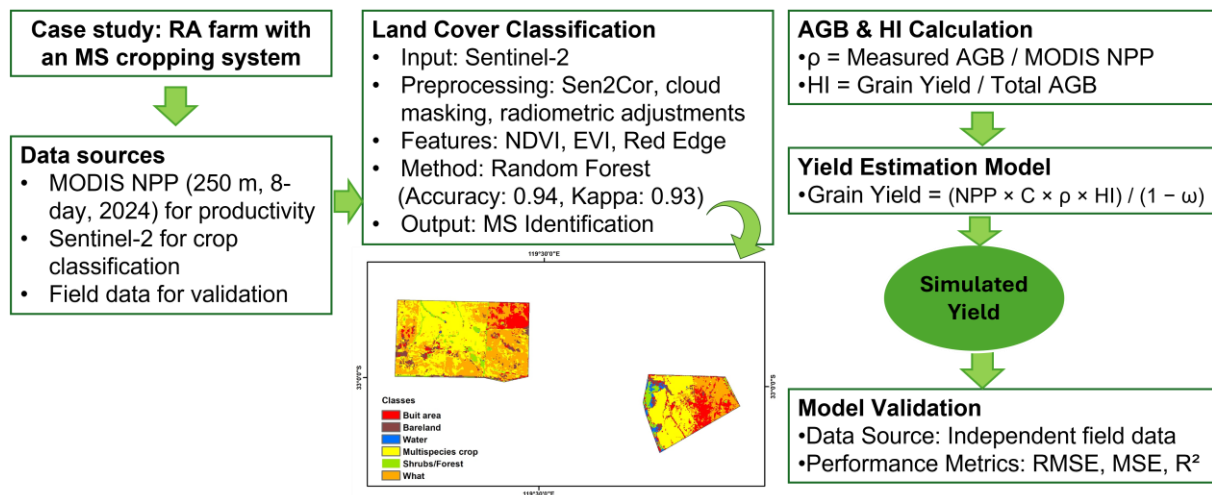


Figure 1. Workflow for multispecies crop yield estimation integrating RS, ML, and field data.

Results

The land cover classification model, developed using Sentinel-2 imagery and a Random Forest classifier, achieved high accuracy (overall=0.94; Kappa=0.93), ensuring precise differentiation between MSC and wheat fields for NPP allocation.

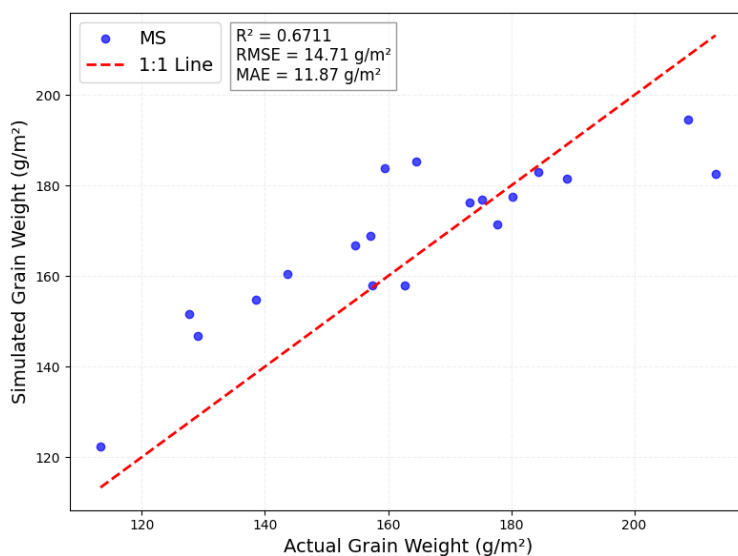


Figure 2. Comparison of simulated and actual grain weight (g/m²) in MSC.

The yield model explained 67.11% of the variation in actual grain weight ($R^2 = 0.671$), with RMSE=14.71 g/m² and MAE=11.87 g/m², indicating moderate predictive performance (Figure 2). These results support its effectiveness in integrating RS with field-based MSC yield data, while also highlighting areas for refinement.

Discussion

The yield estimation model explained 67.11% of the variance in actual grain weight, indicating moderate predictive accuracy. However, the 250 m resolution of MODIS NPP introduces uncertainties in biomass allocation, as MSC systems may be aggregated within a pixel—an issue common in heterogeneous landscapes (Yi et al., 2020). NPP allocation accuracy

depends on crop-specific parameters (ρ , HI), which vary with species and environment. Multi-season, region-specific calibration could improve predictions (Zhang et al., 2020).

Sentinel-2-based land cover classification achieved high accuracy, enabling reliable differentiation of MSC, wheat, and other land uses---critical for precise NPP assignment. Yet, finer-scale yield variation remains influenced by soil, microclimate, and management practices.

Integrating multi-source RS could improve spatial and temporal resolution. Sentinel-1 Synthetic Aperture Radar (SAR) provides captures biomass via crop canopy moisture sensitivity, while high-resolution PlanetScope imagery supports in-season crop monitoring (Yi et al., 2020). Deep learning techniques such as Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTMs) further improve prediction by capturing complex nonlinear crop growth dynamics, offering potential for scalable RA assessment.

Conclusion and Recommendation

This study presents a scalable, cost-effective approach for estimating MSC yield by integrating MODIS-derived NPP with ML, supporting yield estimation for precision agriculture and diversified cropping systems associated with RA. While mixed land cover and biomass allocation (ρ , HI) introduce uncertainty, future work should refine species-specific models, incorporate high-resolution RS (e.g., Sentinel-1, PlanetScope), and apply advanced ML techniques to boost accuracy and adaptability for data-driven RA decision-making.

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Designing cropping systems to supply anaerobic digesters at the territorial scale

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Keywords: Anaerobic digestion, nitrogen supply and leaching, carbon storage, modeling

Introduction

Contemporary agriculture faces multiple challenges and, beyond its primary mission of feeding the population, is increasingly called upon to address global objectives such as renewable energy production and the decarbonization of the economy. In the context of agroecological and energy transitions, anaerobic digestion, the biological process that breaks down biomass to produce biogas and digestate, emerge as a promising solution.

The development of anaerobic digestion plants within agricultural systems and landscapes offers an opportunity to redesign cropping systems, with the goal of optimizing biogas production, the nitrogen cycle and ecosystem services provision (e.g. water quality regulation, organic carbon sequestration).

Our study proposes a methodology that accounts for the entire system, its services, and impacts, both at the parcel scale and within the broader territorial dimension. For that, we used participatory workshops and an integrated assessment and modelling (IAM) approach to design and assess effects of innovative cropping systems on ecosystem services, nitrogen cycle and biogas production at the territory level. We applied our approach in two contrasted study areas:

- A predominantly cereal-growing region (eastern France).
- An intensive livestock farming area in Brittany (western France)

Methods

In each study area, a workshop to design cropping systems (crop rotations and managements) that optimize the ecosystem services was held with farmers, representatives of chambers of agriculture and researchers. These experts designed several possible crop rotations, adapted to provide biomass to anaerobic digester, reduce nitrogen losses (ammonia and nitrates) and increase ecosystem services like erosion control, carbon storage and nitrogen self-provision. These crop rotations were used in our simulations to build three alternative scenarios: SC25%, SC50% and SC100%, where the percentage reflects the share of cultivable land replaced by new rotations.

In each study area, simulations of the MAELIA platform were used to provide an initial diagnostic of biogeochemical cycle (water, nitrogen, carbon) and yields. This baseline scenario represents the current state of our simulated farms without anaerobic digestion systems. MAELIA is a multi-agent platform for IAM of agricultural landscapes and bioeconomy systems. It assesses environmental, economic, and social impacts of changes in farming, biomass chains (e.g. anaerobic digestion with the SYS-Metha Model), recycling (e.g. digestate management), resource management (e.g. water), considering global change (Therond et al., 2014).

Data required by MAELIA were collected and integrated to represent the current situation of each study area : climatic grid data for the last 30 years (SAFRAN), soil map, spatial boundaries of fields and their observed crop rotations (Land Parcel Identification System). The crop management (crops, sowing/harvesting periods, tillage, fertilization) of the main production situations were collected through dedicated surveys with farmer and agricultural advisors. In MAELIA crop management are presented through IF-THEN rules in order to be able to simulate a consistent spatio-temporal triggering of technical operations in fields in face of climate variability. Based on the available data, 740 ha were simulated for the western France area, and 21 000 ha for the eastern area.

Analysis of MAELIA output indicators highlighted the main effects of alternative scenarios in each study area relative to the baseline. We used random forest and regression trees to identify determinants of cropping system performances within study areas.

Results

To design rotations, stakeholders started from the main current rotations of cases studies and integrated legume, multi-species energy crops and multi-services catch crops (figure 1).

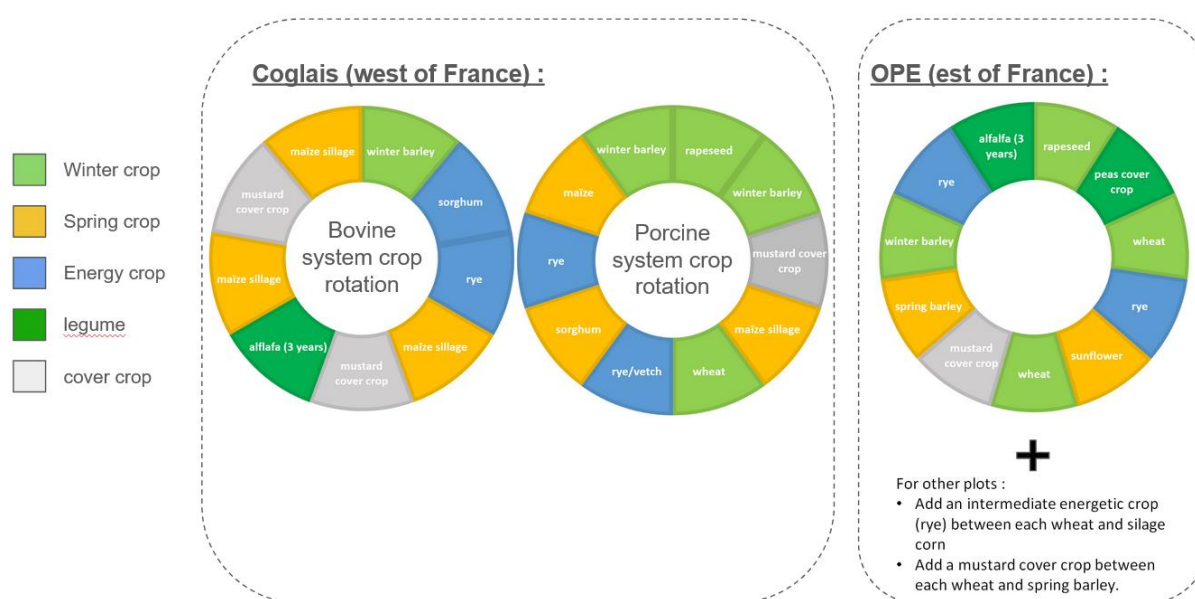


Figure 1: Crop rotations designed during workshops

Examples of MAELIA's simulation results for the Brittany study area are presented in figure 2.

For both territories, ammonia emissions slightly increased, but nitrogen leaching, carbon storage, N₂O emissions and more generally the net greenhouse gas balance did not change significantly. The use of organic fertilizers increased in the alternative scenarios, while synthetic fertilizer use was about halved.

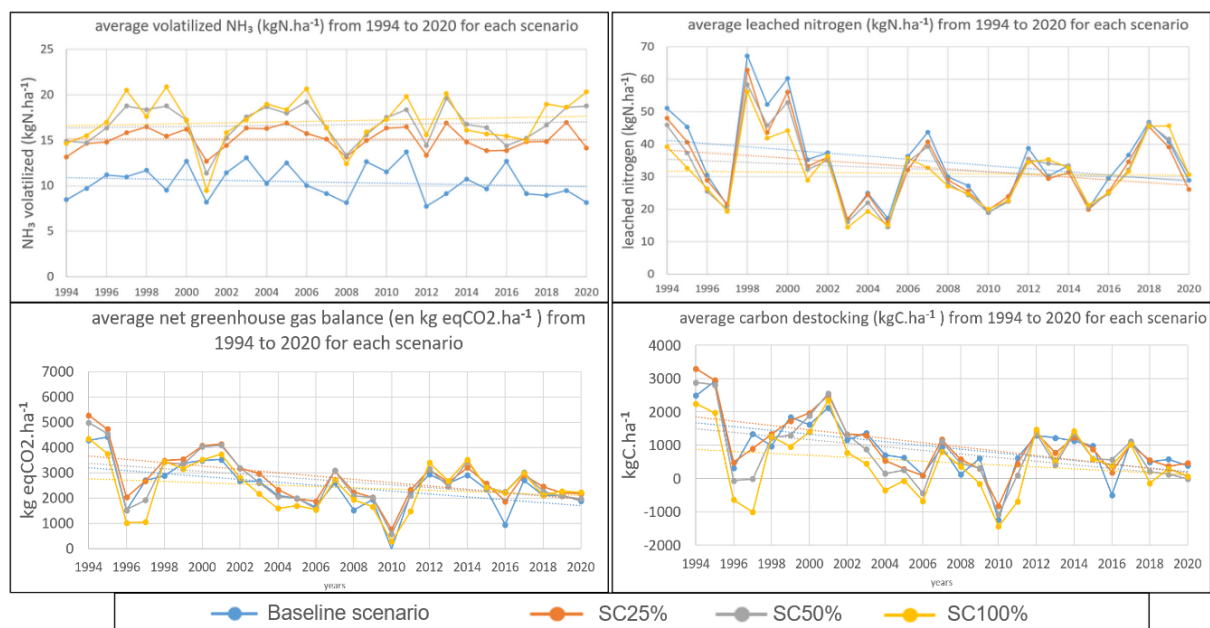


Figure 2: annual mean results of the Brittany area simulations with linear trend lines (Dashed lines).

Discussion

The alternative scenarios allowed for a reduction in the total amount of nitrogen applied at the territory scale, due to the presence of legumes in the rotation (Dalias, 2015), and the substitution of an important portion of synthetic fertilizers with organic ones. This supports farm autonomy from external inputs, especially synthetic fertilizers, a growing focus in current agricultural debates (Guillier et al., 2020). Contrary to expectations, both leaching and the net greenhouse gas balance did not decrease in the alternative scenarios compared to the initial scenario. However, while managing organic fertilization is more challenging, they did not increase. A slight increase in ammonia emissions was observed in the alternative scenarios, which could potentially be reduced further by employing injection techniques during digestate application (Riva et al., 2016; Seidel et al., 2017). Unlike the baseline scenario, alternative scenarios enabled energy production. Improvement of scenarios impacts could be expected through additional design workshops, focused on rotations that deviate more significantly from the initial land management practices.

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The future of livestock farming in Europe: major scenario families derived from european foresights

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Keywords: foresight, livestock production systems, meta-analysis, externalities

Introduction

The European sector of livestock production will be facing inevitable changes in the years to come, and there is a debate on which direction should be taken (1). These challenges involve the response to a global trend for greater demand, environmental impact (climate, ecosystems and intensive resources use), but also less addressed issues such as ethical issues (Human and animal welfare), and human health considerations (nutritional concerns and zoonotic risks) (2). Foresight analysis is a tool that can contribute to the understanding of issues and the emergence of a shared vision of the future. We conducted a meta-analysis of foresight studies considering the time horizon of 2030 - 2050, and describing the possible futures of European livestock productions. The aim was to identify the different families of scenarios built by European politic, scientific and economic stakeholders involved in these foresight exercises, and to identify any externalities or impacts of livestock production systems (LPS) that were neglected in these studies.

Material and methods

We integrated recent (post 2010) grey literature, scientific publications and visions through keyword searches on the internet, CORDIS and Web of Science, and by reaching out to a network of partners. The 210 retrieved documents targeted LPS, agriculture, climate change, and societal issues. They covered global, European, national (within Europe), and sub-national scales. Next we excluded documents with insufficient scenario development, lack of content related to livestock farming, or focusing too narrowly on a single dimension. This process resulted in a final corpus of 71 documents totaling to 214 scenarios.

Scenarios were then coded into a table of 93 qualitative variables, designed according to the expertise of the authors and following an iterative approach during the reading process, and describing 6 domains ("environment", "governance", "economy", "society", "science and technologies", and "livestock production systems"). The dataset was then reduced to 14 active variables (described in at least 80% of the scenarios) and 140 scenarios (providing information for at least 50% of the active variables), then analyzed through Multiple Correspondence Analysis (MCA) with the FactoMineR package of R software. Scenarios were classified using hierarchical clustering based on their coordinates in the MCA.

Results

Neglected topics

A large majority of the corpus described the type of LPS (intensive, extensive...), production volume and trade outcomes. It failed to consider issues linked to the OneHealth concept (90% of the scenarios ignore zoonotic risks), human nutrition (79%), food habits (77%), the impact on the use of dwindling or exhaustible resources such as water (75%) or phosphorus (81%),

and the governance surrounding their management (73%). Services such as subsistence farming (86%), agri-tourism (82%) were also scarcely mentioned.

Families of scenarios

The first three dimensions of the MCA integrated 27.6% of the variance. Hierarchical clustering revealed five families of scenarios. In Table 1, they are described according to the 14 active variables of the MCA and other variables not used in the MCA, but which in the end proved to be well differentiated between families. The "Intensification and technological sustainability for cattle" scenario was found only in the Nordic countries and in France. The "segmentation of production systems" scenario was found throughout Europe, except in the Nordic countries. For the other families, scenarios could be found at European, national or sub-national levels.

Discussion and perspectives

To conclude, the scenarios fail to describe how, in most of them, populations have moved to diets that are less rich in animal products. The two scenario families with clear environmental sustainability objectives seem to indicate a trade-off between the agricultural / technical solutions (agroecology vs. technological innovations) and the economic development of the sector (modest with a reduction in production volumes vs. more productive and flourishing). The corpus proved to be incomplete in its coverage of the social aspects of sustainability, as well as the diversity of services and disservices provided by livestock beyond its economic, food, and climate-related roles.

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	Extensive or agroecologic systems (39 scen.)	Segmentation of production systems (28 scen.)	Monogastrics on the decline (19 scen.)	Intensification and sustainable Technology for cattle (18 scen.)	Intensification and specialization (36 scen.)
LPS	Extensive or agroecologic	Coexistence	Intensive	Sustainable intensification	Intensive
Farm specialization	Mixed or diversified	Big intensive and small diversified	High	Moderate	High
Feed protein origin	autonomy	↗ Europe	Rarely mentioned	↗ Europe	↗ Europe moderately
Animal product consumption	↘ or ↘↘	Communities with contrasted diets	High	Flexitarian diet	= or ↘
Animal product price	↗	Coexistence	Coexistence	↗	Coexistence
Citizen concern*	Env. and AW	Env.	Env. and AW	Env. and AW	Env. moderately
Animal numbers and production volume	↘	= or ↘	= or ↘	= numbers but ↗ volume	↘ numbers and coexistence
Trade balance	Contracted (variant Ext.) or decreased (Agro.)	↗ for high value products	Decreased	↗	↗ or restricted

Agro-industrial sector	Investment (Ext.) stagnation (Agro)	Concentration and investment	Development and concentration	↗ not much described	Developed and concentrated
Territorial specialization	↘	=	=	Moderate	High
Value chains	Short or EU scale	Short and long chains	Long and intermediate plus coexistence	No clear trend	Long and downstream favourable
Environment*	Improved (b)	–	–	Rarely mentioned	Degraded or = Towards land sparing
LPS GHG emission	↘ or neutral	–	–	↘	=

*AW: animal welfare, LPS: livestock production system, Env: Environment (pesticide use, nitrogen cycle, water quality, state of biodiversity)

Table 1: description of the five families of scenarios

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Béné C et al. 2019. When food systems meet sustainability--Current narratives and implications for actions. World Development. 2019; 113: 116--130.

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Agricultural context determines environmental effects of co-product use alternatives in four European regions

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Keywords: Co-product utilization, nutrient circularity, regional agricultural systems, nitrogen flow model

Introduction

The decoupling of sub-systems in agriculture is ongoing, resulting in a strong dependence on imported feeds and fertilisers. Integrated agricultural systems in which crop production, livestock, and consumers are connected through recycling of available co-products (e.g. manure, crop residues, household organic waste), may reduce losses to the environment and utilise inputs more efficiently (van Loon et al., 2023). Mismanagement of co-products can lead to nutrient surpluses, resulting in eutrophication, emission of nitrous oxide (N₂O) which contributes to global warming (Myhre et al., 2013), and soil degradation (Urrea et al., 2019). Previous research has focused on individual indicators, often overlooking potential pollution swapping and trade-offs between different indicators (De Vries et al., 2015), and comparative analyses across contrasting regions are limited. This study assesses how co-product use in agriculture affects food production and its environmental performance in multiple European regions, and evaluates how regional context affects the optimum use of available co-products.

Methods

An exploratory regional nitrogen flow model (Vonk et al., 2025) was applied to evaluate co-product use options across four European regions: the Limfjord catchment (Denmark, L-DK), Drenthe (Netherlands, D-NL), Ariège (France, A-FR), and Fife (Scotland UK, F-UK). Three co-product types were assessed: (1) manure (direct application vs. anaerobic digestion), (2) crop residues (removal, retention, or anaerobic digestion), and (3) household organic waste (no agricultural use, composting, or anaerobic digestion). In each region, N balances were constructed for the agricultural production system with crop and livestock production including biogas and composting. Based on these N balances, indicators were quantified with general available parameters (e.g. IPCC, EEA) and national census data, including food production, GHG emissions, agricultural energy balance, effective organic matter (EOM) inputs to the soil, soil N surplus, and N losses.

Results

Co-product availability varied across the four case study regions. The Limfjord catchment (L-DK) and Drenthe (D-NL) had the highest manure availability due to intensive livestock production, whereas Ariège (A-FR) and Fife (F-UK) had less manure available. Crop residues were most abundant in the cereal-producing regions of Fife and the Limfjord catchment. Household organic waste was a relatively small co-product stream in all regions. In livestock-dense regions (Limfjord catchment, Drenthe), manure digestion was the most effective strategy for reducing GHG emissions (ranging between -2.0% and -19.8% in all regions, Table 1) and improving the net energy balance, but also led to reduced EOM inputs (-1.1% to -25.3%). Crop residue retention was most beneficial in cereal-dominated regions (Fife and

Limfjord catchment), enhancing EOM inputs (+2.8% to +15.9%), while anaerobic digestion of crop residues significantly improved energy balances (+11.1% to +195.5%). Organic waste from households contributed relatively little to overall system performance but provided minor energy benefits through digestion (+3.1% to +8.2%) or improved EOM inputs through composting (+2.5% to +4.9%).

Co-product	Scenario	GHG emissions (%-change)				Net agricultural energy balance (%-change)				EOM inputs to soil (%-change)			
		A-FR	D-NL	F-UK	L-DK	A-FR	D-NL	F-UK	L-DK	A-FR	D-NL	F-UK	L-DK
Manure	Anaerobic digestion	-4	-20	-2	-18	+25	+88	+6	+55	-16	-25	-1	-9
Crop residues	Anaerobic digestion	+2	0	-4	+2	+93	+11	+195	+84	+8	+3	+16	+16
Crop residues	Retain crop residues	0	0	+2	+1	+1	0	0	0	+22	+5	+39	+31
Organic waste	Anaerobic digestion	+2	0	0	+2	+5	+4	+8	+3	0	0	0	0
Organic waste	Composting	+3	0	+1	+3	0	0	0	0	+5	+3	+4	+2

Table 1: Effect of regional context on the percentual change (%) in greenhouse gas (GHG) emissions, energy balance, and effective organic matter (EOM) inputs to the soil in all scenarios compared to the reference scenario (Direct application of manure, Removal of crop residues & Not using organic waste in agriculture) A-FR = Ariege in France, D-NL = Drenthe in the Netherlands. F-UK = Fife in Scotland UK, L-DK = Limfjord catchment in Denmark.

Discussion and perspectives

The regional context determines availability of co-products (Bedoić et al., 2019) and affected the performance of alternative co-product use options. Co-product availability and other regional differences, such as manure storage systems and livestock types, played a role in determining effectiveness of co-product management. While anaerobic digestion reduced emissions and enhanced the net agricultural energy balance, EOM inputs were lowered, potentially with long-term implications for soil quality (Schjønning et al., 2009).

Regional specific parameters allowed to capture differences in biophysical characteristics and management practices between regions, but limited data availability restricted the differences that could be analysed. Therefore, more generic parameter values were sometimes used to ensure that methodological differences would not influence the model outcomes. For example, ammonia losses from manure application depended on the mode of application (i.e. injection, band application, surface spreading), while only a broad distinction between wet and dry climates was made for N₂O emissions from manure application.

There is an increasing demand for local biomass, ranging from soil amendment or feed in agriculture to biomaterials and renewable energy sources, some of which could be supplied by better utilising co-products. In the end, each kilogram of co-product can only be used once. Our generic modelling approach allows coupling of the available co-products in multiple

European regions with the impact of their potential use, and highlights important trade-offs between different indicators for environment and productivity. Trade-offs between environmental and agronomic indicators, like improved net energy balance but reduced EOM inputs to soil after manure digestion, highlight the complexity of co-product use, crucial for developing policies or subsidies that promote best practices without unintended effects. Our study suggests that prioritization of co-product utilization should first consider the regional co-product availability, while setting clear objectives (e.g. environmental impact, agricultural production) to navigate between trade-offs and synergies.

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Fab4farming: assessing the impact of disturbance gradients on agrobiodiversity for sustainable farming systems design

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Keywords: Agroecology, Pesticide Reduction, Biodiversity, Disturbance Gradients

Introduction

Industrialisation of Western agriculture led to a considerable increase in agricultural yields by introducing specialised systems based on increasingly heavy mechanisation (Van der Ploeg, 1993). The technological advances made by such industrialisation led to a sharp increase in the use of agrochemicals and synthetic fertilisers, on large-scale monocultures using high-yield varieties (Van der Ploeg, 1993), as it occurred in Wallonia (Belgium). This transition has had deleterious effects on ecosystems and their ability to provide ecosystem services (Stoate et al., 2009). To overcome these effects, agroecology aims to provide a response that reconciles agricultural production with social and environmental sustainability through locally adapted practices that restore Functional agrobiodiversity (FAB) and associated ecosystem services (Boeraeve et al., 2020). This study hypothesises that reduced tillage and reduced agrochemical use enhance FAB, supporting complex prey-predator networks, and increasing the delivery of regulating and provisioning services. The objective of this study is to assess the FAB in a diverse array of farms in Wallonia and to explain the variations observed by constructing disturbance gradients.

Methods

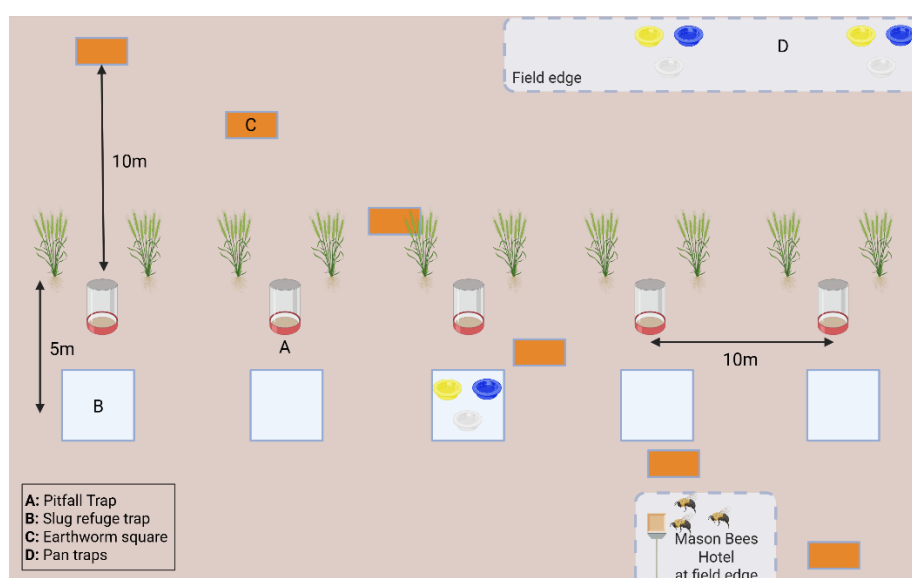


Figure 1: biodiversity assessment protocol within the FAB4Farming project (2024-2027). A = Pitfall trap (Carabids); B = Slug refuge trap; C = Earthworm square (spade test and chemical extraction); D = Pan traps (visiting pollinators).

Sampling focused on 40 winter cereal fields across Wallonia (Belgium) representing a gradient of agricultural practices: conventional (CVA), soil conservation (CA), organic (OA), and organic conservation (OCA) systems (the number of replicas is consistent within each category). A phone call survey was conducted to assign each farmer to a schematic category. A diverse array of organisms was sampled at the centre of each field, including carabids, earthworms, pollinators and soil microorganisms (Figure 1). Biodiversity assessments measured FAB structures, while farmer surveys documented technical practices.

Agricultural practices were translated into disturbance gradients along two axes. In cultivated environments, the main disturbances are phytosanitary treatments and soil disturbances (Gardarin, 2024). Establishing disturbance gradients using indicators is expected to show higher explanatory power than system categorisation. Collected data covers three years of interventions preceding the sampling year. Gradients were constructed by the diversity of practices within each of the 4 schematics categories (CVA, CA, OA and OCA).

Chemical disturbance gradient:

Chemical disturbances in agroecosystems occur through agrochemical use, with direct lethal, sublethal, or indirect effects on terrestrial invertebrates (Beaumelle et al., 2023). As use indicator, the Index of Active Substance per Crop (ISAC) (Durenne et al., 2021) (based on active substances (a.s.), not commercial product as the treatment frequency index) was used; while in terms of risk indicator, the Pesticide Load (PL) (Kudsk et al., 2018) and the under-development ISAC+ indicator (alike PL but based on a.s.) were calculated. The a.s. residues in the soil were extracted and quantified to precisely assess the exposition that may occur within the fields (QUeCHeRS method on 42 a.s., Anastassiades et al., 2003 adapted to soil).

Mechanical disturbance gradient:

Soil mechanical disturbance is known for its impact on soil organism communities (Van Capelle et al., 2012), soil functions and resilience (Stavi et al., 2016; Pittelkow et al., 2015). So far, the literature mainly provides comparisons between tillage practices (ploughing vs. no-ploughing), with inconsistent results (Müller et al., 2022). Mechanical disturbance gradient was described through the Soil Tillage Intensity Rating (STIR) which considers the intensity of every action that disturbs soil by quantifying and qualifying the type of soil operation (inversion, fragmentation, compression, etc.), its speed, and its depth and surface.

Preliminary Results

As the sampling is still ongoing, we present preliminary results based on the 2024 sampling (22 farm sampled and interviewed, replicates are consistent within the 4 systems).

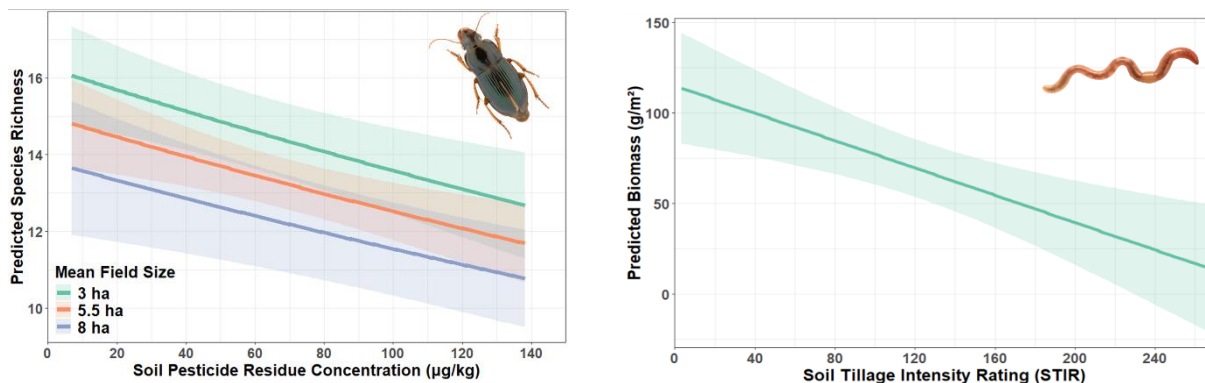


Figure 2: Left plot: evolution of the predicted carabid species richness (GLLM, $n = 22$) along the soil pesticide residue concentration ($\mu\text{g/kg}$, log-transformed, $p = 0.004$) for 3 mean field sizes categories (ha, $p = 0.02$). Fields ≤ 3 ha are in green, ≈ 5.5 ha fields in orange and fields > 8 ha in blue. Right plot: evolution of the predicted earthworm biomass (LM, $n = 21$) along the soil tillage intensity rating (STIR, $p = 0.004$).

Regarding the chemical disturbance, we have found that the carabids species richness is significantly reduced as the soil agrochemicals residue concentration and mean field size increases (Figure 2, left). This result comes from a Generalized Linear Mixed Model with p-values respectively equal to 0.004 and 0.02.

Regarding the soil mechanical disturbance, the gradient has been established by the STIR calculation, and we have found a significant relation between STIR and the earthworm biomass (Figure 2, right) (Linear Model, $p = 0.004$, $n = 21$, $R^2 = 0.84$). This means that the higher the STIR is, the less earthworm biomass will be found within fields.

Discussions and Perspectives

By shifting from broad farming system categorisations to a gradient-based approach, this research offers a nuanced perspective on how specific practices, rather than system labels, influence biodiversity and ecological functions (Gardarin, 2024; Boeraeve et al., 2022).

One of the major contributions of this study is the development of chemical and mechanical disturbance gradients as explanatory variables for FAB dynamics. This methodological shift from broad farming system categorisation aligns with recent literature suggesting that system-level comparisons often mask the diversity of practices within them (Chassain et al., 2024). By integrating these gradients, our research refines our understanding of how farming decisions shape ecosystem functions.

Our preliminary results on disturbance gradients underscored the benefits of low-input and reduced soil disturbance for maintaining functional agrobiodiversity.

Despite its contributions, this study has certain limitations. The disturbance gradient approach, while offering a refined analytical framework, requires detailed and consistent data collection on farming practices, which may introduce variability due to farmer self-reporting.

The results are expected to guide policy recommendations for sustainable agriculture by identifying specific practices that enhance biodiversity and ecosystem services. By bridging ecological data on several taxa, this research lays the groundwork for a more resilient and biodiverse agricultural landscape in Wallonia and beyond.

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Power demand of cropping operations: an indicator to plan ahead the need for renewable power to fuel tractors

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Keywords: energy transition, cropping operations, power demand, seasonal variability

Introduction

Since 1950, European agriculture has undergone radical changes due to industrialization and mechanization, which have supported increasing yields, labor productivity, farm size and specialization. These transformations are intimately linked with the energy transition of agriculture from traditional biomass self-fueling to the extensive use of fossil fuels (Harchaoui and Chatzimpiros, 2018b, 2018a).

Yet, current systems are facing challenges including fossil fuel supply risks, vulnerability against climate change and environmental sustainability. In addition, within the context of the energy transition, agricultural systems are expected to provide bioenergy as a substitute for fossil fuels to other sectors (IPCC, 2019). These challenges call for rethinking agricultural systems design to ensure food security while minimizing impacts and energy use in production.

This transition requires shifting machinery from fossil to renewable fuels (Staie et al. 2024), demanding seasonally-informed energy planning due to the intermittency of sources like electricity and biogas -- an aspect neglected in current literature (Rahman et al. 2022).

This paper estimates the seasonal variation in agricultural machinery's fuel demand -- quantified as the fuel power required for cropping operations -- and its sensibility to the penetration of agroecological practices, an important feature of the transition (Sanz-Cobena et al. 2017). This is a key element to plan ahead a matching renewable energy supply for tomorrow's agriculture.

Methods

The analysis focuses on main field operations for the main cropping systems in France. The Ministry of Agriculture provides detailed data about the practices regarding the 20 main field crops and the grasslands (regrouped in 7 categories), covering 24 Mha (Agreste, 2024). The study includes all these crops, for which a crop calendar was available.

For each operation and crop, the power demand is estimated using equation 1. Agreste provides the area S_{crop} and the number of passes n_{pass} for the considered operation. The energy intensity E_i (fuel use per ha) is determined by averaging values from the available literature. The timespan T_{days} allocated for the operation is given by the published crop calendar (Agreste 2010). The hours worked per day t_{hours} is assumed to vary between 6 and 12 depending on the season and operation type.

$$P_{work} = S_{crop} * n_{pass} * \frac{E_i}{T_{days} * t_{hours}} \quad (1)$$

Pwork is then smoothed over the calendar time slot and within a workday following a normal distribution. The sum of Pwork per crop and operation provides the total power distribution of cropping operations over the year.

The method is repeated for two alternative scenarios assuming higher penetration of agroecological practices. Following the European goal for 2030, Scenario A assumes 25% organic crop area: industrial fertilizer spreading is adapted to organic fertilizer spreading and herbicide spreading is changed to mechanical weed control. For comparison, scenario B assumes 25% no-till crop area, meaning no deep tillage operations and direct seeding.

Results

Current power demand estimate

Figure 1 shows power distribution for a full production campaign in the current situation in France. The grey areas represent the overlapping preceding and following campaigns. Results show significant seasonal variability, mainly driven by tillage and harvesting, particularly for winter wheat. Power demand peaks at 35 GW, and contrasts with fertilizing and pesticide operations which are more evenly distributed. Total energy consumption equals 57 PJ, with average intensity in cropland of 3.8 GJ/ha.

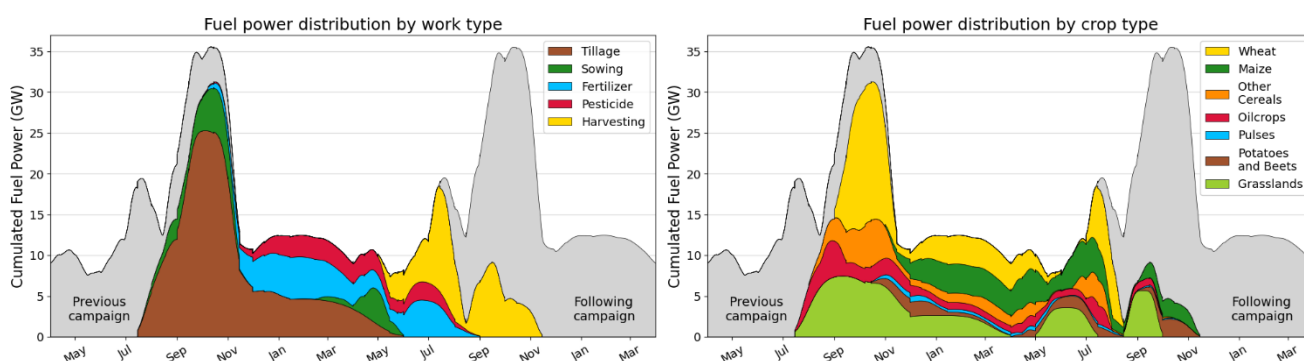


Figure 1. Fuel power distribution for cropping operations per operation and crop type.

Estimate for agroecological practices

For alternative scenarios, results suggest that organic cropping operations require more mechanical power for weed control, and no-till cropping operations allow a significant decrease in peak power demand due to reduced tillage.

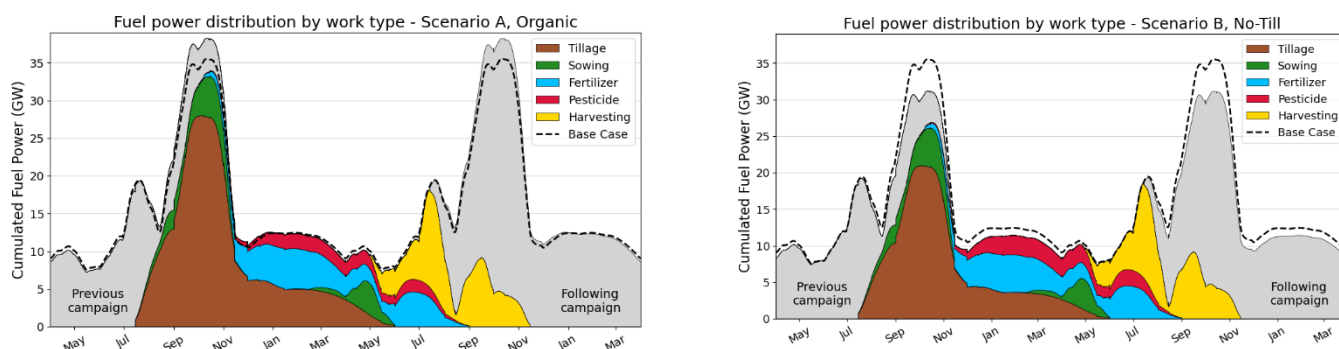


Figure 2. Fuel power distribution for cropping operations, scenario A and B.

Discussion and perspectives

This study quantifies the seasonal variability of power demand for cropping operations, neglected in current literature. Yet, it seems crucial for the energy transition to anticipate power demand, given the challenges brought by seasonal variability of renewable sources.

Potential substitutes to fossil fuels include biofuels or electrification. Concerning bioenergy, recent studies show that agriculture is today structurally deficient, making it unlikely to achieve energy self-sufficiency through bioenergy alone (Harchaoui and Chatzimpiros 2018a). Renewable electrification seems promising given the progress of battery-powered vehicles, although challenges regarding autonomy and nominal power remain (Scolaro et al., 2021). However, while fossil fuels or biofuels allow unconstrained power supply, electrification is more sensitive to the variabilities of demand and renewable supply. This study allows to anticipate future power demand from agriculture, to ease its integration in a decarbonized energy system.

A limit of the study is that results are aggregated for France and do not reflect variability in farming practices and farm types. Also, the hours variables had to be assumed, and can be approximately validated with farmyard debit data.

Perspectives of this work include:

- Inclusion of indirect energy use (e.g. fertilizer manufacturing) to assess trade-offs between agrochemistry and cropping operations energy demand.
- An explicit relationship between farm size, agricultural population, power demand and machinery fleet size.
- Assessment of a fleet size oversizing, compared to the peak power demand.

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The controversial role of plastics in agricultural systems

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Keywords: agricultural plastics, resource use efficiency, pollution, agro-ecology

Introduction

The growing production and use of plastics has been accompanied by increasing pollution (Yates et al., 2024). This pollution is not only due to increases in mismanaged plastic waste. It also stems from the ability of plastics to degrade, fragment, disperse, transfer their constituents, and adsorb and then desorb contaminants from their production, during and after their use. Although the proportion of plastics used in agriculture may seem small compared to that of plastics used to package food, on farms, plastics are in close contact with soils, feed and food in the making. However, from the perspectives of some actors, these plastics are essential to the agro-ecological transition of agriculture as saving forages, water and pesticides (CPA et al., 2019). They are also authorised and used in organic agriculture. The sustainability of agricultural plastics, in all its dimensions, and the role to be assigned to them in the design of agricultural systems are therefore issues of concern to society, researchers and public authorities.

Methods

This is why, the French Agency for Ecological Transition, the French Ministry of Agriculture and Food, and the French Ministry of Ecological Transition requested a Collective scientific assessment (CSA) (Pesce et al., 2021). In this CSA, experts from different disciplines brought together evidence and knowledge from the peer-reviewed scientific literature. More specifically, in this paper, we present the results of a literature review that crosses disciplinary perspectives of history of science and technology, agronomy, biogeochemistry and ecology. The literature search was tailored to research questions associated with each discipline. From the Web of Science database, 3015 articles published between 2000 and 2023 were retrieved. At the end of the screening process, 506 articles were selected for full-text analysis.

Results

The historical analysis shows that plastics have spread throughout food value chains since the 1950s. They were first widely adopted downstream in value chains, then upstream, mainly in cattle and horticultural production. The European Union 1962 common agricultural policy contributed to drive this adoption by promoting technological means towards increasing agricultural productivity. Plastics were associated with the industrialisation of agriculture, success in improving crop yields and labour productivity and thus in increasing food and feed production. Plastics replaced other materials and practices on farms. They deeply transformed forage conservation with the use of stretch films to wrap haylage bales and silage films to cover silage in silos. They can be linked to the heavy reliance of cattle systems on conserved maize

and grass, and of dairy and mixed systems on maize silage. Plastics made environmental conditions controllable with the use of greenhouses, tunnels, mulches and drip irrigation, and thus made land artificialisation, and even soilless crop production possible.

In the agronomic literature, considerations of the sustainability of agricultural plastics were restricted to those of common agronomic objectives with the objective of improving yield being the most investigated. A range of agrochemical inputs and infrastructures technologies, among which plastic mulches or tunnel coverings, applied to a single crop were usually compared at the plot or field level, based on on-station experiments conducted in one or two growing seasons. Although the high labour intensity of horticultural products likely drove the replacement of labour using plastics technological solutions, farmers' socio-economic objectives and constraints were overlooked in the literature. Although an issue of concern, the sustainability of plastics as compared to that of pesticides remained under-researched. Trade-offs between short-term yield benefits and environmental impacts of plastic production, use and disposal on, e.g., soil and water quality were also not analysed.

The biogeochemistry and ecology literature focused on the environmental dimension of the sustainability of plastics and shows that agricultural soils are heavily contaminated by particulate plastics. These particulate plastics partly result from the degradation of plastic inputs and infrastructures used for crop and livestock production breaking down from macro- to micro- and nano-plastics. Moreover, the accumulation of particulate plastics in the soil, air and water environmental compartments affect ecosystem functioning and is likely to affect the provision of ecosystem services, including the provision of food in the long term.

Discussion and perspectives

Plastics transformed food value chains and co-evolved with them, contributing to mass production and mass consumption in global and long food value chains. In doing so, plastics are failing to sustain the resources on which people rely. Incremental increase of resource use efficiency by increasing dependency on agricultural plastics and to the detriment of soil health and ecosystem functioning do not correspond to agroecological practices (Wezel et al., 2020). Further diagnosis at the level of farms, value chains and sociotechnical system, considering objectives, constraints and practices of actors, would broaden the window of opportunity for redesign.

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Assessing the environmental variability of miscanthus cultivation for the bioeconomy: insights from ex-ante and ex-post LCA approaches

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Keywords: Bioeconomy, Sustainability, Territorial design, Life Cycle Assessment

Introduction

The bioeconomy is part of an agro-economic transition aiming to reconcile productivity, environmental sustainability, and economic resilience. Among emerging biomass crops, *Miscanthus x giganteus* is considered a promising resource for bio-based value chains due to its high yield potential, low input needs, and perennial structure.

However, its environmental performance remains uncertain and highly dependent on local conditions. Yield, input use, and carbon storage vary significantly with soil characteristics and crop management. This variability challenges the assumption of miscanthus as a universally sustainable option and calls for context-specific assessment tools.

Life Cycle Assessment (LCA) offers a robust framework to evaluate environmental impacts "from cradle to grave." When adapted to territorial contexts, LCA supports informed design of biomass value chains by revealing sustainability trade-offs.

This study compares two miscanthus systems using territorial LCA: an ex-ante scenario assuming intensive management and high yields (UCAC), and an ex-post evaluation of low-input, real-world practices (MISTICC). The objective is to examine how local factors affect environmental outcomes and to draw practical insights for the design of sustainable, locally adapted bioeconomy strategies.

Methods

To assess the environmental performance of miscanthus-based systems in different territorial contexts, we applied a territorial LCA based on ISO 14040/14044 standards. This method quantifies environmental impacts across the full life cycle, from input production to field operations and biomass harvest.

We used both generic and site-specific data. Impact assessments were based on Agribalyse 3.1 and Ecoinvent 3.10 databases. Soil carbon dynamics were modelled using Simeos-AMG (Clivot H and al., 2019) accounting for long-term changes under miscanthus depending on soil type and practices.

Two contrasting systems were compared: UCAC study (ex-ante) assumed high yields and intensive input use (fertilizers, pesticides) on soils with low organic matter. MISTICC project (ex-post) evaluated actual low-input systems (no fertilizers or herbicides) on organically rich soils (2.84%) in Hauts-de-France.

The life cycle inventory was built using a territorial data collection protocol: Field interviews with farmers to document real practices; simulation modelling to estimate carbon fluxes based on pedoclimatic data and crop history.

Results

The comparison of the two case studies revealed major differences in environmental performance, driven primarily by crop management and soil characteristics.

In the UCAC ex-ante scenario, miscanthus was assumed to achieve high yields under intensive management with synthetic fertilizers and herbicides. In contrast, the MISTICC ex-post scenario showed lower yields, shaped by local conditions and extensive practices with no chemical inputs.

Soil carbon dynamics also diverged (Figure 1). On organic-rich soils (2.84%), MISTICC showed a potential carbon loss, suggesting a risk of soil degradation. UCAC, on lower mineral soils (1.72%), projected a net carbon gain, contributing positively to climate impact mitigation.

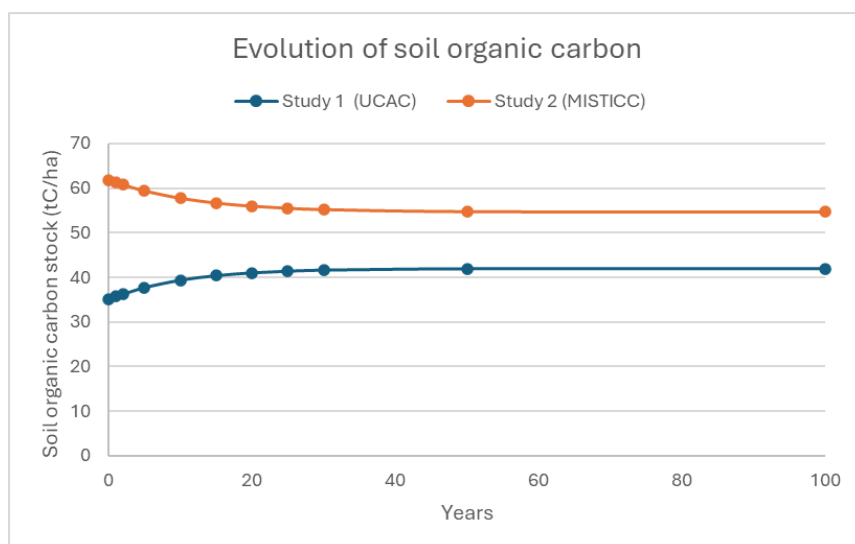


Figure 1: Evolution of soil organic carbon

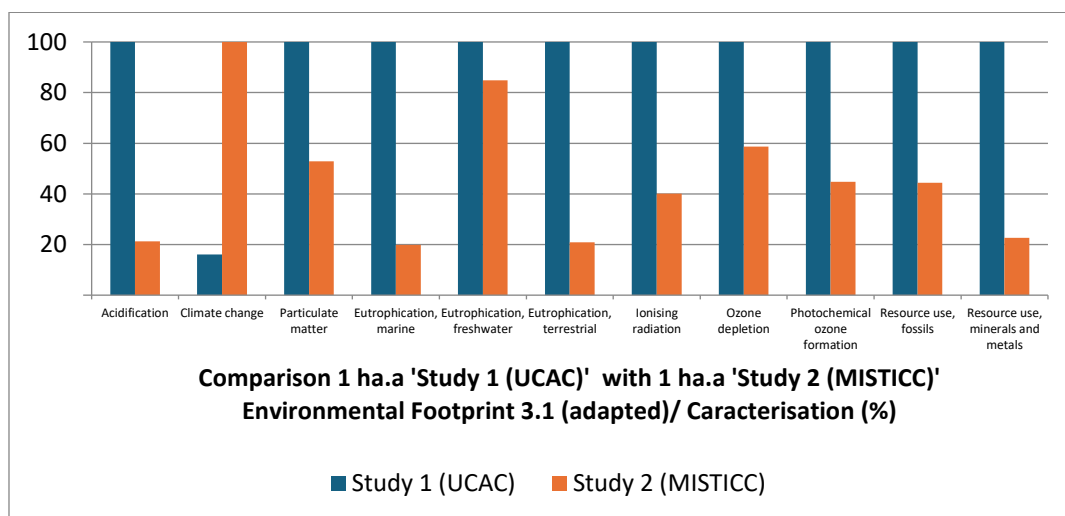


Figure 2: LCA results

These contrasting carbon trends influenced the climate change indicator in the LCA (Figure 2). However, UCAC also had a higher environmental footprint in several categories (acidification, eutrophication, ozone depletion, resource use), mainly due to greater input consumption and energy use.

Both systems used similar machinery, confirming that management choices and soil types drove environmental variability.

These findings highlight key trade-offs between productivity, soil carbon balance, and overall environmental impact. They show that local conditions and practices substantially affect the sustainability of miscanthus-based systems, underlining the importance of place-based assessments in bioeconomy strategies.

Discussion and Perspectives

This study shows that the environmental performance of miscanthus cultivation is not intrinsic to the crop, but highly dependent on local conditions---particularly soil organic matter and input intensity. Comparing an ex-ante, high-input scenario with an ex-post, low-input case revealed significant differences in both climate indicators (via soil carbon fluxes) and environmental impacts (e.g., acidification, eutrophication).

These results align with Pogni et al. (2020), who found that nitrogen fertilization alone accounted for up to 66% of miscanthus-related impacts on marginal soils. Their study confirms that input management is a critical leverage point for improving sustainability.

Beyond quantifying impacts, the challenge lies in integrating LCA results into transition strategies. As highlighted by Loiseau et al. (2022), coupling territorial LCA with decision-support tools (e.g., agent-based modelling) can help stakeholders explore sustainable agricultural pathways. Our study contributes to this vision by showing how territorial LCA can reveal trade-offs and support collective decision-making.

Yet, current LCA databases often lack specificity, limiting the accuracy of local assessments. Our approach, based on farmers interviews and process-based modelling (Simeos-AMG), highlights the value of ground-truthed data.

We can move from assessment to action in agroecological and bioeconomy transitions by embedding LCA in design-oriented frameworks.

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Assessment of the agroecological performance on family farms in central Tunisia using the TAPE framework

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Keywords: Agroecological, Family Farms, Assessment, TAPE FRAMEWORK

Introduction

The intensification of agricultural systems has played a key role in increasing global food production, helping to satisfy the increasing demands of a rapidly growing population (Muchiutti et al., 2024). However, these advances have often come at the expense of natural resources and ecosystem sustainability (Moeller et al., 2023). Faced with these challenges, agroecology emerges as a promising solution with multiple benefits---including improving the income of households, enhancing food security, promoting social justice, and reducing negative environmental impacts (Barrios Latorre et al., 2023; Gomori-Ruben and Reid, 2023). The FAO initiated a series of global and regional dialogues on agroecology, engaging a broad spectrum of stakeholders. One of the major outcomes of these consultations was the development of the Tool for Agroecological Performance Evaluation (TAPE) analytical framework (FAO, 2019). By integrating social, economic, and environmental dimensions, TAPE serves as a strategic instrument for guiding public policies and fostering sustainable agricultural development in response to contemporary challenges (Mottet et al., 2020; Costa-pereira et al., 2024).

This study focuses on the Sbikha delegation in central Tunisia. Like many rural areas, Sbikha faces pressing challenges such as water scarcity, soil degradation, and climate change, all of which are exacerbated by limited access to markets and financial resources. This research aims to assess the agroecological performance of family farms using TAPE framework to identify key levers for strengthening farm resilience and explore viable pathways for scaling up sustainable practices adapted to local contexts.

Methods

This study was conducted in the Sbikha delegation, located in the governorate of Kairouan. Smallholder farming dominates the local agricultural landscape, with households of less than 10 ha being a key pillar of the region's economy and cultural heritage. A total of 50 family farming was selected, ensuring a diverse representation of agroecological transitions, basing on the following criteria: farm size ≤ 10 ha and family labor $\geq 50\%$ of the total workforce. Farms are featured by diverse production systems, with a notable emphasis of vegetable crops (e.g. tomatoes, onions, chili peppers, peas, watermelon and melon). These farms sustain local food production and preserve traditional farming practices and local knowledge, ensuring the transmission of age-old techniques across generations.

We adopted the TAPE framework grounded in the 10 principles of agroecology and closely aligned with the Sustainable Development Goals. The TAPE is designed to be adaptable to different agricultural contexts and is particularly well-suited to family farming rather than large-scale commercial farming. It is consisting of three main steps, supported by a diagnostic (step 0) and included an optional typology (step 1 bis). Step 1 aimed to assess the extent of

agroecological adoption actually by households. Step 2 evaluated agroecological performance across three key dimensions: economic (e.g., farm income and market access), environmental (e.g., biodiversity and water use efficiency), and social (e.g., gender inclusion and food security). Data were collected through structured surveys conducted with 50 farmers, supplemented by observations from local agricultural administration officials. In the final step, findings from Steps 1 and 2 were validated through participatory discussions with farmers and stakeholders.

Results

The 50 farms studied achieve an average Characterizing Agroecological Transitions score of 41%, meaning they are not yet advanced in their agroecological transition. The highest average scores across the 10 agroecological elements are related to the social aspects ("culture and food traditions" (68%) and "human and social values" (61%)). This reflects the local population's strong attachment to customs and traditions related to food sovereignty. This strong connection stems from the recognition and appreciation of local agricultural practices, as well as the community's ability to manage its food resources.

The farms studied exhibit low scores for the elements of "responsible governance" (11%), "co-creation and sharing of knowledge" (24%), and "circular and solidarity economy" (32%). These elements depend on interactions within local markets, the presence of producer networks, and relationships with consumers and intermediaries. It is also important to note that there are very few such organizations in Sbikha. This lack reduces the bargaining power with institutional actors and limits their access to technical and financial support.

Although farmers use practices related to agroecology (such as drip irrigation, composting, and crop rotation) the concept itself is largely unfamiliar to most of them. There is also a lack of participatory processes to encourage the development of agroecological innovations among peers. This gap is linked to the low educational levels of farmers, with only 18% having completed secondary education. Additionally, there is almost no training available to help farmers develop the knowledge needed for agroecological practices.

Our results show the limited integration of crop-livestock systems, as feeding the herds still depends heavily on externally purchased inputs especially during periods of drought. This dependence on external inputs, while it may increase productivity in the short term, leads to a moderate level of resilience for farmers. Indeed, those who have attempted to reduce their reliance on these inputs have often faced a decrease in income. To encourage this transition, financial incentives, technical support, and public policies are needed to demonstrate the long-term benefits of agroecology.

Finally, the results highlight the unsustainability of the households especially concerning youth employment. While family farming remains a central economic activity, it has proven ineffective in addressing the critical issue of youth unemployment or in creating long-term employment opportunities. Moreover, only 4% of the women surveyed find themselves in a favorable economic situation, a figure that highlights the deeply rooted marginalization of women's roles within households. Additionally, 32% of farms demonstrate unsustainable productivity per hectare (Productivity value per ha is $< 1/3$ of the national average value of production per hectare/year), with agricultural yields significantly below the national average. This limitation significantly hinders their potential for economic growth and long-term viability.

Discussion and Perspectives

The evaluation of farm households in the Sbikha delegation reveals a low rate of agroecological transition. This momentum could increase with the implementation of more

targeted support policies, improved access to necessary financial resources (e.g. tailored subsidies and low-interest credit mechanisms), and the development of a robust technical support network (e.g. awareness programs, youth networks, and specialized training programs in agroecology). Furthermore, raising awareness among farmers about the medium- and long-term benefits of agroecology---both in terms of economic profitability and environmental sustainability---could encourage a broader adoption of these practices. While the TAPE method is a valuable tool, it could be further improved to enhance its accessibility, flexibility, and relevance across a broader range of agricultural and socio-economic contexts.

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Assessment and enhancement of cattle farming services in northwestern France landscape

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Keywords: Cattle farming, ecosystem services, landscape scale, agrobiodiversity

Introduction

In the shift towards more sustainable cattle farming, feed management and nutrition are key to both farm resilience and environmental impact (Wilkinson & Lee, 2018). Cattle farming, including both dairy and suckler, has declined in the Pays de la Loire region over the past 20 years, affecting food production but also potential ecosystem services (ES) (Dumont et al., 2019). Different cattle production systems provide varying levels of ES, influenced by the specific environmental characteristics of the region (Suškevičs et al., 2023). The PRESENCE research project aims to better understand stakes towards the sustainability of livestock farming systems in three local areas in northwestern France (La Roche-sur-Yon, Coëvrons and Vallée-du-Loir). In this abstract, we present our work on the Coëvrons area.

Methods

We chose a qualitative approach with semi-structured interviews: (i) the first 6 interviews were conducted with territorial stakeholders (institutions, socio-economic actors...) to assess their perception of ecosystem services (ES) especially the supply service of livestock farming systems ; (ii) the second involved 65 livestock farms and focused on the diversity of cattle farming systems, with results analyzed using factorial analysis and hierarchical clustering and an assessment of the ES associated with the profiles was made ; (iii) longer interviews (n=4) on farms with varying production intensities (associated with feeding strategies) in cattle farming systems in order to explore the relation between production intensity and agrobiodiversity (i.e. apart from biodiversity recognized as a resource by farmers for agricultural production). These interviews provide insights into (i) intra-farm agricultural diversity, (ii) the impact of climate and economic pressures on feeding strategies, and (iv) the management of agroecological infrastructures and landscape features.

Results

Recognition of ecosystem services

The Coëvrons area (figure 1) is a rural area with a high number of grasslands and with a dominant activity of livestock farming (cattle, mixed, dairy). This activity shapes both the landscape and the local economy. Local authorities focus on protecting these activities as they result in a strong area's identity. Local stakeholders have various interpretation of the concept of ES: (i) socio-economic actors focused their discourse on employment and food supply while (ii) local authorities focused on cultural and territorial identity through the maintenance of environmental quality and landscape. Public-private collaborations are crucial in structuring more these services, supported by various policy instruments like labels, charters, and local planning regulations according to the 6 interviews conducted.

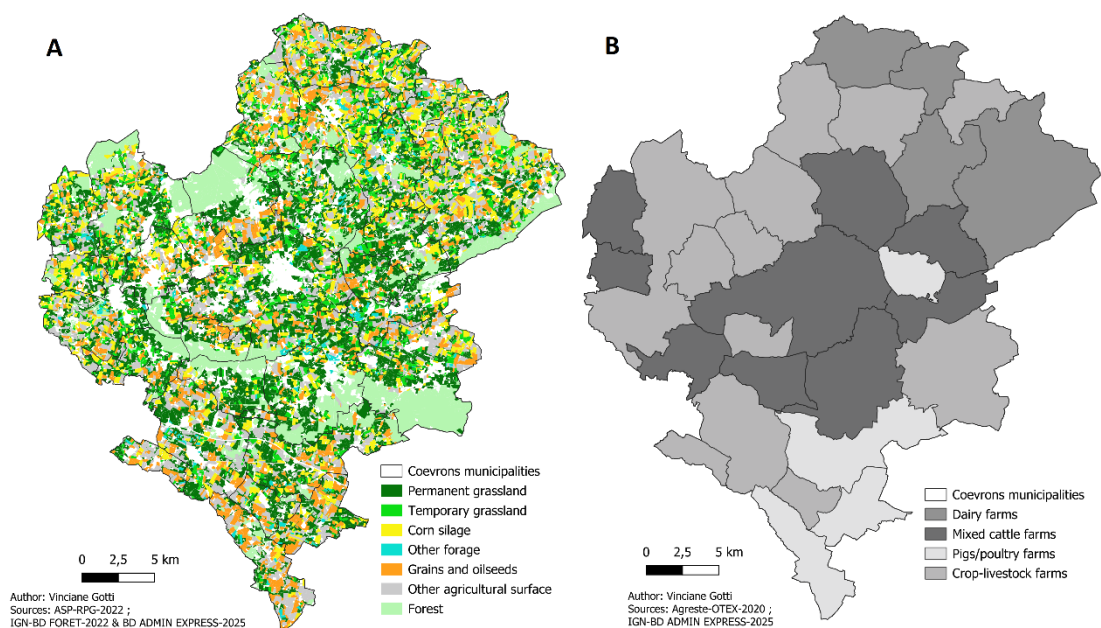


Figure 1: Map of the distribution of land use (A) and livestock orientation (B) in the Coëvrans

Characterization of livestock farming systems' profiles

A survey of 65 livestock farms identified 11 farm types (4 dairy, 5 suckler, 2 mixed) across the three areas (figure 2).

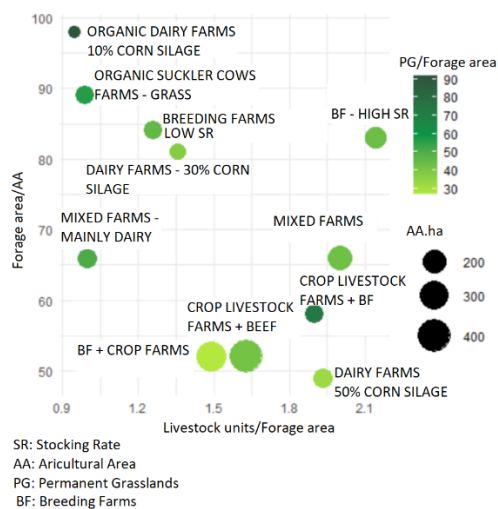


Figure 2: Farms typology based on structural and functional data

Dairy and mixed farming systems contribute significantly to food production and employment. Suckler farms and grass-fed systems play a key role in biodiversity conservation and rural vitality.

The profiles found in the Coëvrons area are (i) organic suckler cows farms, grass fed, (ii) breeding farms and crop farms, (iii) crop livestock farms, (iv) dairy farms with 50% corn silage and (v) organic dairy farms with 10% corn silage on the feeding system.

Focus on relationships between feeding strategies and agrobiodiversity: a case-study approach (n=4)

Farm 1 (organic dairy farm) links the climatic changes to more adaptations on farm such as stopping the silage maize due to too wet winters to try other forages (sorghum, meslin, Brazilian oats and cabbage radish): they want to produce with what they have on-farm, limiting outside buying. Farm 2 (dairy farm) links the lesser use of pesticides to a greater presence of earthworms and finds satisfaction in it, they also affirm that if the weather does not allow good forages or cultures, they will buy feed outside. Farm 3 (suckler cows) links the increasement of maize in the area with the increasement of boars' and deers' population which is an issue for their farm (plowing, biosecurity). Farm 4 (organic suckler cows) is a 100% grass farm as the land cannot be plowed; for them it is an opportunity to work in total autonomy, and they try to design their hedgerows to manage the water runoff in order to have access to more lands for his cattle in winter by draining them. Livestock farmers have various perceptions and contributions to biodiversity, speaking differently about the links they make between their feeding strategies and the agrobiodiversity of their farm.

Discussion and Perspective

ES in cattle farming are not yet fully integrated into policy and practice (Zhang et al., 2007). The identified typologies and case-studies suggest that diverse farming models contribute differently to ES in line with Dumont et al. (2019). Future research could explore incentives for farmers to adopt multifunctional approach that promote biodiversity, rural vitality, and food production. The use of exploratory, statistical, and qualitative methods highlights the complexity of characterizing ES, and refining these approaches will improve comparability across regions. Ongoing economic and climatic shifts influence cattle feeding strategies and land-use decisions (Klerkx et al., 2012). Strengthening collaboration between farmers, policymakers and researchers is essential for fostering sustainable cattle farming models (Darnhofer et al., 2012), opening up opportunities for further interdisciplinary research and policy development to address socio-ecological and economic challenges.

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Proposals to recover agricultural activity in Mexico City

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Keywords: Agrosystems, public policy, nutrition, land use

Introduction

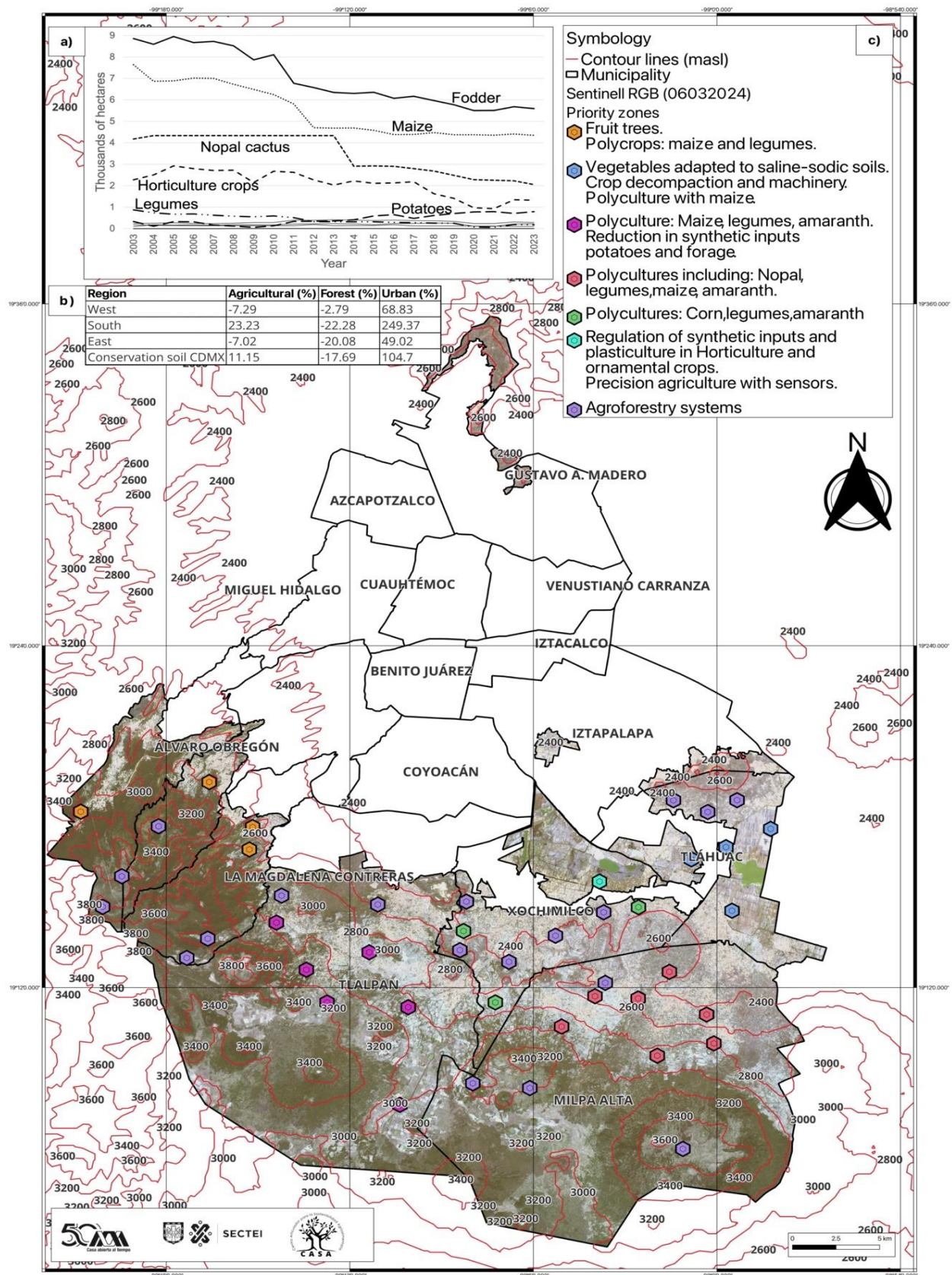
Agriculture's importance in urban and peri-urban areas is recognized for providing food by shortening supply chains and as an ecosystem service provider, being a key factor for sustainability. (Almeida et al., 2024). In Mexico City (CDMX), there's peri-urban agriculture in a legally protected territory named conservation soil, representing 59% of the territory (Castelán, et al., 2016). Population in agricultural activities is 16000 people in 11000 production units. (INEGI, 2020). CDMX's agrosystems are mostly managed by small producers who sometimes, seeking for better income, abandon their fields, contributing to land use change (GCDMX, 2020). Agriculture in this territory has been practiced since 1500 BC. During the late Aztec period (1325-1521) irrigation networks enabled the development of "chinampas," a sustainable agriculture pillar, alongside the "milpa" system, which combines maize, beans, squash, and other crops to maximize efficiency and conserve genetic resources (UNAM-DGCS, 2023). The objective of this research was to characterize agricultural production in CDMX, estimating potential provision of food and nutrients, and to propose public policy guidelines in pursuit of developing a systemic and integrative vision of the territory.

Methods

Dynamics for 72 agricultural products were analyzed using data from Mexico's official agricultural information system (SIAP, 2023), considering surface (ha) and volume (ton), grouped in 10 classes: horticulture crops, fruit trees, fodder, ornamentals, legumes, maize, potatoes, nopal cactus, amaranth, and fungi. Land use (2018-2024) was determined considering five classes: agriculture, forestry, urban, grassland and water, using 10-meter resolution pixel images from Sentinel-2 satellite. A supervised classification was made using QGIS Dzetsaka model (QGIS, 2025). To determine nutritional apport, production from 2023 (agriculture and livestock) was considered (SIAP, 2023) for 14 essential nutrients (López-Ridaura et al., 2021), and population was defined with National census data (INEGI, 2020). Three productive regions were determined, according to agricultural production type, edaphoclimatic characteristics, management and vulnerability.

Results

From 2003 (24655.9 ha) to 2023 (14876.7 ha), sown surface in agricultural land use decreased by 39.66%. Municipalities with largest agricultural surfaces (Milpa Alta, Tlalpan, and Tláhuac) reduced their planted surface by 39.78%, 30.89%, and 62.62% respectively, whereas Xochimilco, where most ornamentals are produced, maintained stability. Ornamental plants (229%) and potatoes (199%) have surface increment; fodder (63%), maize (57%), nopal cactus (47%), horticulture (58%) and legumes (80%) have decreased (Fig. 1a). Of the conservation soil, 45% is agricultural (7 of 16 municipalities). Satellite images allowed to determine an increase in urban land from 4121.85 ha to 8437.81 ha (104.7%), and in agricultural land from 35296.20 ha to 39232.71 ha (11.89%). Forest land decreased from 46633.65 ha to 38381.19 ha (-17.69%) (Fig 1b).



In 2023, five products provided at least 5% of the population's needs for two or more nutrients: nopal cactus (13), milk (10), potato (8), maize (7) and pork (4). Total production apportioned more than 10% in vitamin C (44.3%), calcium (16.03%), iron (14.75%) and vitamin A (12.13%). CDMX features diverse agrosystems. Mountainous areas (2600-3900 masl) have seasonal agricultural practices. West (Álvaro Obregón, Cuajimalpa and La Magdalena Contreras), grow mostly fruit trees and maize, often as monocultures. South (Milpa Alta and Tlalpan) is dominated by forage, nopal cactus and maize cultivation. East (Xochimilco and Tláhuac) is the lake zone (2200-2250 masl), characterized by "chinampas", which are intensive agricultural systems primarily growing horticulture, ornamentals, and maize, either alone or mixed with other crops.

Discussion and perspectives

According to the image analysis, a linear trend of change in land use from forestry to agricultural, and from agricultural to urban is observed, which, linked to migration of farmers to the city, is reflected in a reduction in production that impacts not only in nutrition supply and ecosystem services but also in the loss of agrosystems function as a buffer against ongoing urbanization pressures. Based on the three proposed productive regions, differentiated public policy is proposed (Fig. 1c): (1) West. Improvement of existing agroforestry areas, diversifying fruit tree species, and incorporating forest species. Legumes and horticulture crops should be incorporated into current maize crops to promote polyculture and to strengthen nutritional value. (2) South. Impulse of agroforestry systems and nopal cactus, interspersing planting with horticultural crops, legumes, amaranth and maize to reduce soil erosion and strengthen the amount of nutrients. (3) East. Impulse of horticulture's production and diversity, along with legumes and amaranth to improve nutritional value; ornamental production should avoid use of toxic chemicals. "Chinampa" must remain as the leading productive system, because of its ecological and cultural relevance, and the vulnerability of this region. Change detection in temporal dynamics constitutes a valuable tool for urban planning. Methodological lines contributing to the modeling of urban growth and changes in land use, can build alternatives for sustainable spatial configurations (Humacata, 2022).

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Livestock farm strategies to cope with a hot and arid climate: the case of Qatar

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Keywords: climate change, environmental impacts, dairy cattle, sheep

Introduction

Qatar is a small Gulf country that has experienced a major economic boom since the 2000s thanks to the exploitation of oil and, above all, liquefied gas. Its population has risen from 27,000 in the 1950s to almost 3 million today. Ensuring food security for this population has been declared a national issue because Qatar not only has a harsh climate and poor soils, but is also located in a highly unstable geopolitical area [1]. Fostering local animal production has been an important part of this strategy and as a consequence milk production has been multiplied by 4, red meat and poultry meat by 3 over the last decade [2]. However, whereas the aim of the previous food security policy was simply to increase resilience and prepare for future food crises, the objective today is also to produce while preserving resources and the government no longer wants to "waste" resources to support livestock systems that do not provide sufficient services to society. Several papers have studied the nexus between food, water and energy in Qatar [3] and a shift to regional and organic diets [4] but they have made very rough assumptions on livestock production systems without considering their diversity. The objective of this presentation, is to illustrate this diversity, and to give to insights of their strategies and the services they provide.

Material and method

In this presentation, we shed light on the strategy, productivity and contribution to food security, the environment and culture of structurally contrasting livestock systems in Qatar. The analysis is based on the 2022 Qatar Agricultural Census, the authors' professional experience in Qatar, interviews conducted on two farms and supplemented by published information.

Results

According to the agricultural census, there are 7831 agricultural holdings: 99% belonging to individuals and 1% to companies or government. Two companies dominate the dairy sector. Baladna is one of it. This farm has today 19,000 head of Holstein cattle with around 10,000 lactating cows inseminated with semen from the USA and producing around 12,000L/lactation. To reach this level of productivity, the buildings are cooled down using large fans placed in front of continuously flowing water for more than six months of the year. It is a flagship of Qatari high-tech agriculture. However, it is requiring a lot of water (around 700L/cow/day) which requires energy to pump it and above all to desalinate it (13 kg CO₂e/m³, [5]). The farm has no agricultural land and imports all its feed, mainly from Spain, USA and South Africa. According to our assumptions, this may lead to a carbon footprint around 2 kg CO₂e/Lmilk (without allocation) and blue water foot print of 27 liters of local water / milk. The company has its own plants to process feed, to compost manure and to package milk, yogurt, cheese and juice. Production is regular throughout the year, the products are widely distributed in supermarkets and well known to the general public.

Individual farms generally own a well, have crop production, sheep and goats [6]. They represent 6% of holdings. The farm interviewed have 20 ha with date palms, vegetables and

fodder, 30 ewes, 30 goats, 400 laying hens raised outdoors under a canopy and protected from strong winds. These types of farms have a traditional image, with landscape, recreational and cultural value. Improved fat-tailed ewes produce around 1.5 liters per day when feeding lambs, and between 2 and 3 liters in other cases. There is no milking during the hottest season. The milk is mainly consumed by the extended family, and sometimes sold to the farm restaurant's cheese dairy, which has difficulty in obtaining regular supplies from surrounding farms. To achieve high levels of production per animal, the feed contains a lot of concentrates (1 kg imported wheat and barley bran / day / ewe). Around 800 m³ of irrigation water are used per ton of fodder produced, implying a blue water consumption of almost 1,000 m³/l of milk. Groundwater is becoming increasingly salty, so the farm is investigating solutions such as desalination (costly and polluting), or the use of treated wastewater (requires trucking and storage facilities).

The largest number of farms are compound farms (43%), which are concessions of around 2,500 m² on public land, with no arable area or wells. Finally, roving holdings on public land (23%) are the closest to the historical system, but with an air-conditioned caravan for the foreign shepherd, dependence on feed purchase, and less mobile flocks. Flocks have in average 220 head of sheep and 85 head of goats, but with rather low productivity: 0.7 lambs produced/ewe, 13% of the flock slaughtered or sold [7]. Owners are more interested in livestock than in productivity [6]. The main environmental risk is overgrazing.

Conclusion

The industrial farm could meet Qatar's milk needs, as long as feed could be imported in sufficient quantities and could provide competitive milk with the support of public policy and above all benefit from cheap energy. Small farms have mainly a cultural and landscape values but is facing the challenge of saline and declining underground water. A larger number of farms and more detailed information would make it possible to assess farm performance, but it is difficult to obtain sensitive information, as it is either not collected, or employees do not want to communicate information that could cost them their jobs.

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Comparative analysis of energy and nutrient flows in two agri-food systems in Brittany

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Keywords: circularity, territory, agri-food systems, livestock

Introduction

Livestock regions often have significant nitrogen surpluses. There is therefore an urgent need for an agroecological transition in these regions, which requires a redesign of livestock production systems to reduce their environmental impacts. This study aims to develop an integrated assessment framework at the scale of local agricultural territories, an organisational level that has been little studied, to describe current nitrogen and energy flows. The comparison of territories will help identify region-specific opportunities and constraints to tackle nutrient circularity as well as their footprints and impacts.

Methods

Case studies

Two contrasting agri-food systems (AFS) were studied in Brittany, France, both of which are intensive livestock territories. The Oust à Brocéliande communauté (OBC), encompassing 37,000 ha of agricultural area in Morbihan, is characterized by a livestock density of 3.55 LSU.ha⁻¹, with an equitable distribution between dairy cattle, pork, and poultry. The Pays de Fougères (PdF), which covers an area of 68,000 ha in Ille-et-Vilaine, has a livestock density of 2.65 LSU.ha⁻¹, mostly constituted of dairy cattle and a higher proportion of grasslands.

Modeling structure

Our study is based on the analysis of material flows to characterize nitrogen and energy flows (Harchaoui and Chatzimpiros, 2018; Harder et al., 2021). The AFS is subdivided into three subsystems: (i) agricultural production, (ii) human consumption and (iii) biogas. The agricultural production is further subdivided into four subsystems (Fig. 1): (i) cropland, categorized into 44 crops; (ii) grasslands and annual fodder, divided into 13 categories; (iii) herbivores, comprising cattle, sheep and goats, and (iv) granivores, comprising pork and poultry. Data uses agricultural census data, aggregated nitrogen flow declarations and energy statistics at the intercommunal level for the year 2020. For each system, nitrogen indicators related to productivity, efficiency, surplus, autonomy and circularity were assessed alongside indicators reflecting both direct and indirect energy use, including energy from biogas production.

Results

The productivity and N use efficiency of AFS in OBC surpassed that of the PdF (Table 1), due to a higher livestock density and greater proportion of granivores. However, despite the elevated N use efficiency, OBC experienced a higher N surplus due to its higher N inputs. Over 60% of the N surplus in both territories originated from livestock systems. Our analysis indicates that the dairy systems in PdF improved the AFS's autonomy. Nonetheless, both regions are net negative protein producers due to substantial imports of feed (Fig 1). Energy

use is 30% higher in OBC due to higher feed and fertilizer use. In both AFS, total energy use is 95% dependent on fossil fuels and indirect energy accounts for half. In contrast, the anaerobic digesters account for only 10% of the energy use. Furthermore, the external land requirements for feed are nearly equivalent to the total agricultural area of each system, highlighting the high land footprint associated to feed import. The recycling rates for N in both territories are around 50%, indicating potential for enhancing internal recycling.

Dimension	Indicator	Unit	OBC	PdF
Productivity	Net productivity	kgN.ha ⁻¹	115	93
	% animal products in net production	%	79	77
Efficiency	NUE	%	47	42
Environment	N surplus	kgN.ha ⁻¹	131	128
Autonomy	N autonomy	%	16	24
	Land requirements for feed imports	'000 ha	107	148
Circularity	% manure converted to biogas	%	9,1	9,3
	Recycling rate	%	56	51
Energy	Total energy use	GJ.ha ⁻¹	18,3	14,2
	direct energy use	%	53	54
	indirect energy use	GJ.ha ⁻¹	47	46
	Energy produced by biogas plants	GJ.ha ⁻¹	3,4	3,1

Table 1. Comparative analysis of agri-food systems metabolism across two case studies

Discussion

Our method allows describing N and energy flows of small territories, which is original. It reveals that both territories present total N inputs around 200 kgN.ha⁻¹, comparable to other European livestock-intensive regions like Flanders and the Cleves district (Papangelou and Mathijs, 2021, van der Wiel et al., 2021). However, their N use efficiency and productivity were notably lower due to an even greater specialization in livestock production compared to our case studies. Metabolism analysis indicates that a systemic transition is necessary to bring AFS within N planetary boundaries (around 55kgN.ha⁻¹). To do so, they could adapt livestock production to locally available resources and limit the dependency to imported feed and fertilizer.

High N surplus underscores the necessity of reducing livestock numbers, while current energy policies promoting biogas continue to rely on livestock manure as feedstock. Enhancing circularity may lead to an increase in livestock reared indoors to increase manure recovery. However, animal welfare considerations advocate for outdoor grazing. Our next steps are to quantify these boundaries of antagonisms.

Perspectives

This metabolic assessment framework facilitates the exploration of multiple scenarios, highlighting the synergies and trade-offs between feed, food, territorial, and energy autonomy within the AFS. As it uses public data, the methodology can be adapted to other territories. However, conducting a sensitivity and uncertainty analysis would ensure robustness and reliability of the results. Our next steps involve using this framework to design scenarios with local stakeholders of both territories.

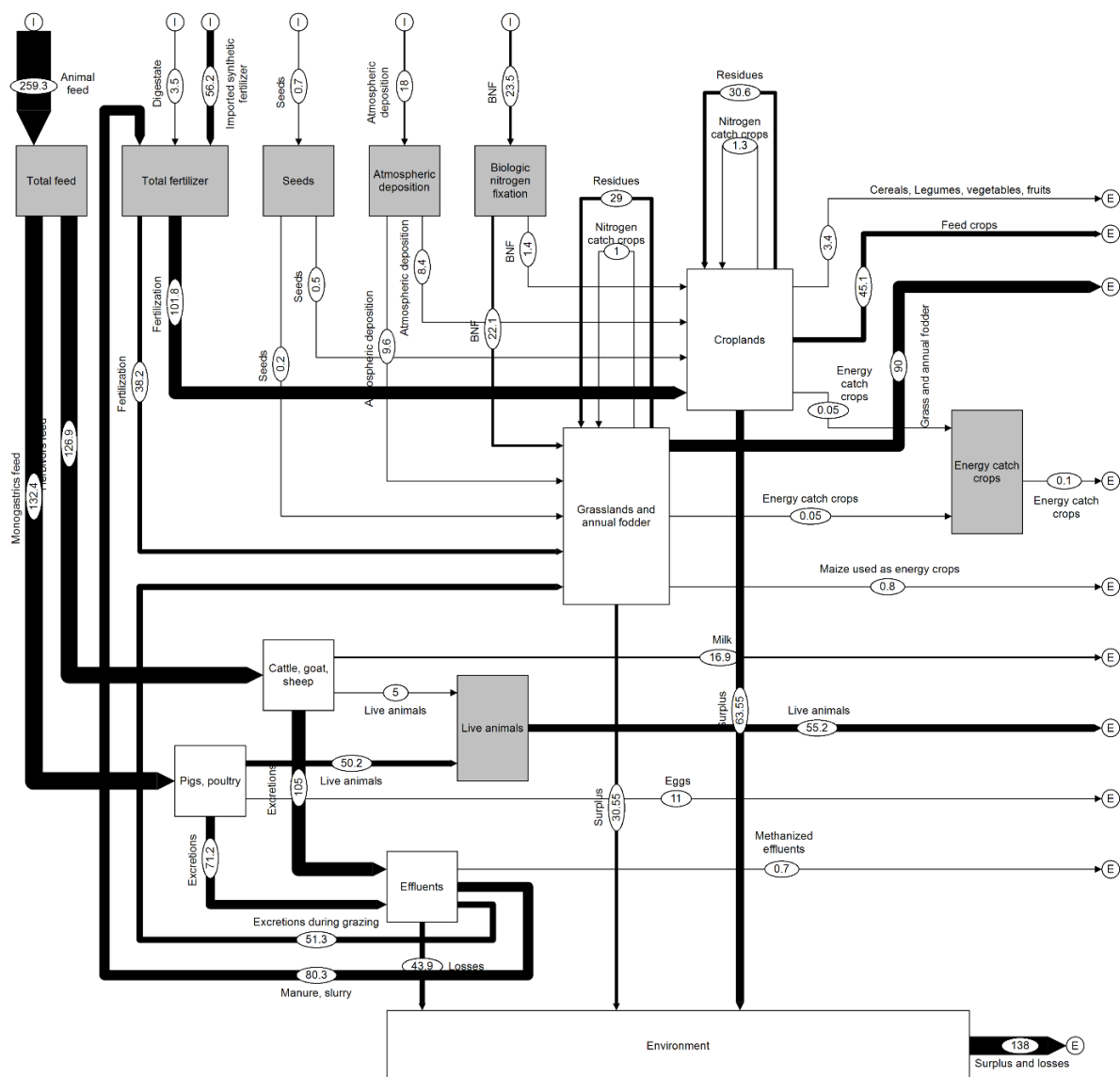


Figure 1. Nutrient metabolism in the OBC agricultural production system.

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Trade-offs between farm profitability and GHG emissions

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Keywords: GHGs, economics, trade-offs, benchmarking, livestock, innovations

Introduction

The livestock industry is considered a key contributor to climate change, leading to calls for a move towards more plant-based diets (Takacs et al., 2022). Meanwhile, innovative livestock farming practices can have substantially lower greenhouse gas (GHG) emissions and provide economic benefits, when compared to conventional approaches (Bonnin et al., 2021; Morgan-Davies, 2021). Different innovations can have environmental and economic trade-offs, in accordance with livestock (e.g. beef, dairy and pig) or innovation type (Morgan-Davies, et al., 2021; Norton et al., 2022). It is important to assess the economic and GHG trade-offs of innovative livestock farming systems to understand what role specific innovations could play in a transition to a more sustainable food sector (Funes-Monzote et al., 2009a). The present study assessed different dairy, beef and pig farming case studies characterised by their innovations in feeding, breeding and management, examining their profitability and GHG impact and benchmarking this against averages for the farm type.

Material and methods

Sixty-five farms were assessed across eight case studies, with each case study including between five and fifteen farms. Specific dairy innovations included 100% grass-fed cows in Switzerland (CHdairy100grass), milking automation and ear tag-based animal monitoring in Italy (ITdairyautomonitor), measuring cattle for individual GHG methane mitigation in the Netherlands (NLdairyCH₄monitor), and cross breeding dairy cattle in Sweden (SEdairycross). The beef innovation was 100% pasture-fed production in the UK (UKbeef100grass). There was also an innovation integrating beef production into dairy herds in Switzerland (CHcoupled). The pig innovations involved the substitution of soya with local legumes, in Poland (PLpigLeg). There was also a Danish case study which involved agroforestry in pig and dairy pastoral systems (DKAgrofor).

A total of 65 farms across eight case studies were assessed, using an adapted version of the Public Goods tool, namely the Re-Livestock tool (https://mvarc.eu/tools/dev/re-livestock_tool/), a tool which assesses sustainability at farm level (Smith et al., 2024). Economic data included annual income and costs for a representative year between 2018 and 2024, which was used to calculate the net income of each farm. The average net farm income of the case study was compared to the average net farm income for that livestock type in the country, using data from the Farm Accountancy Data Network (FADN) as well as Agroscope-derived data for

Switzerland. This data was used to assess profitability against national benchmarks. Inputs gained from the Re-Livestock tool were used to assess the GHGs with AgreCalc, a Life Cycle Assessment based tool for carbon footprint evaluations of farming systems. The average kg of CO₂ equivalent was determined per kg of product (milk, beef, and pork) and per hectare for each case study. GHG impacts were then compared across the case studies.

Results

Results show that CHdairy100grass, ITdairyautomonitor, SEdairycross, UKbeef100grass, DKAgrofor, and PLpigLeg outperformed national profitability benchmarks. In particular, UKbeef100grass achieved a net farm income over eight times greater than national averages, primarily due to low input costs.

For GHG emissions, CHdairy100grass, NLdairyCH₄monitor, SEdairycross, CHcoupled, and PLpigLeg had GHGs lower than the national benchmarks per kg of product. Most notably CHcoupled (17 kgCO₂eq/kg meat deadweight) had around 35% lower GHGs for beef than the AgreCalc-based industry benchmark, due to decreased feed and enteric methane emissions. Additionally, NLdairyCH₄monitor had 25% lower emissions (0.86kgCO₂eq/kg milk) than the benchmark for dairy. Similarly, PLpigLeg (3.2kgCO₂eq/kg meat deadweight) had around 25% lower GHGs than the benchmark for pig farming, due to low feed emissions. When considering GHGs per hectare, CHdairy100grass, SEdairycross, ITdairyautomonitor, UKbeef100grass, DKAgrofor, and PLpigLeg all had lower GHGs than the benchmark, with PLpigLeg having around 99% lower GHGs per hectare than the sector average.

Three case studies showed both increased profitability and reduced GHGs compared to benchmarks (CHdairy100grass, SEdairycross, and PLpigLeg). Moreover, correlations between GHGs and profitability identified a negative relationship between profitability and GHGs for UKbeef100grass (i.e. profitability increasing with decreased GHGs), while the reverse relationship was observed for PLpigLeg.

Discussion and perspectives

Building on existing literature that examines learning from innovation within socioeconomic and sociotechnical niches in the agri-food sector (e.g., Norton et al., 2022), this study highlights the potential benefits of livestock innovations. While three case studies had both reduced GHGs and increased profitability, in reality no single system excels across all dimensions of sustainability. A holistic perspective is therefore essential when evaluating the merits and transformative potential of different innovations and there would be a benefit in expanding this research to include a wider multi-criteria analysis of the environmental impacts and services provided by the systems, based on the Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines (El Hage, 2012).

Specifically, this study illustrates that innovations in livestock farming can simultaneously enhance profitability and reduce greenhouse gas (GHG) emissions, aligning with previous research (Morgan-Davies, 2021; Bonnin et al., 2021). However, the findings are based on a relatively small sample size (65 farms), with data collected across multiple countries that encompass diverse socio-economic conditions and agro-climatic zones. To address these limitations, future research could either focus on assessing innovations within a single country, using larger sample sizes, or could group farms based on key characteristics through the positive deviant approach (Ulukan et al., 2022), or heatmap-based clustering (Norton et al., 2022). This approach would help reduce uncertainties related to farm- and region-specific factors, providing a clearer understanding of how different innovations perform in distinct contexts.

Our findings can have important implications for policymakers, offering insights into the role that specific innovations could play in promoting sustainability within the livestock sector. By identifying innovations with the potential to deliver environmental, social, and economic benefits, this study can help inform strategies aimed at fostering a more sustainable agricultural system.

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Multicriteria assessment of cropping systems performances in Madagascar highlands reveals trade-offs between agroecology principles

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Keywords: sustainability, fertilization, smallholder farmers, labor demand

Introduction

To address the challenges faced by farmers, including population growth, food insecurity, low-income, land and natural resources pressure (Blanchart et al., 2021; Di Roberto, 2021), different stakeholders (public authorities, non-governmental organizations) propose various solutions ranging from conventional intensification to diversified systems relying on agroecological principles for soil fertility. In practice, the systems implemented by farmers combine both approaches. While numerous sustainability assessment frameworks exist, most rely on a generic panel of indicators. Yet, the context of family farming in Madagascar's highlands calls for tailored criteria to inform farmers and decision-makers about the strengths and limitations of agroecological practices. Here we suggest a set of 11 indicators considered relevant for assessing the sustainability of these cropping systems, essentially focused on subsistence. These indicators aim to assess the relevance of cropping systems in terms of food production, maintenance of soil fertility, connection with livestock systems, profitability, and labor productivity. They were selected to evaluate sustainability aspects at the field level, while also addressing issues from a systemic perspective: at farm (fodder availability, labor) and territory levels (biomass use). We have applied these indicators to two contrasting systems: rice monocropping and rotation of rice-fish farming and potato, with different fertilization methods.

Methods

The study was conducted in the Vakinankaratra region of Madagascar's highlands. We used farm surveys data from "TPP Agroecological Viability" and "DINAAMICC" projects. Databases included information about cropping systems (inputs, costs, cropping calendars) and labor requirements for every cropping system activity. Sustainability was evaluated using 11 indicators based on the three pillars of sustainability (economic, environmental, and social), categorized as follows:

- Economic: Fodder independence (Fodd_Indep), fodder unit produced (FU_pr), labor productivity (LabProd), gross margin (GM). Fodd_Indep and FU_pr reflect the reliance to external input and additional forage purchase.
- Environmental: carbon input (C_in), biomass use minimization (Biom_min), Nitrogen (N), Phosphorus (P) and Potassium (K) balances (N_bal, P_bal, K_bal). Biom_min represents the amount of biomass required for organic fertilizers.
- Social: Energetic value (Energ) representing the system's contribution to food security through calorie supply, and Workload minimization (WL_min) corresponding to the labor required for the system implementation.

In this communication, we apply this set of indicators to two contrasting systems: rice monocropping with 4 fertilization methods (mineral fertilizer only (MF), organic fertilizer only (OF), mix of organic and mineral fertilizer (OF+MF); and no fertilizer (NF)) and a rotation of potato and rice-fish farming (Rice-fish/Potato) with the same four fertilizations.

Cropping systems	Fertilization management			
	MF	OF	OF+MF	NF
Rice monocropping	64	42	35	36
Rice-fish / Potato	10	10	18	21

Table 1. Number of plots used in the calculation for each cropping system and fertilization management

The calculations for each indicator were performed for one year, considering both seasons (rainy and dry), i.e. for crop rotations, calculations included two crops (rice and the crop previous rice). For all indicators, no chemical analysis was implemented in the laboratory. Reference values for nutrient contents and fodder units were acquired from literature and applied to the agronomic data to estimate nutrient balance, fodder unit produced, and fodder independence.

Results

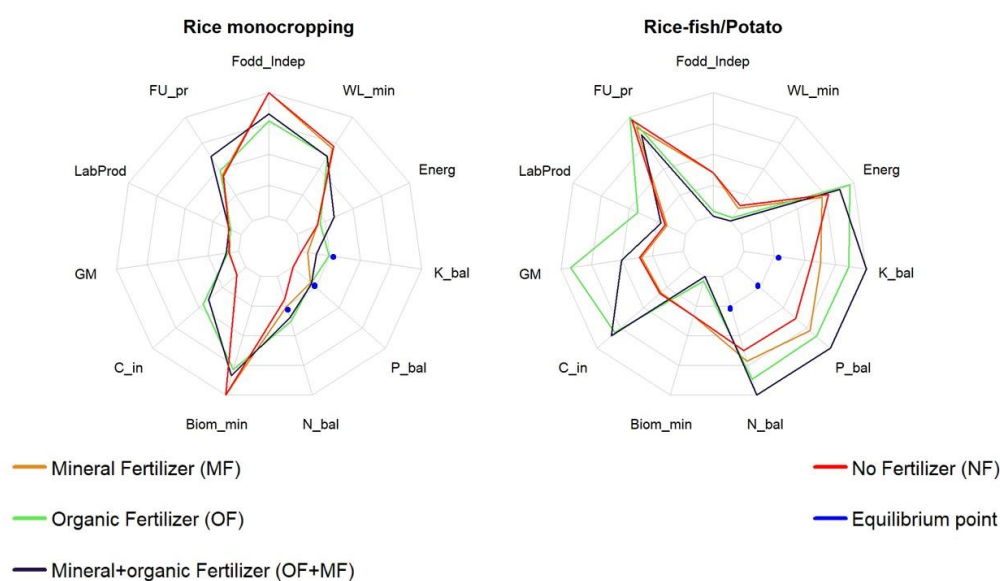


Figure 1. Performances of Rice monocropping and Rice-fish/Potato and fertilization methods according to the 11 indicators. Equilibrium points for nutrient balances represent zero value.

Figure 1 shows that Rice-fish/Potato has higher fodder unit produced, carbon input, nutrient balance, and energetic value, especially in OF+MF and OF; but requires more workforce than in monocropping. In rice monocropping, we observed lower labor productivity, gross margin, negative nutrient balance and lower carbon input, but requiring less workforce. Systems using more organic fertilizers have less fodder independence (cropping systems under OF and OF+MF) and logically require more biomass (low biomass minimization). Regarding fertilization strategies, we observe that even in non-fertilized rice fields (NF), there is a positive

nutrient balance, as the field benefits from the fertilizers used in potato cultivation, and the fertilizers used in potato cultivation were considered in the calculation.

Discussion

The trade-offs between indicators highlight the difficulty of identifying the "optimal" cropping system. Our study suggests that farmers' strategies are context-driven and do not necessarily follow a single solution (conventional or agroecological). In terms of fertilization management, surprisingly, solutions based on organic fertilization do not greatly increase the workload. Organic fertilizers seem to be an interesting prospect for farmers. However, their production requires the maintenance of a cattle herd and/or access to collectible biomass. The evaluation of cropping systems on the field scale already shows these trade-offs in terms of constraints and performances, but it does not allow a complete diagnosis of the systems' feasibility on a larger scale, given the constraints of competition for farm scale (cash flow, labor) and landscape scale (biomass). Farm scale assessment would allow better assessing farm performance sustainability for some components that could be overestimated at the field scale (Lairez et al., 2023).

Perspectives

Farming systems sustainability can hardly be assessed based on field scale evaluation, as there are many trade-offs and synergies between sustainability components emerging at farm scale. Based on this diagnosis of cropping systems, a farm model will be mobilized to evaluate the feasibility of these cropping systems at farm scale, i.e. taking into account resource availability at the household level. In addition to this contextualization of cropping systems, the modeling process will allow exploring different scenarios of agroecological innovation at farm scale.

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A new framework for agroecological energy assessment: demonstration on 34 French agroecosystems

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Keywords: ecosystem services, energy return on investment (EROI), replacement cost method, natural capital dynamics

Introduction

Developing a bioeconomy is increasingly advocated to mitigate the impacts of fossil energy consumption on climate change. However, the dependency of modern intensive agriculture on industrial inputs compromises its energy efficiency in providing biomass to meet material and energy needs (Harchaoui & Chatzimpiros, 2018) and is directly involved in exceeding several planetary boundaries. Switching to agroecological agriculture models relying on ecosystem services (ES) that support biomass production rather than industrial inputs would reduce dependency on fossil energies and improve the input efficiency of biomass production. Energy assessment is required when designing agroecological systems aimed at producing biomass for energy production (Arodudu et al., 2017). Energy assessment of these systems requires covering not only the energy footprint and its energy performance but also the role of ES in supporting biomass production. The latter has been carried out through economic valuation (Tibi & Therond, 2024), production function approach (Grammatikopoulou et al., 2024) and emergy method (Perez-Soba et al., 2019) but, to our knowledge, not through an energy assessment. In this study, we present an original conceptual and methodological framework to assess the sustainability of agroecosystems, at the farm gate, from an energy point of view.

Conceptual and methodological frameworks

First, energy flows were represented within the boundaries of the agroecosystem, including the production system using inputs and producing outputs, as well as an agroecological dimension captured by the natural capital, which provides ES (Figure 1). External inputs (EI) consumption is accounted for using the cumulative energy demand indicator from the LCA framework (Hercher-Pasteur et al., 2020), which considers the production, storage, and transportation processes. The energy embodied in ES was assessed using an energy replacement cost method. Each ES was associated with a mechanical operation and/or EI that would be used as a substitute in the absence of that ES. The cumulative energy demand of the fossil-based replacement was considered the energy-equivalent weight of the ES. The total energy flow attributed to ES corresponds to the sum of the energy equivalents of the eight ES considered. Output production was accounted for its energy content. Last, natural capital dynamics were assessed according to Dardonville et al. (2022).

Five indicators were derived from these calculations and selected to assess the energy footprint, energy performance and the role of ES in supporting biomass production:

(i) the EI consumption, i.e., the absolute fossil resources consumed to value the energy footprint of external inputs; (ii) the energy return on investment (EROI), i.e., the energy produced per unit of EI, to assess the energy performance; (iii) the agroecology degree, i.e., the ratio between the energy of ES and EI, to account for the role of ES; (iv) the relative yield performance, i.e., output performance compared to mean yields of NUTS 3 regions to provide more insights on output performance and, (v) the natural capital dynamics to account for medium-term impacts of agroecosystem on the potential ES levels.

The expressiveness of the approach is tested on a case study consisting of 34 contrasted agroecosystems identified within 28 French farms in the Grand Est region (NUTS2) of France. Data are provided by farmer surveys from Dardonville et al. (2022) from 2019.

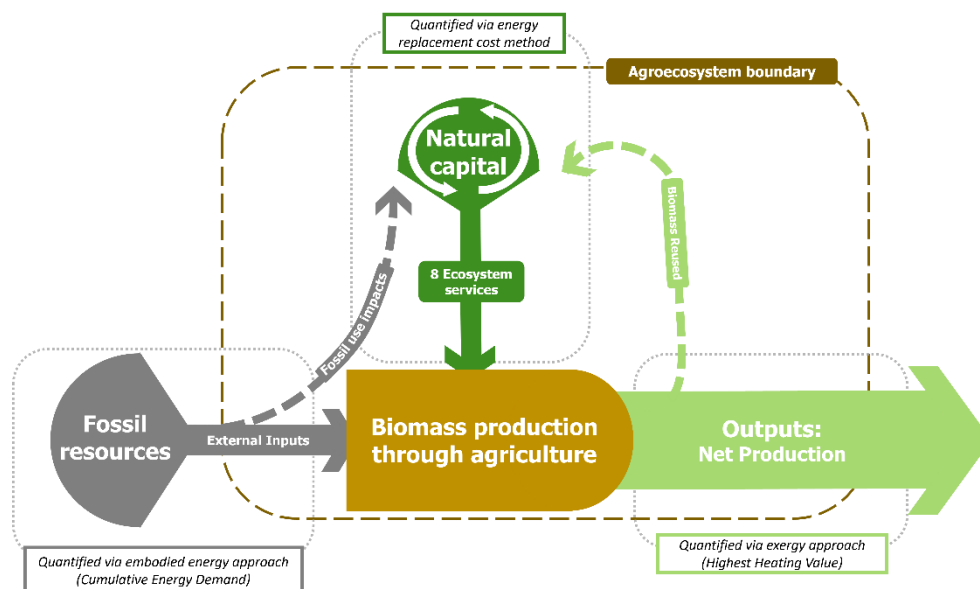


Figure 6: Schematic representation of energy flows within the agroecosystem boundaries, and their method of quantification.

Results

The calculation of the five indicators for the 34 agroecosystems in the case study revealed that the three organic ones (agroecosystems #2, #15, and #28) had the highest energy return on investment and agroecological degree but with a low relative yield performance (Figure 2). Meanwhile, other agroecosystems have overall comparable energy efficiency, low to very low agroecological degree, but varying dynamics concerning natural capital. For these conventional and intensive agroecosystems, energy footprint, based on EI consumption, increases in correlation with output.

Discussion and perspectives

Our energy assessment framework, through an original set of indicators, highlights the role of ES in biomass production in terms of energy footprint and efficiency, as well as the interplay between external inputs and ES in agroecosystems. Our results clearly show that nutrient-supplying ES should be prioritized to improve energy efficiency, for example through the integration of legume-based leys in rotations. Nevertheless, due to the design of the replacement cost method, biological regulation ES are associated with a very low energy replacement cost, which is largely disconnected from their actual ecological importance. This is verified by the comparison with the results of Dardonville et al. (2022), which show that high average ES level does not necessarily correspond to a high ES energy flow. This confirms that the sustainability of agroecosystems should not be assessed solely from an energy point of view, but should also integrate other dimensions of sustainability. In this perspective, our methodological framework will be integrated into the MAELIA multi-agent platform (Misslin et al., 2022) to perform energy, sustainability and resilience assessments of territorial bioeconomy systems.

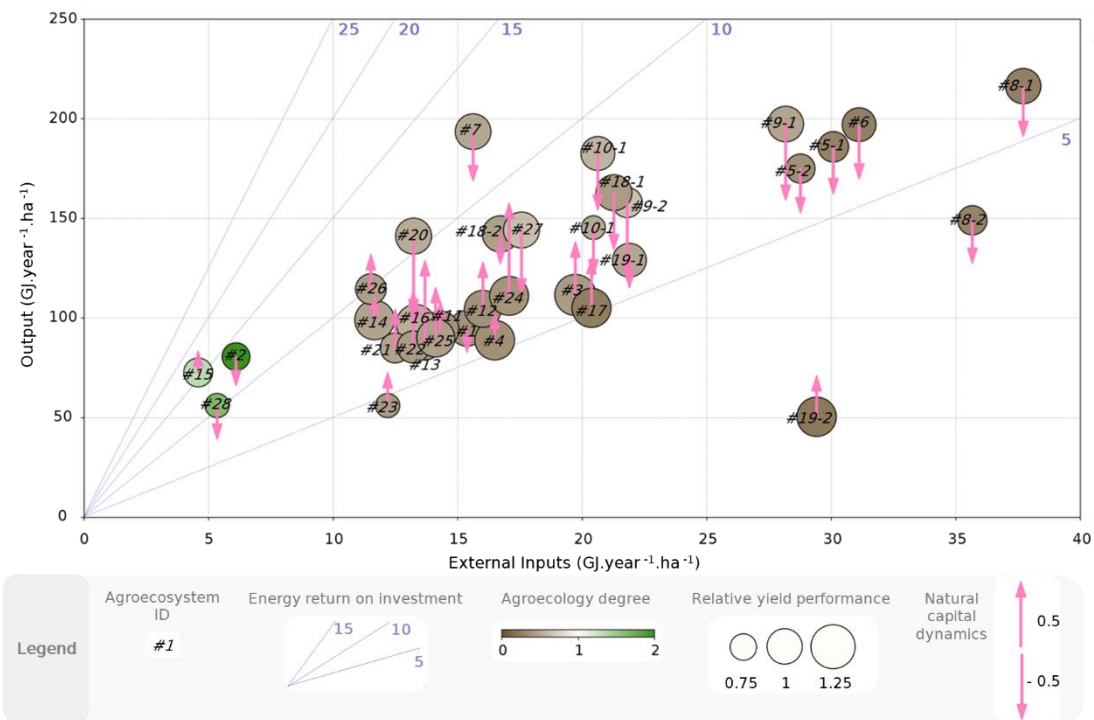


Figure 2: Graphical representation of energy and agroecological performance indicators for 34 agroecosystems in France's Grand Est region (NUTS2).

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Co-created multi-criteria assessment framework to evaluate the potential of agroecological initiatives in Europe

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Keywords: Multi-criteria, agroecology, evaluation, Europe

Introduction

Agroecological on-farm experimentation is increasingly occurring within contexts emphasizing co-developed, participant-centered experimentation. The mainstreaming of this approach has opened two research lines: (1) the development of analytical frameworks suited to the evaluation of different agroecological innovations in diverse farming systems and contexts and (2) the assessment of whether the operationalization of such frameworks can deliver actionable insights of support to local transition processes. While several frameworks for the on-farm evaluation of agroecology have been developed in recent years, they rarely explicitly address the second research line. Furthermore, their application within European agroecological farming systems remains limited, raising questions about existing indicators' relevance. This research aimed to address these knowledge gaps by co-developing and operationalizing a novel multi-criteria assessment framework to (1) demonstrate the potential of agroecological farming system at farm and field scales within European initiatives and (2) assess their contributions to local transitions.

Methods

The framework was co-developed by researchers and facilitators of 11 initiatives called Innovation Hubs (IHs) and engaged in Agroecology-TRANSECT through in-person workshops and follow-up meetings (2023-2025). These IHs are spread throughout Europe and represent a diversity of farming systems, agroecological practices and co-innovation arrangements. The co-development addressed the definition of the framework's objectives, evaluation criteria and principles, and indicators and metrics (both core and optional, i.e., IH-specific). Initially implemented in three IHs in Belgium, Guadeloupe and Spain, it is currently extended to all others (2024-2025) and the operationalization is foreseen to continue until the end of the project in 2026.

Results

We present results from the co-development and operationalization of the framework. 9 evaluation criteria were co-defined based on an inductive analysis of workshops' outputs and criteria selection processes of 13 existing tools, including TAPE (Mottet et al., 2020), OASIS (Škorjanc et al., 2021) and Memento GTAE (Levrard et al., 2019): *planned and associated agrobiodiversity, climate adaptation and mitigation, economic resilience, agroecological knowledge, participation in networks, job satisfaction and creation and animal health*. They are evaluated through 45 core indicators monitored in all IHs, complemented by additional specific indicators. These indicators were co-developed with IHs' facilitators based on the framework's objectives, a review of established indicators in existing tools (mostly from OASIS (Škorjanc et al., 2021)). In the final framework, data collection involved farm surveys and field monitoring. The assessment addresses specific practices and farming systems in each IH. The framework also enables field-level comparisons through intervention vs. control (absence of a practice or contrasting levels of integration of a practice) or a space-for-time substitution approach.

We will present individual results for each farm and IH, as well as a transversal analysis of core indicators in all IH, and preliminary insights from the participatory interpretation and dissemination of results. Based on the results from the pilot testing in 3 IHs, agroecological practices and positive impacts include the implementation of carbon management and climate change adaptation practices, the frequent integration of livestock (81%), extensive approaches to grassland management, fertilization and plant protection, the presence of semi-natural habitats, a significant increase of earthworm biomass in integrated fields and high levels of economic autonomy. However, a low economic and crop diversification was noted, as well as a low integration in local markets.

FARM-LEVEL: CORE AND OPTIONAL INDICATORS

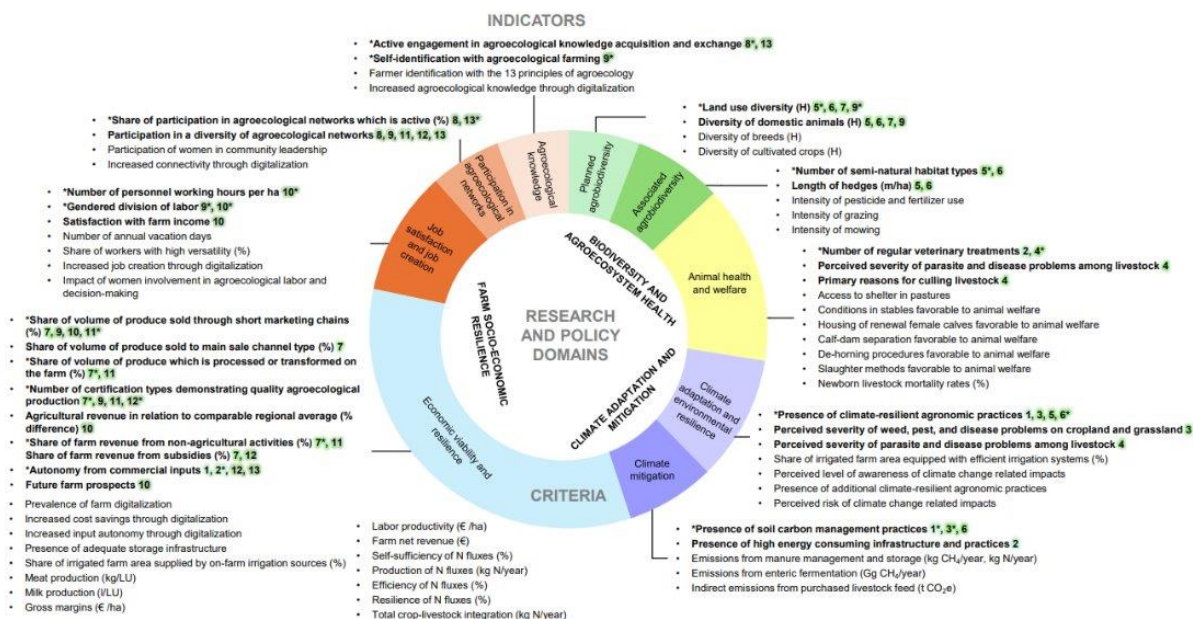


Figure 1. Research and policy domains, evaluation criteria, and indicators assessed through the MCA framework at the farm-level. Indicators listed in bold represent core indicators, while the remaining indicators are optional and applied only in a sub-set of networks. Links between each core indicator and the 13 agroecological principles are illustrated through their respective codes highlighted in green (where 1 = recycling; 2 = input reduction; 3 = soil health; 4 = animal health; 5 = biodiversity; 6 = synergy; 7 = economic diversification; 8 = co-creation of knowledge; 9 = social values and diets; 10 = fairness; 11 = connectivity; 12 = land and natural resource governance; 13 = participation). Starred indicators (*) represent the practice-based indicators which characterize farm-level adherence to each agroecological principle.

Discussion and perspectives

Co-created tools and frameworks are essential to provide standardized, comparable evidence on agroecological farming systems' performance. They can guide policymakers and stakeholders while supporting agroecological initiatives and practitioners in transition processes and decision-making. The framework aims to meet both objectives. Thanks to its co-development approach and specific indicators, it is tailored to the context and objectives of each IH, thereby strengthening the possibility of providing actionable results for farmers and IHs' actors to support their agroecological transition. Furthermore, activities to share the results with farmers and other relevant stakeholders are planned and encouraged. The use of core indicators common to all IHs and control plots for field measurements are open doors for a transversal analysis that could contribute to the second objective provided that the analysis allows us to overcome the differences in context and implementation of the framework between the IHs. As the operationalization of the framework is still ongoing, further analysis will allow

to deepen the results and bring insights on both transversal and specific performances of the implemented agroecological practices and systems.

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A new indicator framework for multicriteria assessment of co-designed agroecological crop rotations

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Keywords: multicriteria assessment, cause-effect chain, INDIC database framework, cross-analysis indicator framework

Introduction

To meet the major challenges facing agriculture which involve an increase in agricultural production while preserving natural resources and adapting to new climatic conditions, in-depth rethinking of agricultural systems is urgently required (Wezel et al., 2014). This rethinking hinges in particular on the redesign of crop rotations (i.e., the sequence of crops grown in a more or less regular or long cycle) which need to be more diversified and composed of crops adapted locally in view of climate change. The TRANSFORM project aims at accelerating the innovation of co-designed arable and mixed farming crop rotations, as nature-based solutions to deliver multiple economic, societal and ecosystem service benefits. To support this co-design process, an assessment framework is needed and must include indicators of ecosystem services and environmental impacts induced by a change in crop rotation. The framework must be adaptable for use in different regions to meet local constraints and objectives, and by different stakeholders (e.g., farmers, researchers, public authorities). To our knowledge, there is no already-existing method that meet all these criteria (Lairez et al., 2015). The aim of this work was to propose a list of indicators that is structured to facilitate a judicious selection of indicators to be used for the multicriteria assessment of innovative crop-rotations, integrating ecosystem services and tailored to case-specific constraints and objectives.

Methods

To support the selection of indicators when performing multicriteria assessment of agricultural systems, (Bockstaller et al., 2023b) built the *INDIC database framework*. This database offers an initial structuring according to themes and sub-themes for each dimension of sustainability. We paired this database with a new *cause-effect conceptual framework* (Bockstaller et al., 2023a) which is resumed in six entities relating either to causes, system status and functioning and effects. This framework is based on an integration of previous conceptual works (e.g., Payraudeau and Van Der Werf, 2005) and has the benefit of being more precise and less linear. Our research group was tasked with proposing a first list of indicators to assess crop rotation sustainability. The relevance of the proposed indicators was considered according to its position in the so-created *cross-analysis indicator framework* (Figure 1) with respect to the main purpose of our study (i.e., to focus on environmental impacts and services induced by a change in crop rotation). A revised list of indicators was established and was supplemented, when necessary, with additional indicators to better describe a theme or sub-theme deemed under-represented. The resulted indicator list was divided in two categories: 1) *key-performance indicators*, related to system functioning, properties and impacts that are best able to describe the services and impacts of crop rotations ; and 2) *complementary indicators*,

related to causes that are less precise but easier to calculate and more suitable for communication.

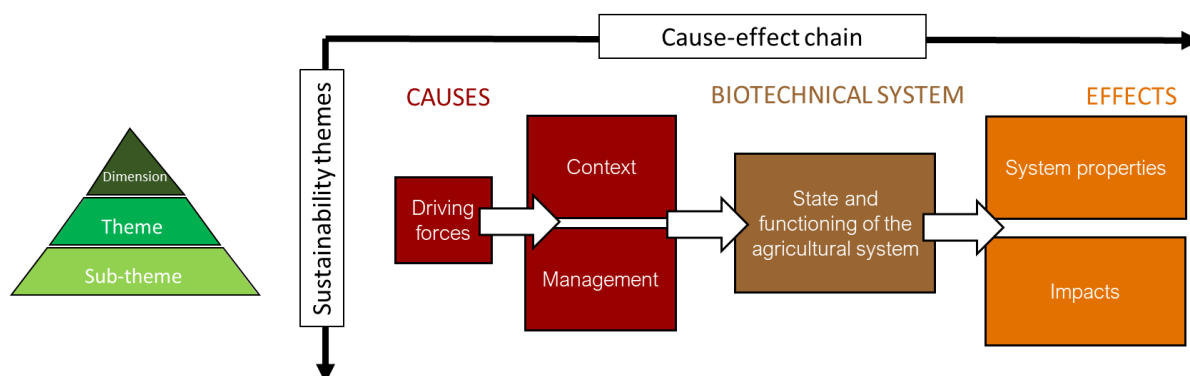


Figure 1. Cross-analysis indicator framework combining INDIC database framework and the cause-effect chain.

Results

The final list consisted of 74 indicators, of which 53 (respectively, 13 and 8) were related to the environmental (resp., economic and social) dimension. We identified 51 indicators as key-performance indicators. Table 1 provides an extract from the final list for the environmental dimension.

Discussion

Multi-criteria sustainability assessments are indispensable tools for redesigning farming systems according to the agroecological transition. These redesigns require restructuring on several scales and the involvement of a variety of stakeholders. To accelerate this transition, tools that can be adapted to different contexts and users are needed. Here we proposed an innovative method based on a cross-indicator analysis framework to help select the most relevant (in view of the study objective) sustainability criteria and related indicators to be included in multicriteria assessments. This framework has the major benefit to include indicators assessing ecosystem services and environmental impacts, which is rarely considered in today's assessment methods. As a proof of concept, we have applied our method to a specific object of study: assessing the sustainability of crop rotations co-designed for the future, as part of a European project involving several case studies. In the final list of indicators, a large part is related to the environmental dimension of sustainability and concerns the cropping-system functioning and impacts. This is in line with the core aim of the project (focusing on crop-rotation benefits) to reduce environmental impacts and increase resilience through increasing ecosystem services) but the economic and social criteria of sustainability might be under-represented. This will be further reviewed and it could also be adjusted at the evaluation step, when weights are assigned to the final criteria.

Perspective

This bi-dimensional framework will be enriched with an *indicator readability tool* to add a third categorization layer according to the optimal use and possibilities for interpretation of each indicator. From the resulted structured indicator list, we will select relevant sets of indicators based on the stakeholders' feedback on their specific needs and requirements. We will propose a set of assessment methods, from indicator dashboard to aggregative methods, designed to be operational for the stakeholders to be implemented.

Theme	Sub-theme	Cause-effect chain	Indicator
Crop management	Plant diversity	Causes	Functional attribute diversity <i>=f(crop functional traits, number of crops)</i>
	Soil cover		% soil cover <i>=f(crop choice, amount of cover-crops)</i>
State and quality of crops	Crop nutrient status		Nitrogen nutrition index <i>=f(yield, N content)</i>
State of soils	Soil state parameters		Soil depth <i>=f(soil and climate local context)</i>
			Clay content <i>=f(soil and climate local context)</i>
Ecosystem services	Soil	State and functioning	Carbon sequestration (I-DRo carbon indicator) <i>=f(crop biomass and distribution in plant, crop pairing)</i>
	Pest regulation		Pest regulation (I-DRo pest indicator) <i>=f(crop associated pests, crop pairing)</i>
	Biodiversity and landscape		Habitat for wildlife (I-DRo habitat indicator) <i>=f(crop associated biodiversity, crop pairing)</i>
Efficiency	Nitrogen efficiency		N efficiency <i>=f(yield, N content in crops, fertilizer applied)</i>
	Water efficiency		Water use efficiency <i>=f(soil water profile, water use for crop, runoff)</i>
Soil	Erosion / runoff	Impacts	Sediment export <i>=f(soil properties, climate, slope, soil cover)</i>
	Physical quality (compaction)		Soil compaction indicator <i>=f(soil degradation/restoration)</i>
	Soil chemical fertility (organic matter)		C balance <i>=f(C input by fertilizer and crop, C losses)</i>
	Soil chemical fertility (P)		P balance <i>=f(yield, P content in crops, fertilizers applied)</i>
Quality of groundwater and surface water	NO ₃ transfers		Cumulative amount of NO ₃ -N leached at the base of the soil profile <i>=f(soil sensitivity to leaching, fertilizers, crops sequence)</i>
	Pesticide transfers and risks		Pesticide risk (I-Phy 3 ground water) <i>=f(pesticide properties, soil sensitivity to leaching)</i>
			Pesticide risk (I-Phy 3 surface water) <i>=f(availability of pesticide, field sensitivity to runoff)</i>

Table 1. An extract from the key-performance-indicators list. For each indicator, a few examples of the factors involved are given.

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Upscaling sustainability indicators: calculation bias due to the use of generic data

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Keywords: multicriteria assessment, upscaling, territory, SYSTERRE software

Introduction

The scale of the plot or the farm is the level most commonly used by agronomists to carry out multicriteria assessments, but agriculture is facing now issues that go beyond those scales and require a territorial approach: adaptation to climate change, management of natural resources, preservation of biodiversity, local food sovereignty, multifunctionality... Assessing the sustainability of systems on the scale of agricultural territories requires tackling upscaling issues (Ewert et al., 2011; Stein et al., 2001). Specifically, this territorial scale raises questions about the acquisition of input data, which is time-consuming when acquired at field level. Generic datasets generated at different scales (Nomenclature of Territorial Units for Statistics (NUTS) level 2 -- regions or 3 - departments) are readily available, containing data on crop rotation, crop management practices, costs of cultivation operations, ... and would simplify the acquisition of data. Nevertheless, using a dataset with generic data may induce bias in assessment model outputs and calculation of indicators (Bechini et al., 2011). This study aims at evaluating the potential bias introduced using generic data on the individual and collective assessment of a group of farms. This is an initial methodological demonstration of the impact of the choice of input data, whether at farm or cropping design system level.

Material and methods

Dataset

The dataset was provided by a dedicated farm survey of a group of 25 farms called the "5 Elements des Sablons", covering around 5,000 ha in the Oise department, North of France. The cropping systems (rotation and crop management data) of the 25 farms, their machineries sales and supply prices, were recorded in the SYSTERRE tool (Toqué et al., 2019) for 3 cropping years, from 2017 to 2020. The crop rotation consists mainly of winter rapeseed, soft wheat and barley, with occasional inclusion of industrial crops (sugar beet and green peas) and maize. SYSTERRE is a multi-criteria assessment tool (technical, economic, environmental and agronomic monitoring aspects) for recording and precisely describing cropping systems and farm characteristics.

Methods

In order to assess the impact of the scaled-up input data, the equipment fleets derived from the survey data were compared with a standard equipment fleet based on expert knowledge. The cost of technical operations was standardised on the basis of the costs set out in the mutual aid scales of the French Chambers of Agriculture. The crop management practices remained unchanged, only the equipment was modified (i.e., equipment settings, work rate, fuel consumption).

Indicators

To estimate the bias related to the use of generic data at the farm scale rather than detailed survey data, two indicators were selected:

- Total greenhouse gas emissions (GHG), in order to assess the impact of a standard equipment fleet on the environmental dimension (upstream greenhouse gas emissions from the equipment fleet and greenhouse gas emissions from fuel). This indicator is calculated by SYSTERRE on the basis of the GESTIM+ v2020 references (Tailleur & Gac et al., 2020).

Equation 1: $\text{GHG Total (kg CO}_2\text{eq/ha)} = \text{GHG Seeds} + \text{GHG pesticides} + \text{GHG fertilizer} + \text{GHG Equipment} + \text{GHG Volatilization} + \text{GHG leaching} + \text{GHG CO}_2 \text{ from CaO} + \text{GHG Crop Residues} + \text{GHG Fuel}$

- net margins, to assess the economic dimension (including variable and fixed costs)

Equation 2: $\text{Net margin (€/ha)} = \text{Direct margin} - (\text{farm rent} + \text{Diverse costs})$

With: $\text{Direct margin (€/ha)} = \text{Gross product} - \text{Operating costs} - (\text{Mechanization costs} + \text{Irrigation mechanization costs} + \text{Salary costs} + \text{Family Agricultural social security} + \text{Other mechanization and labor costs associated with the farm} + \text{Short-term financial expenses})$

Results

Total GHG emissions (Equation 1) calculated using standard equipment data underestimate actual emissions by an average of 1%. This represents a reduction of 33 kgeqCO₂/ha with a maximum underestimate of 88 kgeqCO₂/ha and a maximum overestimate of 17 kgeqCO₂/ha. The correlation between the two sets of data is R² 0.997. Calculation of the net margin (Equation 2) using standard operating costs underestimates the average margin by 14%, i.e., 58 €/ha. The use of standard equipment allows us to simulate the variability of the net margin between farms and between years, with an R² of 0.960.

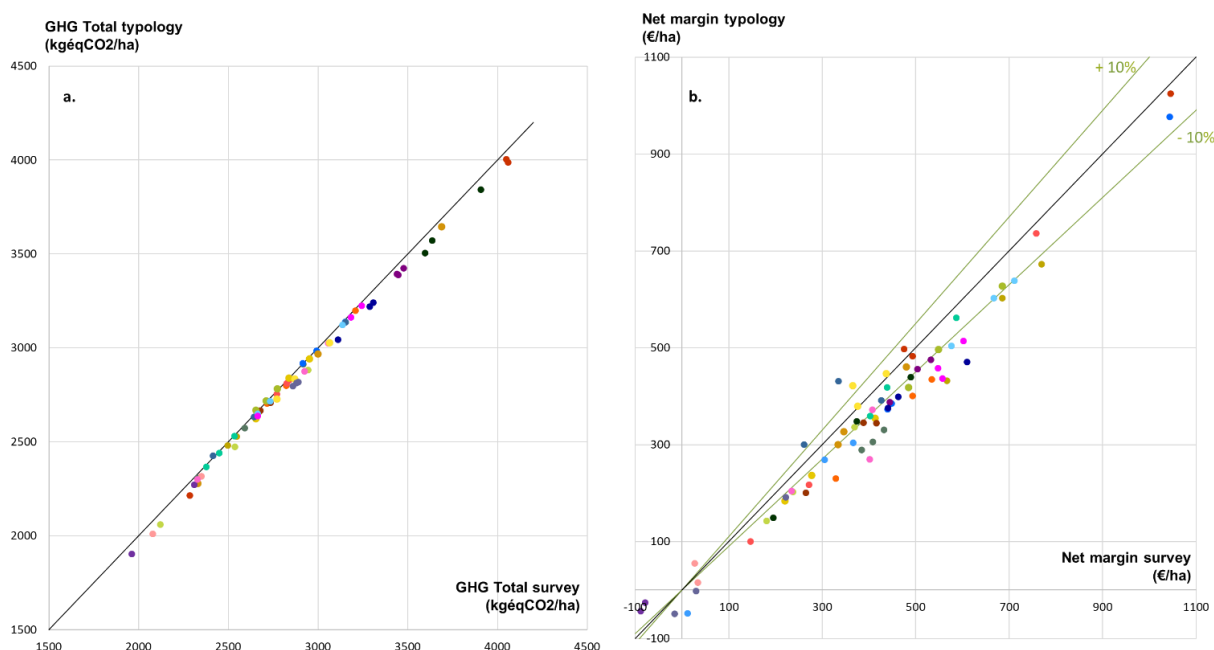


Figure 1. a. Comparison of total greenhouse gas emissions from surveys and standard equipment. One colour per farm. b. Net margin from surveys and standard equipment. One colour per farm.

Discussion / Conclusion

The initial results of the study are encouraging. Standard costs of cultivation operations slightly distort the results at group level and could therefore be used in studies at this level. Nevertheless, it will be important to confirm them on other datasets acquired in a variety of agricultural production contexts.

The next steps will be to compare the performance bias of a standard crop management practices with the survey data and to compare the impact of a "fixed" crop management practices (i.e. date - operation) with a flexible itinerary under constraint formalised in the form of a decision rule (i.e. "if ... then ...") as used by the MAELIA IAM platform (Therond et al., 2014), which will make it possible to simulate other processes (soil-climate, hydrological, meteorological, ...) on a larger scale: further steps towards changing the scale of the study.

Acknowledgements

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Facilitating assessment of the sustainability of cropping systems by understanding use situations

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Keywords: sustainability, multicriteria assessment, cropping system, use situation

Introduction

Models to assess the sustainability of cropping systems have been developed in various agricultural sectors. Among them, MASC (arable crops) and DEXiFruits (fruit crops) are multicriteria assessment tools based on the DEXi qualitative aggregation technology. They can support transitions towards innovative systems, including those reducing pesticide use. They provide a global and systemic view of the impacts of the practices and changes proposed or initiated. Feedback from designers and users highlights that the evaluation results are a resource for discussing priorities and trade-offs, between farmers and advisor or within a peer group, to design (and conduct) an innovative cropping system or systems trials for experimenters. However, many suggestions for enhancing the models and their functionalities were also made, in order to improve evaluation or facilitate their use.

The E-DISC project aimed to improve the DEXi tools by meeting the specific needs of the different types of users of these models. The results of a diagnosis of usage situations (Cerf et al., 2012) were used to design, with users, a web application meeting the main needs expressed. This work and tool are presented here.

Method: from the diagnosis of use situations to identifying the functionalities to be integrated to improve DEXi tools

In order to identify the functionalities to be implemented to improve DEXi tools, we first characterised the diversity of their uses. 21 interviews were conducted with a range of potential users of multicriteria assessment tools. This enabled us to define 'user stories', based on contrasting *personae* and professional contexts, highlighting the different ways of assessing the sustainability of cropping systems in advisory, training and experimentation activities.

On this basis, a workshop was organised with the project partners to draw up a list of the main functionalities to be implemented, leading to a first paper model of a web application. This draft was tested in specific use situations before being coded in the form of a web application.

Results: the web application IZI-Eval and its main functionalities

Outcomes from the diagnosis of use situations

Analysis of the interviews enabled us to construct seven 'user stories' highlighting new needs and user profiles, linked to different professional contexts. For example:

- User support needs to go further than simply supporting the web application and should include tutorials on some of the concepts of multicriteria assessment. It has led to a complete overhaul of the section of the MEANS website dedicated to DEXi models and to a benchmark for the creation of a community for these sustainability models.
- A new user profile, situated between users and DEXi model designers, has been identified, which adapts existing models according to its needs and may require sensitivity analyses to understand the consequences of these modifications.

Following this analysis, the workshop with the project partners led to the listing of the 6 main functionalities (Table 1). Based on these outcomes, we created a first draft on paper of a web application able to provide 4 of the 6 identified functionalities in a simple way: IZI-Eval. The application was developed with *RShiny* and tested with volunteers in and outside the project.

1	A tool for training players/students in evaluation, sustainability and systems approaches
2	A tool that is easy to use, fill in (in conjunction with other tools) and read/interpret
3	A tool with references to help you understand and compare
4	A tool that explains the results, based on the input criteria
5	A tool that adapts to the user's needs and context
6	A tool that unites and communicates, around a community or a label

Table 1. List of the six main functionalities to be integrated to the DEXi tools. (Numbers 1 and 6 were not yet integrated into Izi-Eval).

Finding references for arable crop systems and arboriculture

It is quite easy to find data at both national and regional scales on average performance of farms and/or cropping systems in France, using national statistical services. However, it is much more difficult to quickly find the same references for more local or specific contexts (e.g., what is a "good" gross margin for organic cropping systems with tillage crops only in the Aube French department)? Using this new feature will spare time. Data of the DEPHY Farm network stored in Agrosyst database (both described in Adeux et al., 2022), were used to produce references. Our aim is to update these references and produce new ones with our own calculation of indicators.

Creating auto-reports and synoptic graphs to help interpretation of results

In addition to the complexity of filling in the inputs to the DEXi-based sustainability models, the results of the assessment can be difficult to grasp, despite the existing possibilities in the software. We wanted to provide graphical outputs that can be used as a discussion aid or to highlight the main results to save time. The application allows creating synoptic graphs (Figure 1) to easily see differences between assessments of different cropping systems. Development of automatic reports with the main results is also planned for the near future.

Performing sensitivity analyses

As mentioned earlier, two groups can implement sensitivity analyses designed for DEXi models: designers of a new model, and users that adapt an existing model to their specific use and need to know the consequences of the introduced changes. Moreover, the analysis can have a didactic purpose (e.g. determine model inputs to be filled accurately). To facilitate all these uses, the analyses available on R (package *dexisensitivity* -- Allart et al., 2025) are also in IZI-Eval, for people not accustomed to coding in R.

In addition, other actions have been carried out in E-DISC to ease the multicriteria assessment of the sustainability of cropping systems with a DEXi model:

- improvement of parts of models that were less developed in the initial design (e.g. social sustainability and especially criteria on impact of pesticides on health)
- help users to choose the best suitable indicator to fill in a criterion, among the numerous ones existing (Update of INDIC® database).

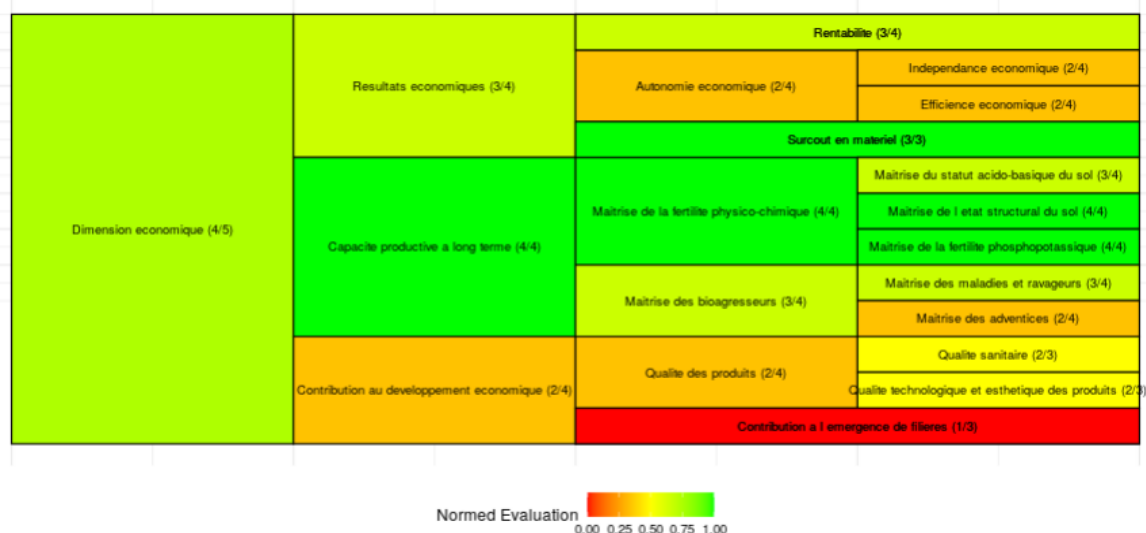


Figure 1. Example of a synoptic table created with IZI-Eval on the economic dimension of sustainability (MASC model). Criteria on the right side are those filled by users, and the one in the left side is the most aggregated. They are coloured from red (worst possible performance) to green (the best performance).

Discussion

The diagnosis of use situation and the following workshop has helped the project partners to take a step back from the models themselves and focus more on their use in different professional contexts. There are remaining difficulties and questions that need to be addressed in the future. Some functionalities need improvement or even development (creation of automatic reports, integration of all stages in the same application -- from filling the model to analysing the results).

Moreover, testing of the prototype with end-users of IZI-Eval has permitted the identification of improvements:

- for didactic purposes to have examples of assessed cropping systems for each model;
- to create complementary ways to represent assessments made with DEXi models with end-users (to complement synoptic tables, used extensively by farmer advisors).

Finally, the creation of a community of DEXi model users was identified as a plus their activities.

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Experimenting with farmers: understanding perceptions and assessing agro-environmental performance of occitan cereal systems through modelling

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Keywords: Beliefs, Co-conception, Cropping system, Practices changes

Introduction

In the Occitanie region, where 1/3 of the used agricultural area is dedicated to cash crops, several factors affect the sustainability of agroecosystems. In this context, modeling tools may provide a useful interface to support farmers' agroecological adaptation (Blanc et al., 2024). In particular, the impact of cover crops raises questions among farmers. While increasing soil organic matter appears beneficial for both the sustainable management of agricultural soils and the mitigation of GHG emissions, the effects on crop yields, water availability, socio-economic benefits, are still under study (Rumpel et al., 2022). The durable change in farming practices over time implies changing the way farmers perceive their productive environment (Albert et al., 2022). One's perception is anchored in a social environment (Morton et al., 2017), a place in a society framed in institutions (Darré, 1991; Hodgson, 2006), and an historical and personal context which influences his beliefs and values (Peirce, 2000). Multi-criteria assessment based on simulation of farmers' practices can act as a mediating artifact that may trigger a change of beliefs (Sutherland et al., 2012). This change is expected to depend on farmers' initial belief systems since it would drive the extent to which farmers may take ownership of the multi-criteria assessment.

Methods

The model STICS - Simulateur multi-disciplinaire pour les Cultures Standard (Brisson et al., 2003) is used in this research as a means of mediation. STICS assesses the effects of climate, soil and agricultural practices to inform farmers' choices. STICS has been chosen as a generic and robust model allowing calculation of a large and "invisible" range of agro-environmental variables at the crop plot scale, such as component of water, carbon and nitrogen soil budgets, as well as yields. STICS was calibrated and validated in Southwestern France.

A community of 11 farmers who belong to a network of farmers engaged in decreasing soil erosion (Groupement d'Agriculteurs de la Gascogne Toulousaine - GAGT) volunteered for this research. This network of 90 farmers aims to 'Develop a Sustainable, High-Performance Agriculture that respects the environment, while preserving farmer's income'.

The research strategy is to characterize their perception and its potential evolution, through semi-structured interviews and collective workshops to redesign their farming systems. Lab simulations are run on two plots for each farm over past years, to supply multi-criteria assessments of crop plot performance including agro-environmental indicators. Farmers

engage with the multi-criteria assessment during collective workshops that aim to make new practices emerge. The interpretation of these changes will stem from an abductive approach.

Results

Multicriteria assessment

We focus on (1) potential soil organic carbon (COS) storage in different cropping systems (fig.1) in recent years and in scenarios involving agricultural practices such as cover crops that are supposed to modify water storage dynamics and increase COS, (2) GHG balance (N_2O , CO_2) of these cropping systems, (3) identifying limiting agronomic factors and meteorological variability and (4) yield (in quantity and quality).

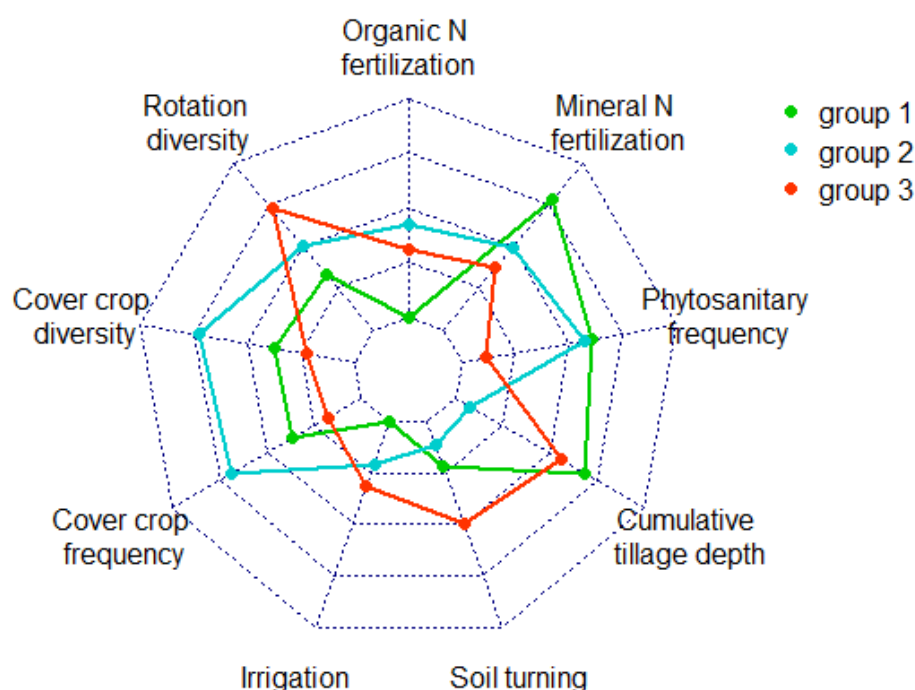


Figure 1. Farmers' plots classification according to 9 determining variables for agri-environmental assessment

Farmers' typology and expectations

The interviews have been conducted before workshops. Collected data allowed characterizing 3 plots groups structured by agricultural practices involved in the multicriteria assessment (fig.1). The interviews show that farmers are interested in understanding processes at work in their plots. Above all, they want to increase soil organic carbon, and soil fertility. They are aware that some factors considered in the assessment might enhance their decision-making, and that engagement with practices might be inspiring.

Discussion and perspectives

The adopted research strategy is expected to improve ways to work and experiment with farmers using modeling, thanks to their reflexive approach on their practices and capacity to change. It is in line with research on the presence of digital technology in agriculture (Schnebelin, 2022), the use of companion models (Hossard et al., 2022), and the use of

simulated data to co-design adaptation strategies (Blanc et al., 2024). The originality is to comprehend farming systems to investigate the interactions between the modelling results, farmers' beliefs and practices at the plot level. This co-research study should lead to the co-production of new knowledge about the benefits, the barriers to the adoption of agroecological practices in occitan context, and to the identification of necessary trade-offs to meet both environmental and socio-economic needs.

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When farmers commit to supporting their organic farming system: how to talk about positive externalities from sustainability diagnosis?

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Keywords: Livestock farming, Multicriteria assessment, Water catchment area, Communication

Introduction

The Saffré area is 5,800 hectares drinking water catchment. The local stakeholders are committed to pesticide-free farming by 2040 to preserve water quality. A research project has been undertaken to contribute to this objective. More detailed background will be given in the communication entitled "toward a pesticide-free territory: how different methods could be combined to achieve this goal?". This work has highlighted not only the local strengths -- a large proportion of grassland areas and farms that are already using organic farming methods -- but also the threats it is facing. Grassland areas are declining in favor of crops that consume more pesticides, and the cyclical downturn in demand for organic products is slowing down farm conversion to organic farming (Ballot et al., 2024, Bellon et al., 2023). In this context, a group of farms has been created by eight breeders, all in organic, livestock farming, breeding dairy or suckler cows.

The aim of the group is to maintain the economic and social viability of organic farms in the Saffré basin to secure the acreage in organic farming, or even to create the necessary conditions for their progress. Atlantic'eau (Territorial water board) and INRAE are both supporting the group toward this aim, through various actions. These actions involve 1) investigation of opportunities to catch more added value, through milk, meat or crop processing and direct sales and 2) communication about organic farming positive externalities to support the demand.

Method

The eight farms varied from 90 to 150 hectares. They all had in common a dominant share of grassland (at least 50% of acreage, but most frequently 80% to 90%). For all of them, grass is the basis to feed from 50 to 75 cows. Other arable crops were mostly maize or legume-cereal intercrops, used for feed. For two farms diversifying their outlets through direct sales, it was also crops for food, such buckwheat, lentil or potatoes.

To initiate the work, sustainability diagnoses have been carried out on each of the eight farms. The IDEA4 method (Zahm et al., 2019) has been used. This method involves the assessment of 53 indicators, tackling the agroecological, social and economic dimensions of sustainability. Results of these diagnoses will be used to identify strength shared by the eight farming systems, which could feed communication actions. The method is supported by a website, which allowed to compare diagnosis results of the group, with results of 115 other livestock farms diagnosed with this method in Western France. This sample of farms diagnosed was not representative of all farms. For example, it included 38% of organic farms, which is higher than the actual rate for the whole farms population.

To design appropriate communication actions valorizing diagnosis results, we combined different approaches. First, two workshops with farmers were arranged to prioritise

communication targets and identify key messages. Second, we interviewed people experienced with such actions to specify the format and tone of the communication. Available documentation was also considered to complete messages which could be communicated.

Results

Diagnoses highlighted very high agroecological performances (Figure 1), with scores higher than 90 points upon 100 for every single farm. In comparison, the average agroecology sustainability score was 78 for all other 115 livestock farms diagnosed with the IDEA4 method in Western France, with half of the sample ranging from 69 to 89. This agroecological performance relied on perfect scores for the eight farms for a branch called "reduction of impacts on health and ecosystems". This branch gathers five indicators, tackling 1) diversity of crops cultivated and animals bred, 2) reduction of impacts on air quality, 3) reduction of impacts on water quality, 4) attenuation of climate change and 5) use of phytosanitary and veterinary products.

A communication action targeting local representatives was designed to share these results. Indeed, they support that these eight organic farms help protecting water against pesticides pollution, while displaying good performances for other indicators. These performances mainly relied on the valorization of diversified and long duration grassland, to produce organic feed and food, with a very limited reliance to inputs. The format chosen for this action will be a farm visit, facilitating interaction between farmers and representatives. The messages delivered and the tone adopted will benefit from all recommendations gathered.

Discussion and perspectives

Other multicriteria assessment methods than IDEA4 should have been considered (Coste et al., 2025). Yet, IDEA4 was the only method that allows to compare a group of farms with other famers. If it was intuitive that organic farming contributes to prevent water from pesticides pollutions, it was interesting to quantify the sustainability performances of the group of famers, in regards of references available for livestock farms from the same region.

The outputs of the communication action, planned for next September or October, will tell us how appropriate such results are, to convince local representatives to support organic farming.

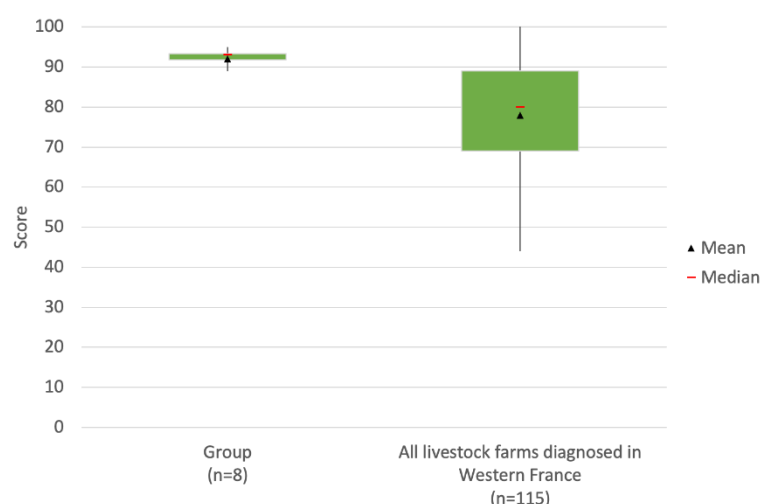


Figure 1. Distribution of agroecology sustainability scores of eight livestock farms in organic farming in comparison with all livestock farms diagnosed with the IDEA method in Western France

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Impact and use's condition of assessment tools mobilized during the co-design of innovative cropping systems for sustainable weed management in groups of farmers

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Keywords: cropping systems, models, weed management, sustainability

Introduction

Weeds are the most damaging pests in field crop systems while simultaneously contributing to biodiversity. Although herbicide use is the most effective cultural technique to manage weed flora, a reduction of uses is need to limit the impact on human health and environment. Alternatives cultural techniques are individually less effective and must be combined at the cropping system scale to improve their effectiveness. The use of mechanistic model such as FlorSys (Colbach et al., 201) and its decision support tool declination DeciFlorSys (Colas et al., 2020) combined with the expertise of stakeholders, can help to understand long-term effects of cropping systems on weed communities. A co-design methodology combining the models FlorSys DeciFlorSys, DexiPM (Pelzer et al., 2012) and farmer's knowledge was developed and tested with farmer's groups. These previous works highlighted the feasibility and the interest of the method for the groups of farmers and their advisors (Cavan et al., 2023; Queyrel et al., 2023).

The aims of this study were) to strengthen the previous technical assessment of the co-design methodology ii) to analyze the usability of DeciFlorSys and its mobilization by advisors during design workshops.

Material and methods

Two groups of farmers were involved, both with different types of farms (with or without livestock, organic or conventional). CIVAM de l'OASIS, with 46 farmers and 2 employees, is based North-Eastern France (departments of Aube and Marne). Main goals for members include an improved resilience of production systems and decision-making autonomy. GDA de Brienne, with 130 farmers and 2 advisors, is based in the Aube department. Its main goals are to support farmers in their crop management and to conduct field trials. The co-design methodology combining models and farmer's knowledge

The co-design approach developed by Queyrel et al, (2023) was implemented. It consists of three main steps: 1) definition of a main issue for the group the associated criteria for success; 2) co-design of at least one innovative cropping system to answer the identified issue, based on the expertise of farmers, new knowledge inputs and the support provided by the facilitation tool, "mission EcoPhyt'Eau"; 3) assessment of the designed systems using the FlorSys, DeciFlorSys and DEXiPM models as well as the farmers' experience. This approach can be adapted to suit the needs and constraints of each group of farmers. Farmers performed a self-assessment of the cropping systems that they designed, based on the criteria that matter to them (defined in step 1). It relies on their own expertise and each score has to be explained. This assessment is then compared to the one performed with the following models:

FlorSyS: is a virtual field on which cropping systems can be experimented with a large range of virtual measurements of crop, weed and environmental state variables (Colbach et al., 2021);

DeciFlorSyS: is a decision support system based on FlorSyS model to design and assess agroecological weed management strategies (Colas et al., 2020);

DEXiPM: is derived from the DEXi software developed for multi-attribute decision making (Bohanec, 2020). DEXiPM allows assessing the sustainability of innovative cropping systems in a context of pesticide use reduction (Pelzer et al., 2012).

DeciFlorSyS uses analysis was carried out by using observations collected during the design workshops. The information's collected were related to farmer's perceptions, and advisors' skills to implement DeciFlorSyS. One observer collected information's related to the farmer's group reaction and the other one was focused on the advisor and the research's team member helping to implement DeciFlorSyS.

Main results

We compared the evolution of criteria between current and innovative cropping systems, assessed by farmers and by models (Table 1).

	Indicators (value expected by farmers and assessed by models)	GDA Brienne		CIVAM Oasis	
		Expected	Assessed	Expected	Assessed
Weed harmfulness for crop production	Yield losses due to weeds	↗	↗		↗
	Lack of resilience of the system when facing a peak of weed pressure	(or ↗)	↘	↗	↘
	Harvest pollution		↗		↘
	Harvesting problems		↘		↘
Weed contribution to biodiversity	Weed species richness		↘		↘
	Weed species evenness		↘		↗
	Weed-based trophic resources for:				
	bees		=		↘
	birds		↗		↗
Components of sustainability	carabids		↗		↗
	Profitability	↗	↗	↘	↗
	Autonomy of the farm	↗ or ↗	↗	=	↗
	Social sustainability	↗ or ↗	↗		↗
	including organization and workload	↗	↗		=
	Environmental sustainability		↗		↗

Table 1: Changes between the current cropping system and the co-designed innovative system, "Expected" by farmers and "Assessed" with models, in both groups. Strong green: significant improvement; light green: positive trend; orange: negative trend; red: significant degradation.

Assessment carried out by farmers was mostly similar to the model results. The discrepancy between self-assessment and model evaluation was a source of discussion to stimulate the design process. Moreover, the use of models allowed evaluating long-term effects of innovative cropping systems (e.g. the lack of resilience against peaks of weed pressure) and a more detailed view of weed harmfulness for crop production (e.g. harvest pollution and harvesting problems were not considered by farmers and decreased in the innovative system of the second farmer) or of other subjects, such as weed contribution to biodiversity.

The sustainability assessment allowed checking that there were no trade-offs identified with the codesigned cropping systems (at least for the main targets criteria identified by farmers). It can also allow discussing trade-offs between objectives (e.g., nitrogen autonomy vs weed management for another farmer -- not shown here).

Observations revealed a gradient of autonomy in the use of the tool by advisors: from simple use of the results of DeciFlorSys to implementation of the tool assisted by a research's team member. We also demonstrated that DeciFlorSys, can be used during a workshop (with enough facilitators and a proper formation) to boost the design process. Based on these experiences, a methodological handbook has been drawn up to help advisors and farm group facilitators to implement the co-design approach.

Conclusion

Model-based evaluation provides a broader, long-term perspective on co-designed systems. Design support tools can be used directly in the co-design workshop to give an initial assessment and prompt new proposals for innovative systems.

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How assessment methods support the design of pesticide free territories

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Keywords: process, case study, stakeholder, pesticide

Introduction

Design approaches at territorial level, as defined by Löfgren (2020), offer an integrated and participatory framework for supporting the agroecological transition, considering specific local features and promoting innovation and sustainability. The Be Creative project aims to design pesticide-free territories with and for the actors. Its study device is based on nine French case studies (CS) (Valantin-Morison, 2021). Throughout the design process, the case studies mobilized assessment methods, explicitly or not, at different stages and for various purposes, as assessment is not an end in itself but a tool to support a process or approach. According to Lairez et al. (2015) it can have various objectives: *describe or generate knowledge, supporting decision-making, and communication with stakeholders*. Through a cross-analysis of the case studies, we try to show how assessment supports the design process by analyzing (1) the assessment methods mobilized, (2) the objects and scales assessed and for what purpose, and (3) at what stage the methods were mobilized within the design process. This work allowed us to propose a reflexive analysis for researchers and stakeholders on the various ways assessment can support the design process using various methods.

Methods

In each territory, a scientific and a local stakeholder carry the design process. We interviewed case study 'managers' biannually to track activities carried out within the design process to build a Chronicle of Change (Chizallet et al, 2020). We ask them to identify each activity according to five types of design activities (Stempfle et Badke-Schaub 2002): (1) understanding the situation, (2) formulating the problem to be solved, (3) exploring solutions (4) assessing transformation impact, (5) supporting the workgroup. For this study, we focused on the activities identified as "assessing transformation impact" first, then identified the activities that used assessment methods within the other types.

We used a grid analysis framework to analyze the assessment activities. This framework specifies, among other things, the stage of the design process, the object assessed, and at what scale. To characterize the contribution of assessment activities to the process, we looked at the activities that followed assessment in the Chronicle of Change timeline, and identified follow-up types (e.g. implementation of designed innovation). After this first analysis, scientific 'managers' were interviewed to validate and complete our analysis.

Results

A diversity of methods

Even though assessment is an integral part of the design process, this step was sometimes difficult to identify. We identified 24 assessment-related activities in seven out of the nine case studies (Table 1). These activities belong to three assessment approaches: observation

assessment (OA), multi-criteria tools (MC) (scenarization or sustainability assessment tools), and expert feedback (EF). The choice of method mainly depended on the objective, but was also opportunistic according to the knowledge, skills, data, and time available.

Case-study number	Name	Type	Main crops	Assessment approach		
				OA	MC	EF
CS01	Safré	Territory	Arable crops + Livestock		2	
CS02	Chaurouze	Territory	Arable crops + Livestock		1	
CS03	Devrouze	Territory	Arable crops + Livestock	2	1	
CS04	POM	Territory	Livestock + Vineyard + Grassland		2	
CS05	Gotheron	Experimental station	Fruits	2	2	2
CS06	CA-SYS	Experimental station	Arable crops	5	1	1
CS07	Scarabée	Farmers' network	Arable crops	3		

Table 1. The 24 assessment-related activities in 7 out of 9 case studies (CS) classified according to the assessment approach OA: observation assessment; MC: multicriteria tool; EF: expert feedback.

The two case studies where no assessment activity occurs are case studies that are in the early stages of the design process. The majority of their activities were part of the *understanding the situation, formulating the problem to be solved, and supporting the workgroup* categories of the Chronicle of Change.

Different objects and scales assessed at different stages of the design process for a variety of purposes

The objects assessed vary from production system to crop management or even ecosystem service. The spatial scale considered for assessment varies from field to territory. Sometimes an assessment activity covered multiple scales, such as field and territory, through expert feedback for example.

Assessment methods were used at different stages of the innovation design process. Depending on the objective of the assessment activity and the stage considered, the method used belongs to an *ex-ante* approach (assessment of a theoretical innovation), *in-itinere* approach (assessment during innovation for adjustment) or *ex-post* approach (assessment after innovation).

MC tools were mobilized *ex-ante* to design and assess potential innovations (CS01 - CS04), to explore various scenarios (CS01 - CS04) or to support decision-making (CS02 - CS03). EF and MC tools were used *ex-ante* (CS05) to adjust prototypes and make decisions before implementation.

The three types of assessment methods were mobilized for *in-itinere* assessment (CS03 -- CS05 -- CS06) to support decision-making in step-by-step design processes.

MC tools were used for *ex-post* assessment (CS01), to communicate on value or *ex-ante* and *ex-post* (CS06) to generate knowledge on an innovation's impact. OA was used *ex-post* (CS05-CS06) periodically to generate knowledge on the impact of an innovation.

Contribution to the design process

We have identified five types of follow-up activity after an assessment (Table 2): assessment, exploring leads, assessing the implementation of an innovation/solution, solution identification, or no action at this stage of the design process. Assessment using MC tools generally contributes to different objectives in a same case study, such as exploring leads at different scale (CS04), supporting *ex-ante* assessment and implementation (CS05) or exploring

scenarios and communicate with stakeholders in order to stimulate implementation (CS01). Assessment based on EF can be used alone (CS05) but is generally followed by MC tools assessment (CS05 -- CS06). As OA are used *in-itinere*, they mainly focus on assessing the implementation of an innovation/solution (CS06) or identifying solutions (CS03). The scope and scale of this type of evaluation can evolve during the design process (CS05-CS06) without necessarily leading to specific actions (CS07-CS03-CS05).

Assessment approach Follow-up activity	Feedback	Multicriteria tools	Observations
Assessment	CS05	CS05 – CS06	
Exploring scenarios		CS01 - CS04	
Implementation	CS05 - CS06	CS01 - CS03 - CS05	CS06 - CS05
No action at this stage of the design process			CS07 - CS03-CS05
Solution identification		CS02	CS03

Table 2. The different case studies (CS) classified according to the assessment approach and to the follow-up activity.

Discussion and Perspectives

Our results indicate that assessment activities lead to different actions and are key activities in the design process. The choice of methods and the timing of their implementation depend on various factors, including the extent to which stakeholders share the objectives of the design process, and the skills and availability of those involved. Regardless of the choices made, making the assessment stages transparent and comprehensible to stakeholders improves the design process (Perrin et al., 2023). Involving stakeholders in all or part of the design process ensures that the resulting solutions are relevant, effective, and adapted to their needs (Triste et al., 2014).

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A tool to assess the territorial sustainability impact of collective catering and support its transition

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Introduction

For many reasons, public food procurement has been described and analysed as a powerful means to support sustainability transition of food systems (Morley, 2021). Despite food procurement policies emerging worldwide and at different scales, the agroecological transition of this sector remains low and disparate. Several studies on design processes to support agroecological transition of farming and food systems highlighted the role and the importance of sustainability assessment (Perrin et al., 2023). This implies to develop multi-criteria, participatory and adaptative assessment tools, especially in the public catering sector (Molin et al., 2021). This work specifically aimed at answering this need through the co-design of a tool to assess the territorial impact of public catering, i.e., the economic, social, cultural and environmental impacts of canteens' practices on their territories (Paus and Réviron, 2010).

Materials and methods

The entire co-design process was built drawing on the guidelines provided by Craheix et al. (2015) to design models assessing agricultural sustainability. Two co-design loops were successively run in 2023 and 2024, each loop involving around 10 persons including catering managers, public officers in charge of food programs and researchers (Figure 1). For the final evaluation (Step 4'), the tool was used on 20 public catering structures in South-West of France covering a certain diversity: different types and sizes of catering structures, different 'levels of sustainability transition', different location. Interviews were conducted with the 20 catering managers to estimate the indicators. Feedback meetings were organized with local authority representatives to share the results from the multi-criteria assessment performed by the researchers based on the collected data. This allowed to discuss the model usefulness to support practices changes and agroecological transition.

Results

Overview of the designed tool

The co-design process resulted in the elaboration of a hierarchical tree of 5 levels composed by twenty-seven basic criteria (Figure 2). The final aggregated criterion ('territorial impact') was qualified with 7 classes (A+ to F) and divided into 3 equally weighted aggregated criteria. Regarding the economic impacts, the development of sourcing strategies based on local or local and organic products was identified as a key practice having a positive economic impact on the territory. The implementation of socio-educational measures was identified as key components of the socio-cultural impacts. The impact on the human health was decomposed in three criteria traducing the ability for the canteen to provide healthy meals and the five basic criteria chosen for environmental impacts covered the main themes known to regulate environmental impacts such as waste or meat consumption. Regarding the indicators, it combined both quantitative (e.g., percentage of total amount of local and organic products) and qualitative (e.g., type of trainings) indicators but all were chosen to be easily obtained either thanks to administration software used by canteen managers to follow their purchase or

by directly questioning canteen staff about their practices during the cooking and the delivery of the meal or the cleaning phase.

Assessment of the designed tool

The stakeholders to which the tool and the results for the 20 sites were presented, agreed on the usefulness of the tool to support agroecological transition at two scales. First, the production of a formal individual assessment in the form of a pedagogic report was considered as potentially useful to engage actors in practices changes at the scale of each structure by making explicit the thresholds to be reached to obtain a greater territorial impact. Second, the cross-analysis of the individual assessments within a same department was also mentioned as potentially useful to engage actions for agroecological transition at the territorial scale through the identification of territorial strengths (i.e., aggregated criteria for which most of the structures had reach high scale) or weaknesses (i.e., aggregated criteria for which most of the structure had reach low scale).

Discussion and perspectives

Several tools to assess sustainability of collective catering have been developed recently (De Laurentiis et al., 2019; Goggins and Rau, 2016). These tools can be distinguished based on what they achieve to do (evaluating the impact of existing policies vs. support the design of news ones), the dimension of the sustainability they focus on (environmental performances vs. more holistic approaches) and/or the methods used (Life cycle Assessment vs. multicriteria assessment). By co-designing with experts an easy-to-use, adaptable assessment tool looking at sustainability at the territorial scale, we assume that we are proposing an original tool, complementary to the existing ones. More long-term experiment, such as prototype test (Ravier et al., 2018) would be needed to explore in what extend the individual and collective assessments are effectively inducing changes in actor's practices that are resulting in a better territorial impact.

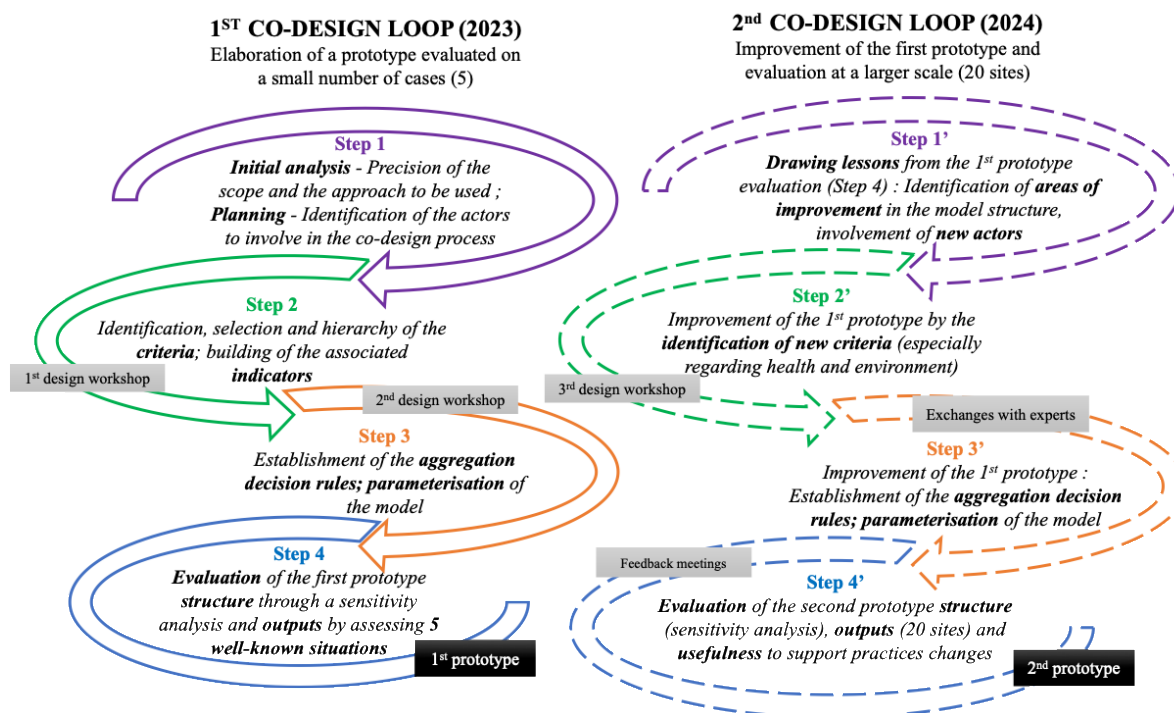


Figure 1. Overview of the co-design process used to design a tool to assess the territorial impact of collective public catering.

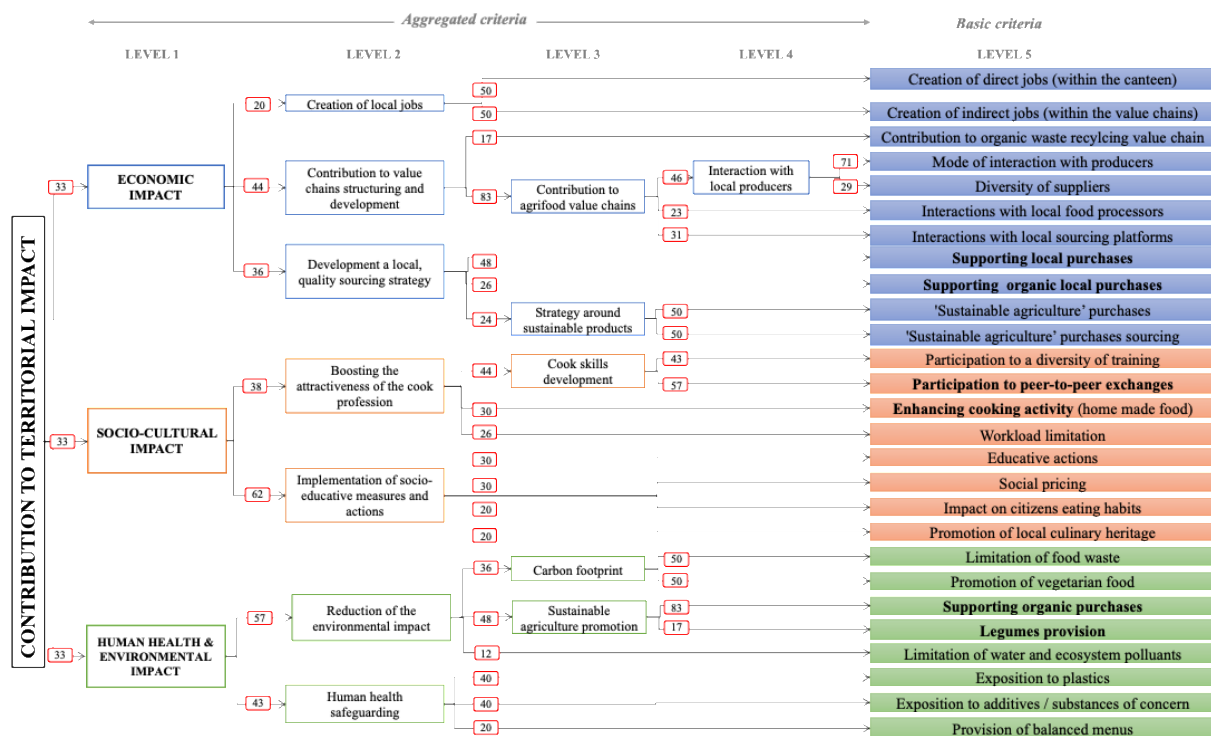


Figure 2. Hierarchical tree obtained through the co-design process.

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