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Investigating farmers' decision-making in adoption of conservation agriculture in the Northwestern uplands of Cambodia

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ABSTRACT

In the Northwestern uplands of Cambodia, the commodification of agriculture in the 2000 s substituted the traditional rotational and diversified cropping systems with monocropping of commercial crops such as maize and cassava. Driven by high market demand, this transition was associated with deforestation, erosion of soils and biodiversity as well as pollution from increased use of chemical inputs. Land degradation observed after a few years of intensive monocropping undermined the sustainability of the overall agricultural system. However, lessons learned from previous failures of crop boom-bust cycles did not materialize as an incentive to adopt alternative sustainable practices.

Along with local villagers we developed a role-play game to investigate farmers' decision-making in relation to land-use transitions and their participation in a Conservation Agriculture (CA) initiative aimed at mitigating land degradation. The game revealed that farmers were still trapped in the boom-bust cycle with commercial crops. Market opportunities and high, short-term economic returns are key parameters in the decision-making process, which mostly overrides environmental aspects. This study shows the importance of opportunity windows for development interventions, the crucial role of farming communities in co-designing alternative cropping systems and the potential of social learning devices to bring CA to scale.

1. Introduction

Over the last two decades, land systems in the Mekong region have been transformed at an unprecedented pace and scale. Foreign and domestic investments have boosted the production and trade of commodity crops. Intensive monocropping of so-called boom crops has altered land use through a process of commodification and simplification that has increasingly replaced traditional agricultural and natural systems (Hall, 2011; Hurni and Fox, 2018; Ingalls et al., 2018). Some recent updates suggest that altogether rice, rubber, cassava, corn, sugar cane, and oil palm constitute more than 80% of the entire cultivated area in the Mekong (Ingalls et al. 2018).

In upland regions, these transformations are associated with deforestation, erosion of soils and loss of biodiversity as well as increased use of chemical inputs, all of which undermine the sustainability of smallholder farming systems (Dufumier, 2006; Castella, 2012; De Koninck and Rousseau, 2013). Within a few years after tree clearing, yields decrease and the value-added of agricultural production declines significantly (Castella, 2012; Lestrelin et al., 2012a, 2012b).

To overcome these land degradation issues, smallholder farmers usually envisage two different approaches. Where forest resources are still relatively abundant, they expand the agricultural frontier to new locations through a displacement process that reproduces the same land use dynamics. But when the forest frontier is closed, the options available to them are few and smallholder farmers usually wait and hope for the next boom crop, despite knowing that such an alternative will not

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provide them with any long-term perspective. In both cases, the decisions that are made often lead to the inexorable repetition of these boom-bust scenarios, which have become a structuring element in agrarian dynamics across the Mekong region (Hall, 2011, Friis et al., 2019).

For all these reasons, boom crops represent a key challenge for farmers, researchers and extension agents who promote sustainable land management. The space for collaborative learning between stakeholders is often narrow, limiting lesson sharing from previous experiences to co-design sustainable land management solutions (Castella, 2012). A better understanding of farmers' decision-making processes through successive boom-bust cycles is key to engaging with them in co-designing more sustainable land use management pathways (Kassam et al., 2019).

This article recounts an encounter between smallholder farmers trapped in successive boom-bust cycles since early 2000 in the Northwestern uplands of Cambodia and a Conservation Agriculture (CA) initiative introduced in 2010 to promote sustainable soil and crop management (Kong et al., 2016). The objective of the study is to understand the conditions under which some farmers have engaged in the CA initiative. We first question the decision making processes of farmers who have navigated through this succession of boom-bust cycles. In this context, we analyze their perceptions and assess their uses of CA practices. To examine these questions through the eyes and experiences of smallholder farmers and not of the CA promoters, we designed and applied a role-playing game with farmers in 6 villages that were going through similar land use trajectories. Building on similar experiences conducted in Lao PDR (Castella et al., 2014; Ornetsmüller et al., 2018), the role-playing game was designed to elicit farmers' perceptions and decisions in a context of rapid land use changes driven by boom crops. Conservation agriculture options were presented to participants during the game as they had been proposed in reality. Altogether, the role-playing game functioned as a deliberative learning process between stakeholders to envisage sustainable land use practices appropriate to the local context and inform land use policies as a whole.

2. A conservation agriculture initiative in Northwestern Cambodia

From 2005 to 2015, the Northwestern uplands of Cambodia in Battambang Province (Fig. 1) underwent massive land conversion from forest to agriculture. Agricultural expansion took place in the context of the peace-making process that followed the reintegration of the last resisting Khmer Rouge bastions into civilian order. Agrarian expansion was driven by high market demand for, and the profitability of, maize, the availability of large tracks of forest with relatively open access rules and spontaneous in-migration of poor and landless farmers from the highly populated lowlands (Kong et al., 2019). As maize and other secondary crops such as sesame or mungbean were cultivated under plow-based management with relatively limited fertilizer use, soil fertility declined quickly with clear negative consequences on crop yields and farmers' incomes.

To reduce the negative impacts of this rapid maize expansion, a research for development project was established in 2010 to promote CA practices. These practices were based on three technical principles: minimizing soil disturbance; permanent soil cover; and crop diversification along with and cover/relay crop species through rotations, succession and/or association (Séguy et al., 2006; Kassam et al., 2019). The project was implemented in 4 villages of Rotonak Mondul District, Battambang Province (Fig. 1). The project brought several proponents – farmers, agronomists, researchers and extension agents in successive learning loops (Husson et al., 2016). Based on the results of the initial diagnosis, improved maize-based cropping systems were developed and tested on-farm (1st loop). Maize associations with cover crops, e.g. stylo (*Stylosanthes guianensis*), rice bean (*Vigna umbellata*) and pigeon pea (*Cajanus cajan*), emerged as promising options and were then included in a farm demonstration network (2nd loop). Technical and economic performances were jointly assessed with farmers and extension agents before the new cropping system was proposed in a pre-extension network (3rd loop).

Farmers engaged in the initiative on a voluntary basis. To support farmers' adoption of CA practices, the project provided a subsidized package including free supply of cover crop seeds, a maize yield guarantee of 4.5 t/ha and an interest-free credit of 250–300 $/ha for fertilizers and CA services, such as no-till sowing. These incentive mechanisms lasted during the period from 2010 to 2012. After subsidy withdrawal at the end of its first phase in 2013, the project continued to provide technical advice through extension agents and no-till sowing services for a fee similar to that of private contractors in the area.

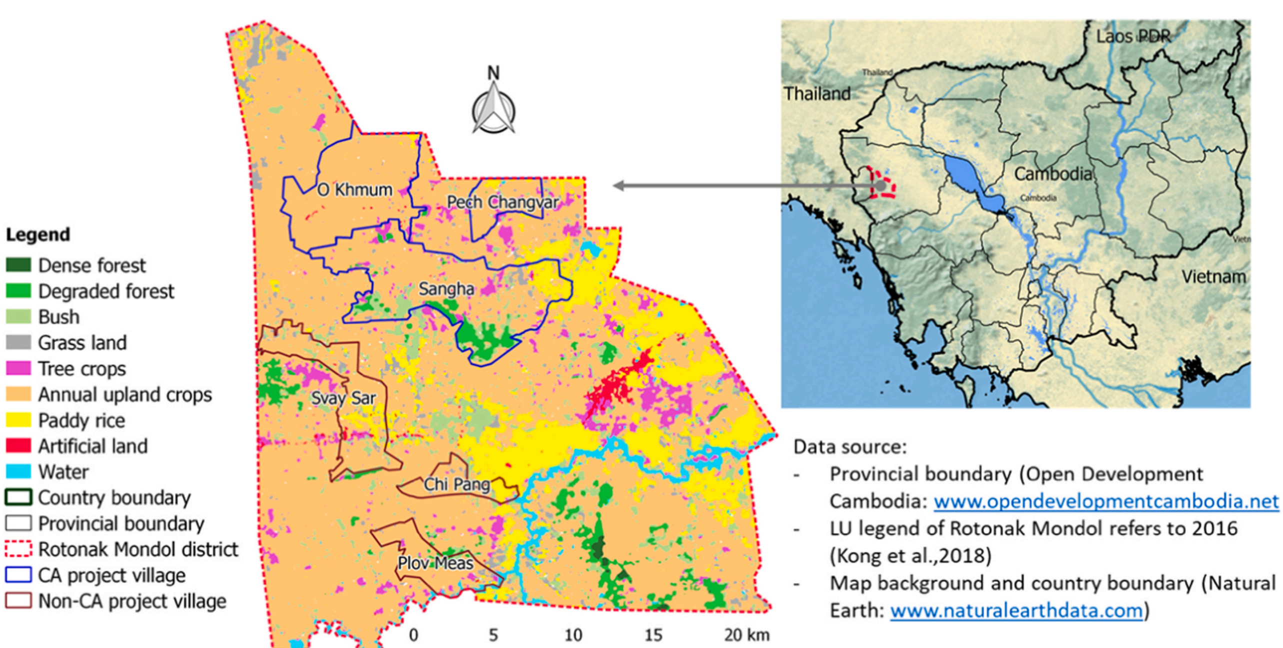

Fig. 1. Land use map 2016 of the study area in Rotonak Mondol District, Battambang Province, Cambodia.

During the initial evaluation of the project in 2014, the results were very promising in terms of adoption and impacts on sustainable maize production (Fig. 2). However, the CA area dropped dramatically in the subsequent years (Fig. 2) due to the decline of maize profitability and higher market prices of cassava at that time. The decrease of cassava profits in 2016 due to a long dry spell associated with a sharp price decrease and lower yields resulting from 3-years of mono-cropping then encouraged the farmers to re-engage with maize in 2017 (Fig. 2).

We now turn to the description of the methodological tools designed to understand why the engagement of smallholder farmers has fluctuated so much over the course of the CA initiative.

3. Methodology

3.1. The use of a role playing game to investigate decision making in adoption of CA practices

A role playing game was designed to understand rapid land use transitions from the perspective of local farmers. Indeed, role playing games (RPG) are a powerful tool to elicit knowledge from local actors and facilitate negotiations between different stakeholders to reach any collective decision. They have been used widely in recent years to manage conflicts over common resource use and develop common understandings on social-ecological systems (Barreteau et al., 2013; Bousquet et al., 2014). In the Mekong region, Ornetsmüller et al. (2018) developed an RPG in Laos PDR to analyze farmers' decisions and understand the underlying process of the maize boom.

Our use of the RPG is slightly different in that we use it as a tool to conduct an ex-post study on farmers' decision making processes in relation to successive boom-bust cycles and participation in the CA initiative. Studying farmers' decision-making in the past was challenging because the judgment of project stakeholders concerning past decisions is biased by their current perceptions or by their role. To address these problems, we use a gaming simulation approach to recreate the conditions that prevailed during the different boom-bust phases at the time of these CA interventions, thus placing farmers in the situations they were in when they made their decisions. As such, the game also serves as a stock taking exercise to learn from past experiences and identify new intervention mechanisms towards sustainable land use practices.

3.2. Knowledge integration from multiple sources and scales

Several studies and surveys informed the game design (Fig. 3, left). We initially conducted a study on the trajectories and drivers of land use change over a 40-year period in a study area (Kong et al., 2019). Based on a village typology established with socio-economic indicators available for the 38 villages of the district (Appendix A), we selected 10 villages by stratified random sampling with 4 villages where CA was introduced and 6 village using conventional tillage (CT). An individual quantitative survey was then applied to 365 households selected through random sampling in each village (confidence level of 95% and confidence interval of 15%) to characterize their farm structure and cropping practices. The survey resulted in establishing a household typology differentiating between upland crop-based smallholder farms, upland crop-based large farms, off-farm income dominated farms and paddy-based farms (Appendix A). We finally conducted in-depth semi-structured interviews with 95 households selected through stratified random sampling in each of the 10 villages to represent the diversity of farming systems identified earlier. These interviews generated detailed information about individual land use trajectories and the technical-economic performance of their cropping systems (Kong and Castella, 2021). In addition, relevant CA project documents were systematically reviewed. A specific survey on the reasons for adoption or abandonment of CA practices was then conducted with 165 households in 4 CA villages: O Khmum, Pich Changva, Reak Smey Sangha, and Baribou. In-depth interviews were conducted with 2 different groups of farmers who had applied CA practices. The first group included CA farmers who had engaged since the subsidy period and/or those who, after the subsidy withdrawal, paid for no-till services. The second group included drop-off farmers who shifted from CA to CT during the subsidy period or ceased hiring no-till planters. The survey addressed 2 consecutive periods: 2010–2012 (with CA subsidy) and from 2013 onwards (after subsidy withdrawal). As farmers who did not enroll with the project were not interviewed, the survey mainly shed light on why CA farmers decided to continue or drop CA practices rather than on why some farmers decided to enroll with CA while other did not. The details of surveyed villages and households are presented in Appendix B.

3.3. The RADA (Resilient Agriculture through co-Design of Agroecology pathways) game

The co-design process of the RADA game took place in two steps: first an expert seminar for prototyping and second the testing and refining of the game with farmers. Half of the expert team members, who were not involved in the CA project (Appendix D), played the role of independent observers questioning the local realities related to land use change, cropping systems, labor management and CA interventions. The other half of the expert team were CA promoters who brought an insider project implementation perspective. The experts reviewed the data generated from the studies introduced in the previous section and developed a conceptual model of land use changes centered on farmers' decision making processes over the past two decades in order to come up with a game prototype.

The game testing and refining process was done through successive learning loops in 3 villages (Fig. 3, middle). The 3 sessions led to refining the rules and parameters of the game and enhancing its playability. The team also gradually refined the roles and procedures for facilitation and

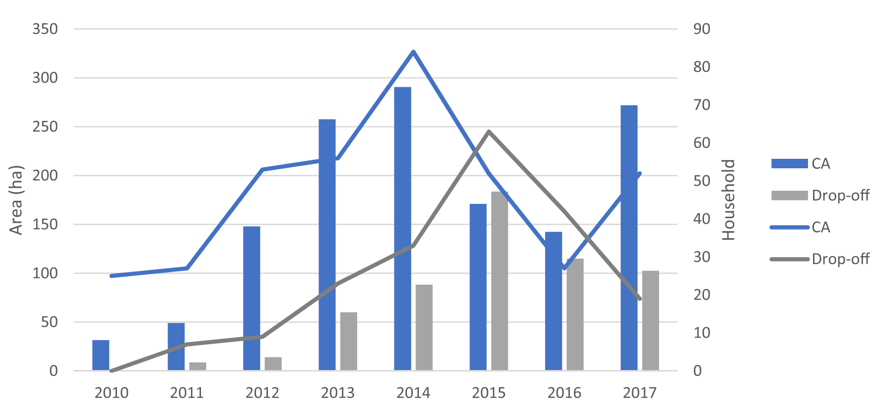

Fig. 2. CA evolution from 2010 to 2012 with subsidies and from 2013 without subsidies.

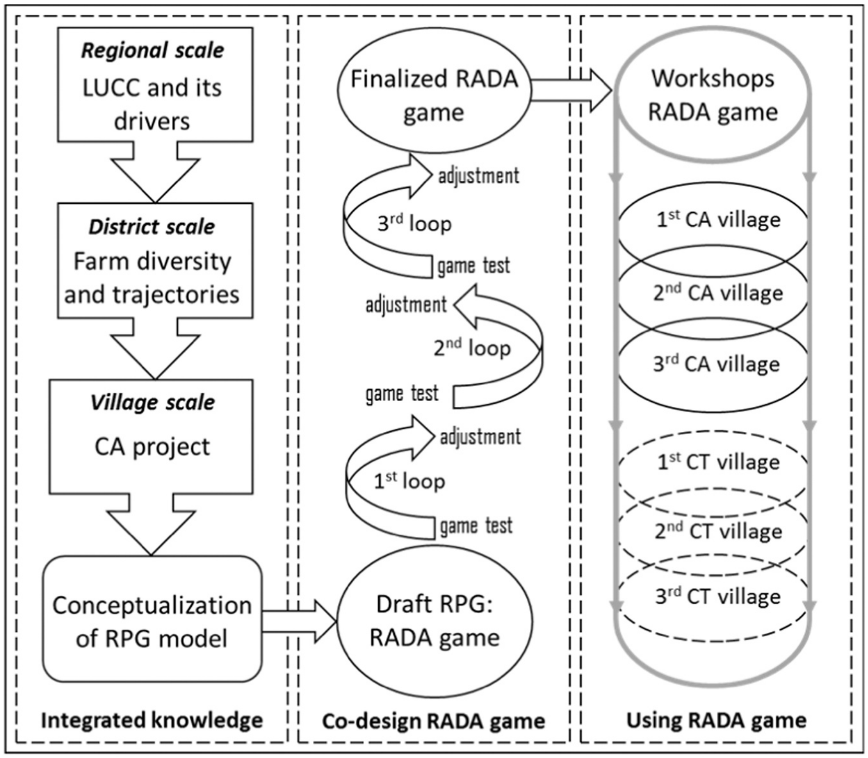

Fig. 3. Graphic representation of the methodological framework.

monitoring. A full sequence of the RADA game contains 6 rounds as shown in Appendix C. Each round corresponds to a specific period marked by the introduction of a new boom crop or technique: peanut and soybean (2002–2006), start of maize (2006–2008), maize boom (2008–2010), CA project (from 2010), cassava boom and orchard (from 2013) and diversification in farm activities (from 2016), i.e. off-farm usually referring to agricultural wage labor and non-farm activities outside the farm. A seventh round was simulated after the game so that the delayed income from mature orchards planted in Round 6 could be accounted for in the results. A round consists of 5 steps: a) round introduction; b) the play; c) risk management; d) result assessment; and e) round debriefing. Details of the co-design process are provided in Appendix D.

The RADA game was subsequently used in 6 villages in Rotonak Mondol District in January 2018. Three of them were target villages of the CA project while the other 3 villages had only practiced conventional tillage (CT) on upland crops. In each village, 8 farmers representing the 4 farm types identified earlier played the game according to the same spatial organization (Fig. 4), allocation of initial resources to each player (Table 1), and rules and parameters (Appendix C).

3.4. Data collection and analysis

Each of the 8 players was assisted by 1 facilitator who recorded the game data and results in 2 pre-defined forms: 1 relating to the economic results, resource changes and investment activities at the farm level, and the other on land uses, cropping practices and risk management at the plot level. The game master took notes on the important changes, interactions, and discussions between the players, facilitated the debriefing discussion at the end of each round to exchange information and learn about land use changes, crop choices, farm resources, innovative techniques and farming constraints. The final collective debriefing included feedback on the game, i.e. how close it was to the reality, how and why it was useful; and the main lessons learnt by both players and facilitators regarding the impacts of boom-bust cycles, perceptions on soil conservation practices, etc.

The emphasis was put on unexpected decisions or events, and emerging patterns that had not been previously observed by CA promoters. Each gaming session was video recorded to complement the game master's notes and clarify discussion content when necessary as many actions happened in parallel during the game. After the game, an individual survey was conducted with each player by the game master in order to understand the logic behind the decisions made during the game, especially the reasons for adopting, dropping out or continuing CA. We then computed a number of economic and environmental indicators to monitor the impacts at both farm and landscape levels (see Table 2).

4. Results: framing farmers' decision making processes

4.1. Market opportunities and economic return as main farmers' decision making drivers

4.1.1. Game

The first round of the game brought the farmers back 20 years to the early migration phase. The choices they made during the game were revolving around the cultivation of rice and additional cash crops such as peanut, soybean, sesame, and mungbean according to the biophysical conditions of their land. The other determinants were the availability of family labor. Farmers decisions were mainly driven by the need to produce sufficient rice to eat while generating income from the cash crops.

In the second round of the game, land productivity – envisaged as a function of obtainable yield, production costs and farm gate prices were the key factors in deciding which crop to cultivate. As maize provided higher economic return than upland rice and rice could be purchased from the market, the farmers expanded maize areas with two cycles per year to their entire upland holdings and also to additional lands rented in neighboring villages. Maize reached more than 70% of cultivated areas in Round 2 (Table 3). Farm income increased 5 times for upland farmers - versus 2.5 times only for those in paddy-based farm type - in Round 2, and 10 times in Round 3 (Table 4).

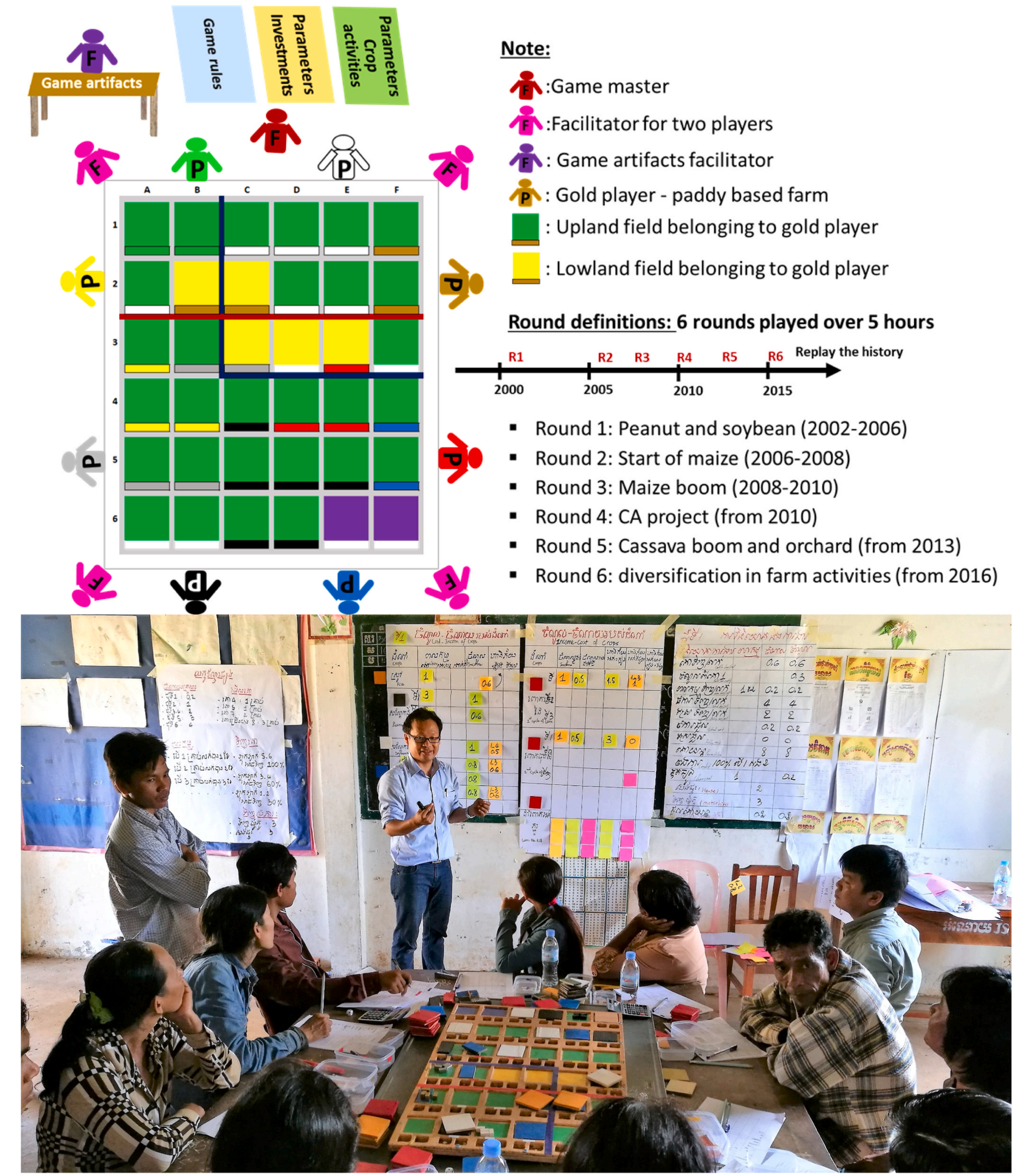

Fig. 4. Spatial organization of the room and definition round of the RADA role-play game.

In Round 4, land productivity dropped as a result of maize yield decline (soil fertility depletion due to intensive tillage and monocropping without organic matter input) and an increase in production costs (increasing agrochemical inputs and mechanization to offset labor migration) (Kong et al. 2019). In Round 5, farmers shifted massively from maize to cassava for its higher productivity, and increased market price. About 39% (from 20% to 61% depending on the village) of the agricultural area on average was converted to cassava (Table 3). Meanwhile, price fluctuations and rainfall variations became increasingly important factors in decision making. To cope with these risks in the game, most resource-rich farmers (i.e. upland crop-based large farm) converted their land to orchards with longan and mango trees while

Table 1
Initial conditions of the RADA game - resources allocated to each farm type.

Farm types (FT)	Color	Upland	Lowland	Cattle	Farm labor	
					Person	Button
Off-farm income dominated farm (FT-1)	Green and blue	2	0	0	2	12
Paddy based farm (FT-2)	Gold and silver	2	2	4	4	24
Upland crop-based smallholder farm (FT-3)	Red and yellow	3	0	0	3	18
Upland crop-based large farm (FT-4)	Black and white	6	0	4	4	24

NB: Upland and lowland areas in number of 1 ha cells, cattle heads, number of persons working on the farm (Person) and monthly labor units (Button).

Table 2
List of indicators used to monitor the game and impacts on landscapes and livelihoods.

Indicators	Definition
Capital (Million KHR)	Total value of investments (land, cattle, orchard installation…etc.) and assets for agriculture (e.g. power tiller) and domestic (e.g. motorbike) use from all households in the village.
Shannon diversity index of land use	Proportion of area of land use type i relative to the total area of land use (pi) in the village is calculated, and then multiplied by the natural logarithm of this proportion (Ln_{pi}). The resulting product is summed across cropping systems and multiplied by − 1.
Mechanization service cost (Million KHR/ha)	Average service cost per hectare and per year for agricultural machineries.
Pesticides use (L-kg/ha)	Average amount of pesticides (herbicides, insecticides, and fungicides) per hectare (quantity of commercial product).
Agricultural productivity (Million KHR/ha)	Total gross value added of crop and cattle divided by the total agricultural land used both inside and outside the village.
Labor productivity (Million KHR/person)	Total gross value added of crop and cattle dividing by the total family labor in the village.
Return on investment (%)	Proportion of total gross value added of crop by the total production cost in the village.
Soil fertility depletion	Sum of average score of soil fertility depletion for each cell/plot within the village from Round 1–7. The depletion score is assessed by expert's knowledge based on the cropping systems, e.g. early wet season maize followed by rainy season maize: − 25% (two plows); cassava: − 30% (two plows and one ridge); improved pasture and rotational grazing: + 15%
Rain and market vulnerability	Sum of multiplication between probability of loss and the amount of loss related to rain and market risks for each practiced cropping system per hectare and per year.
Total cattle (head)	Total number of cattle in the village.

Table 3
Average area (%) of crops grown per villages in the game.

Round	1	2	3	4	5	6	7
Total cultivated land (ha)	**22**	**54**	**59**	**67**	**66**	**70**	**69**
Cassava	0	0	0	0	39	9	7
Chili	2	0	0	0	0	0	0
Cover crop	0	0	0	35	7	12	13
Longan	0	0	0	0	2	4	4
Maize	0	71	68	47	17	17	17
Mango	0	0	0	0	20	37	38
Mungbean	27	14	19	10	3	5	5
Paddy rice	14	7	6	6	5	4	4
Pasture	0	0	0	1	6	9	10
Peanut	20	2	1	0	0	0	0
Sesame	14	4	4	0	0	0	0
Soybean	18	2	1	0	0	0	0
Upland rice	6	0	1	0	0	0	0
Vegetables	0	0	0	0	1	2	2
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Note:
- The value of each crop is the average cultivated area in % from the 6 villages.
- Rounds: 1) peanut and soybean (2002–2006), 2) start of maize (2006–2008), 3) maize boom (2008–2010), 4) CA project (from 2010), 5) cassava boom and orchard (from 2013), 6) diversification away from crop cultivation (from 2016) and 7) including projected income from mature orchards.

others tried to diversify with livestock, vegetables and off-farm activities. The high economic return of mango plantations led to a rapid land use conversion of 20% (from 13% to 11% depending on the village) of the cultivated area (Table 3).

4.1.2. Reality

The first round of the game reflected the reality of the early 2000 s, when semi-subsistence farming with limited access to agricultural inputs and outputs markets and a poor road network prevailed. At that time, farmers were mainly growing rice to feed their families due to difficult market access to purchase rice. Their remaining family labor force was invested in growing cash crops to generate income for hiring workers to continue clearing forests. During that first phase of the transformations, the initial capital brought by migrants from their village of origin, the labor capacity to clear forests and the income generated from cash crop production determined the agricultural land acquired by each household.

From the mid-2000 s, the farming systems became fully commercial (Round 2), with the introduction of hybrid maize and agrochemical inputs, improved market access and road infrastructure (Kong et al., 2019). Full access to agricultural inputs and outputs markets dramatically changed farmer logic from focusing on rice sufficiency to orientation towards maximizing productivity. High economic returns from hybrid maize ushered in a prosperous period from the mid-2000 s. All farmers remember this time as yielding their highest historic income from upland farming leading to improved living standards and asset accumulation (e.g. housing, power-tiller, motorbike). The prospect of getting rich from farming emerged at that time and did so concomitantly in other Cambodian regions (Mahanty and Milne, 2016). The game results confirmed the dramatic land rush associated with forest conversion that took place over a very short period (Round 3). When maize productivity declined in the 2010 s, the majority of farmer shifted to cassava (Round 5) thanks to its high capacity of photosynthesis and nutrients uptake (Cock and Connor, 2021). Some wealthier farmers adapted by moving away from maize and investing in mango plantations and cattle raising. In 2015 for instance, a 5-year-old mango plantation could be rented at 3000$/ha/year or provide 10,000$/ha/year gross income, which is 5–10 times higher than cassava or maize, respectively (Kong and Castella, 2021). High expectations on economic return encouraged farmers to invest in these high-risk businesses, for which most had to take out loans while the mango market was highly uncertain since only for export and limited to a small trading network (Round 6).

Despite limited technical knowledge or economic information on markets and prices, farmers were 'gambling' on new crops with the hope of maximizing their economic returns. As we observed during the game, they often mimicked their successful neighbors in a process of social conformity coined by a participant as '*we succeed together or we fail together*'. The imitation of successful forerunners is a rational risk-coping strategy, notably for poor farmers who cannot afford a failure. For those who are willing and able to do so, investment in tree crops was part of their long-term development strategy to cover and secure costs of higher education for their children.

To a large extent, decisions made during both the game and reality

Table 4
Impact of farmers' decisions on land uses and practices at the successive rounds.

Round	1	2	3	4	5	6	7
Capital accumulation (Million KHR)	1	7	75	127	183	246	246
Shannon diversity index of land use	1.91	1.64	1.64	1.27	1.83	1.84	1.79
Mechanization service cost (Million KHR/ha)	0.04	0.58	0.58	0.53	0.77	0.99	0.98
Pesticides use (l-kg/ha)	0.00	3.33	5.45	4.57	4.33	11.54	12.26
Crop land use productivity (Million KHR/ha)	0.98	3.45	2.55	2.37	2.81	4.90	4.98
Crop labor productivity (Million KHR/person)	0.79	4.30	3.28	5.70	6.58	15.41	16.10
Return on investment (%)	328	229	144	153	140	112	111
Land degradation accumulation (%)	-1	-16	-30	-27	-43	-42	-41
Rain and market vulnerability	0.03	0.10	0.23	0.19	0.15	0.21	0.21
Total cattle (head)	16	24	43	68	69	73	73

Note: The darker the green color, the stronger positive impact.

mirror each other. This allows us to chart the elements that shape farmers' decision-making processes and their relations (Fig. 5). Even if decisions are made at the household level, several external factors on which farmers have little influence structure their decision making processes. These include the climate, land tenure, agricultural policy, market circumstances and, in our particular case, the CA initiative. This figure depicts the factors of production which are the resources farmers have in relative amounts. They engage these resources in farm-based production and extra-farm activities including wages (off farm) and self-employment (non-farming) activities. Farm-based activities evolve according to the boom-bust phase (mungbean>maize>cassava>orchard) and the participation of farmers in the CA initiative. In addition to the amount of production factors available, several variables influence their decisions to combine these activities. These include risk management, experience, interest, opportunities or neighbors' influence. Depending on the performance and success of these different activities, smallholders make strategic decisions in order to maximize their incomes. These imply changes in land assets, labor and debt management, [dis]investment and the level of involvement in CA practices.

4.2. *Opportunistic conversion to new cash crops in the face of land degradation*

4.2.1. *Game*

During the game, it was quite apparent that the players did not

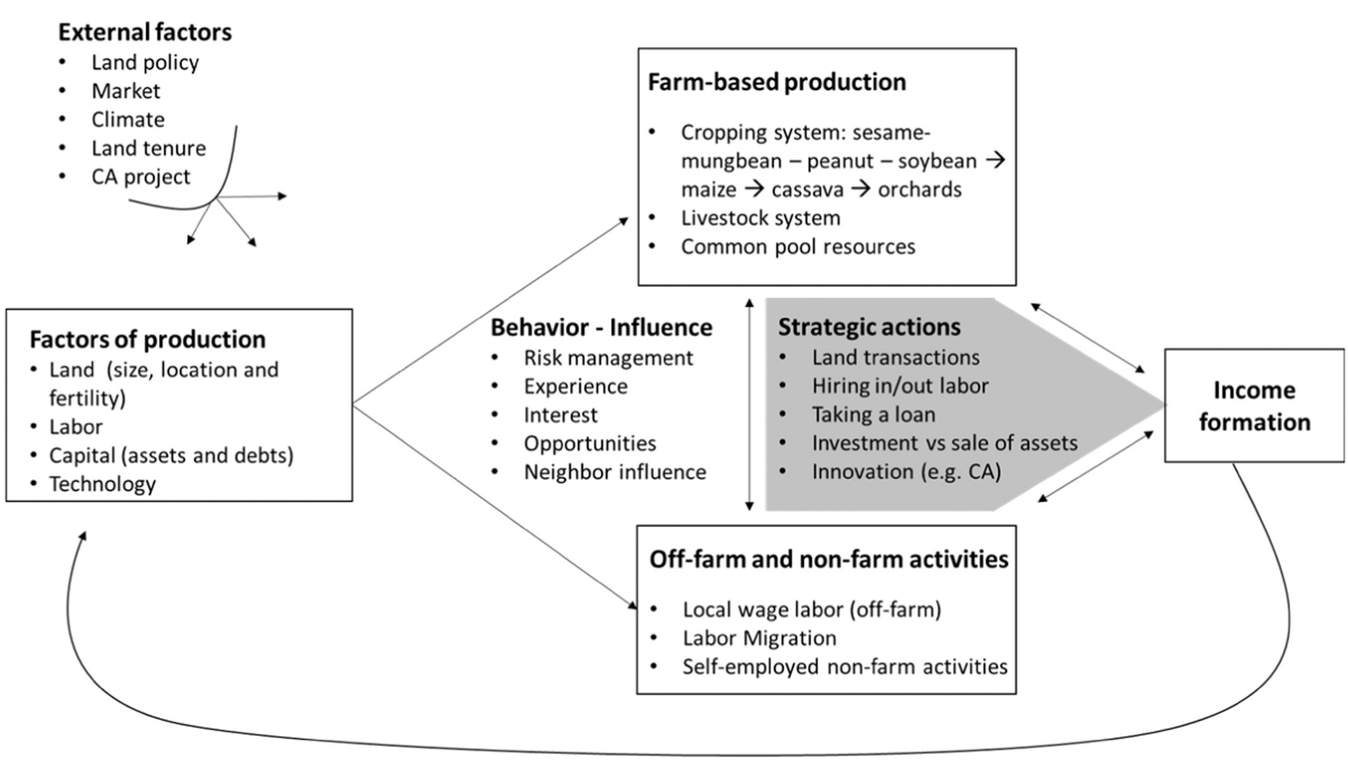

Fig. 5. Diagram describing farmers' decision making process.

anticipate the negative impacts of soil fertility depletion on their farms. During the game debriefing, they explained that when the maize bust phase started and yields were reduced to a critical level (Round 3), they had no choice but to apply chemical fertilizers. The participants in the game added that chemical fertilizers and herbicides were widely promoted by agribusiness companies who convinced them it was their only option to sustain yields. We expected a different strategy to emerge in CA villages as compared to non-CA villages as the former were expected to understand alternative cropping systems. However, only a few farmers in CA villages opted for rotational and sequenced cropping with pulse crops or improved pasture as a fertility management alternative to chemical fertilizers. These farmers explained that they played this way based on their prior experience with CA practices and would have opted for chemical-based maize intensification if they had not been exposed to the CA initiative.

The cumulative effect of conventional tillage systems on soil fertility depletion was simulated by introducing a 'soil capital' parameter that would be depleted over successive years of tillage and monocropping and would be replenished by no-till practices, mulch and cover crops as well as rotations with pulse crops. Their decisions led to 43% soil fertility depletion as compared with the initial soil capital in Round 5 (Table 4). While some farmers adopted soil conservation practices as an option to sustain their yield and income (see next section) the game showed that their preferred action was to switch to another commodity. Players in both CA and non-CA villages, were keen on trying new boom crops to replace maize (cassava in Round 5 and orchards in Round 6). Nevertheless, lessons from past experiences led some players, usually small to medium land farmers, to diversify agricultural activities through cattle raising and off-farm activities in Round 5 (Fig. 6).

4.2.2. Reality

At the initial stage of boom crop expansion, farmers/players often simplified their economic calculations by discounting the risks (Kong and Castella, 2021). They somehow postponed the time they would have to deal with gradual depletion of soil fertility and unpredictable extreme events (both economic and environmental). During the game they had to deal with these risks although they were always hoping for another, more productive alternative boom crop to pop up and to support further economic development as happened in the past with maize, cassava and mango. Otherwise, the alternative income sources for resource-poor households would involve migration in search of off-farm jobs in the garment industry or in neighboring Thailand.

After a few years of maize monocropping, yields began to decrease, although the associated economic loss was temporarily compensated by the increasing farm gate price of maize allowing farmers to maintain their revenues at a decent level. Farmers tended to overlook soil fertility aspects and were not much concerned as long as maize provided higher economic returns than any alternative crop or farm activity. Indeed, problems accumulated at the end of the 2000 s: yield losses, pest damage, agrochemical dependence, production cost increases, indebtedness, price fluctuations, soil erosion, fertility depletion, increasing rainfall variability (Table 4). However, an alternative to maize appeared in the form of cassava which was booming at the same time in other provinces (Mahanty and Milne, 2016). As shown in the game, farmers - particularly those from the non-CA villages - shifted from maize to cassava monocropping, without knowing or being informed of possible adverse impacts. In real life, most farmers did not have enough capital to invest in mango as we observed in the game, so shifting to cassava was the preferred option.

4.3. Perceptions and impacts of the CA project

4.3.1. Game

In the absence of alternative cash crops in Round 3, the players massively opted for CA practices to cope with maize productivity decline. These practices were already known by most players in CA villages and were promoted by game facilitators in non-CA villages for better soil fertility management, higher income and lower labor requirements. The CA adoption rate in the game, up to 80% in both CA and non-CA villages (Fig. 7), was much higher than what happened in reality. Interestingly, the adoption rate was lower in the CA villages. During the game debriefing sessions, farmers from the CA villages recognized their current knowledge of the CA initiative constraints, such as untimely provision of the no-till planter. Generally, the farmers admitted that they were playing the game with their current experience and knowledge of agricultural transformations (soil depletion and yield drops) while they were less concerned by this problem at the time of the CA project when the maize yields were still high.

Even though cassava productivity was higher than that of maize in Round 5, players in the CA villages continued CA practices on about 50% of the cropped area (Fig. 7), compared to only 10% for those in the non-CA villages. This result is consistent with a survey of CA farmers in 2014,

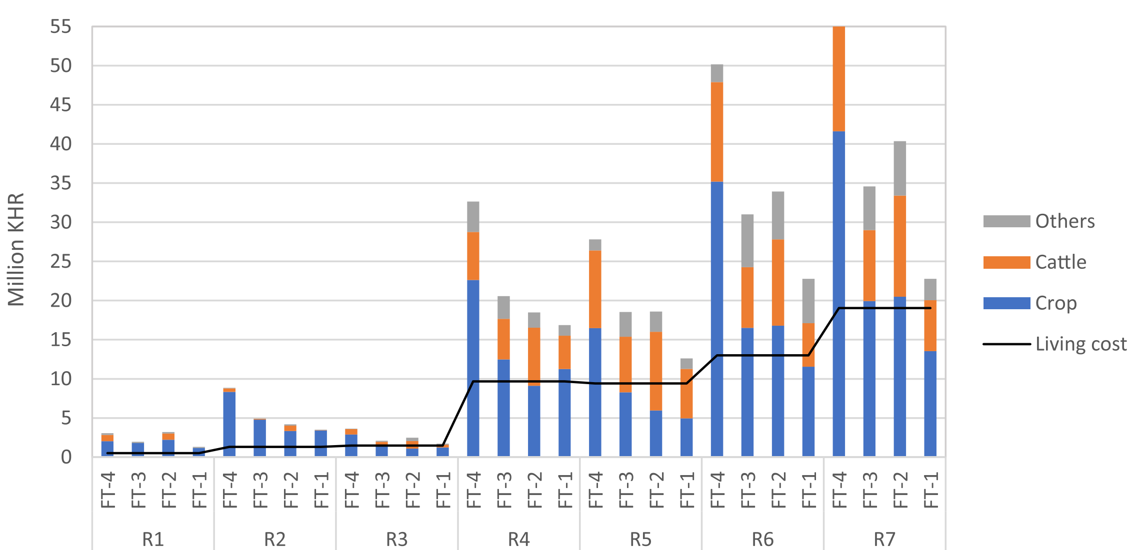

Fig. 6. Composition of farm income for the four farm types identified in Rotonak Mondol. 2002–2005, 2006–2007, 2008–2009, 2010–2012, 2013–2015, 2016–2018, and 2019. Source, Note: - FT-1: Off-farm income dominated farm; FT-2: Paddy-based farm; FT-3: Upland crop-based smallholder farm; FT-4: Upland crop-based large-scale farm, - Constant KHR currency value is computed based on the average inflation rate during the periods corresponding to the successive rounds (R1 to R7), i.e. 2002–2005, 2006–2007, 2008–2009, 2010–2012, 2013–2015, 2016–2018, and 2019

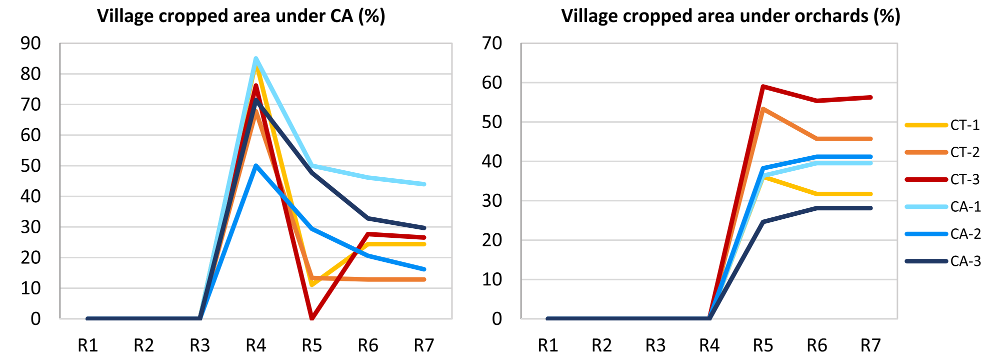

Fig. 7. Village cropped area under CA (%) and orchard (%) during the game.

which found that they practiced CA on more than 50% of their farmland. In addition, CA farmers believed that crop diversification could help them cope with market fluctuations and weather hazards, therefor they shifted to cassava and orchards on relatively smaller areas than in the non-CA villages in view of maintaining more diversified farming systems.

We did not project into future scenarios with the game through simulating additional rounds. However, we could observe how players anticipated the future. Based on game results, and in the absence of convincing alternative land uses, the poorest segments of the farming

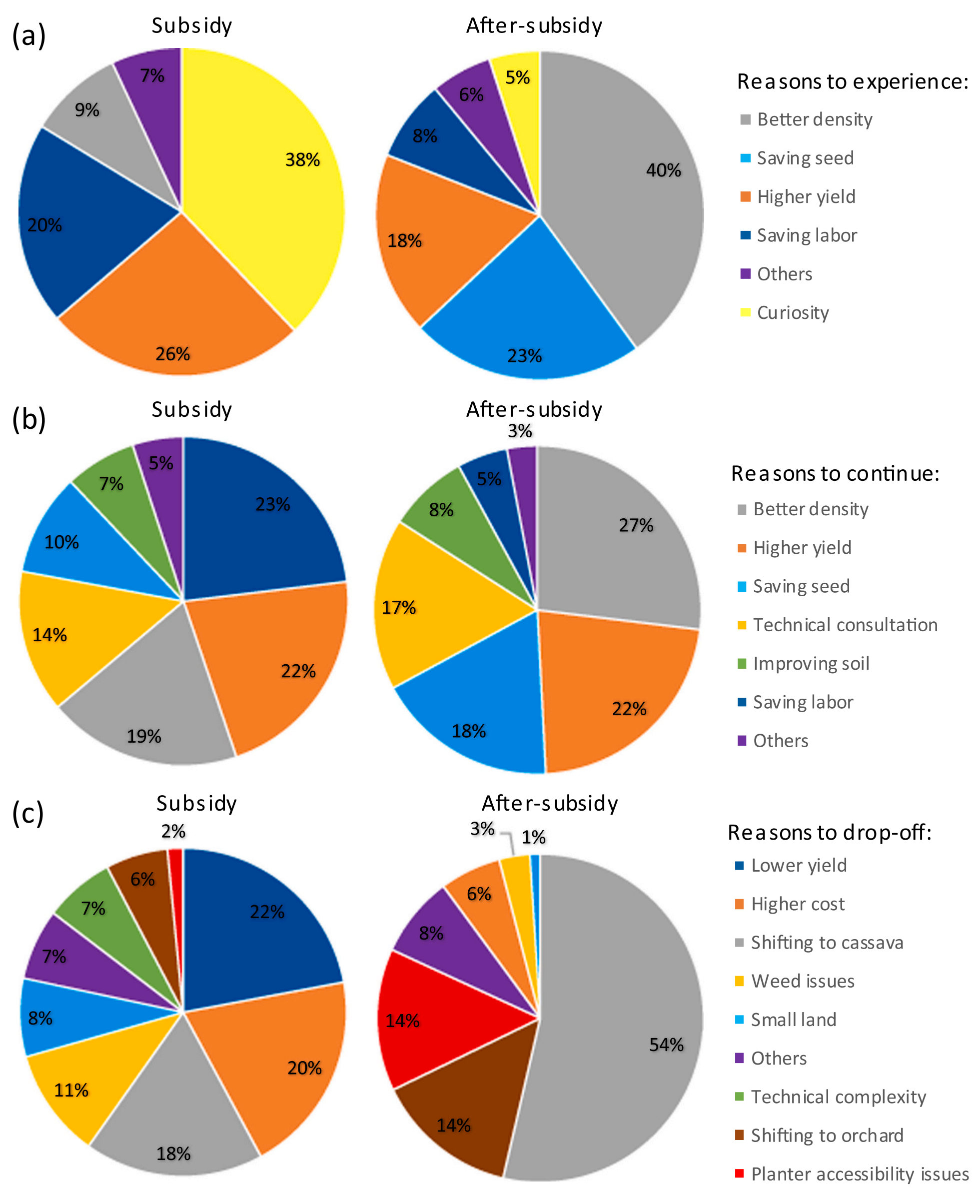

Fig. 8. Reasons to experiment CA then to continue or drop-off during and after the subsidy period of the CA project.

community have no other option than to migrate again thus feeding the rural exodus to Phnom Penh or to neighboring Thailand. This emigration contributes to a process of land concentration in the hands of successful farmers with projected land uses being dominated by orchards and grazing areas for cattle as these activities were considered less risky and require less labor.

4.3.2. Reality

The CA initiative introduced alternative cropping practices through different intervention mechanisms during the two periods mentioned, i.e. with subsidy (2010–2012) and without subsidy (2013–2017). The first period corresponded to the peak of the maize boom, when farmers massively adopted the high-input, mono-cropping system (Kong et al., 2016). The individual interviews conducted with farmers after the game revealed that the most important reasons for farmers to experiment CA were curiosity, zero interest credit, yield insurance included in the package and labor saving no-till planter services (Fig. 8a). The curiosity factor was the highest among the upland crop-based large farmers who wanted to know if CA techniques would improve maize yield and if soil fertility could be maintained. In contrast, the subsidy package and labor savings were dominantly reported among the upland crop-based smallholder farmers, land-poor off-farm income dominated farmers and paddy-based farmers. The opportunity to reallocate the saved labor to other activities was an incentive for CA adoption. Some large upland farms also tried the CA package on some of their land to reallocate the saved labor on CA fields to other maize fields managed under conventional tillage.

As revealed by the individual interviews conducted after the game, the choice to try or maintain CA practices after the end of the subsidy period, was motivated by the quality of sowing, saving seeds during sowing operation, and yield increases (Fig. 8b). These three factors were related to the use of the no-till planter since it allowed precise depth of sowing as compared to other planters or manual sowing, providing better crop density and enabling the crops to grow homogeneously. There was no noticeable difference between farm types in terms of CA adoption during the second period. The increasing number of CA households and areas converted to CA is attributable to the flexibility provided by the technical team on all components of crop management other than the CA sowing service. Farmers thus perceived CA practices as simpler than during the first period when the package was coming with a cover crop they could not harvest because it was used as mulch for direct main crop sowing.

In reverse, the reasons for abandoning CA during the subsidy period were farmers' beliefs they would get the same or lower yield, would incur higher production costs in particular on chemical fertilizers, and high weed pressure, leading to lower economic returns as compared to CT (Fig. 8c). The ban imposed by the project on atrazine and paraquat herbicides, commonly used in CT, made weed control less efficient and consequently lowered yields in already high weed pressure fields. The application of chemical fertilizers to rebalance soil nutrients and boost yields was not fully responsive since the rainfall distribution became increasingly erratic and because some farmers applied lower doses to save them for CT or paddy fields. In addition, large upland farmers complained about the technical complexity of the CA package, which required many operations, strict timing and field care. On the other hand, the small upland farmers who dropped CA explained their decision by citing their small land area and need to harvest twice a year to obtain a higher and more regular cash flow.

After subsidy withdrawal, farmers dropped out of CA exclusively to shift to cassava and orchards (Fig. 8c) particularly after 2015, which led to a sharp decrease in the number of CA farmers both in the game and in reality, without noticeable differences between farm types (Fig. 2 and Fig. 8c). This massive shift was justified by the higher economic productivity of cassava and orchards as compared to maize. There was no CA alternative readily available for cassava since the project did not have a no-till planter available for cassava, and CA for orchards was outside the intervention's scope. Limited farmer access to the no-till planter was also a cause of CA drop-off during that second period. The CA team had only two planters, and the demand for no-till sowing services was not economically attractive for a private contractor to engage in this new business. In addition, availability of no-till planters and their purchase cost were among the main constraints in the dissemination of these tools.

5. Discussion: an ex-post evaluation of farmers' decisions on CA adoption through gaming-simulation

5.1. Using gaming approaches in investigating land use transitions

Despite the limited numbers of players who took part in the co-design (# 24) and implementation phases (# 48) of the game, we are confident that the game captured the main features and trends of the upland villages in the study area. We compared the outputs of the game with those of the surveys through a participatory validation during the debriefing sessions. Participants confirmed that the game adequately captured recent land use changes and farming system diversity. They confirmed that the decisions villagers took in reality had the same causal relations as those they took in the game. As observed by Ornetsmüller et al. (2018) in similar games conducted in Laos, an important scientific implication is that debriefing sessions conducted after each round allowed players to validate or correct the hypotheses researchers made regarding land use trajectories or decision making.

The only important differences between what happened in the game as compared to reality were due to the time gap between the game simulation periods and the current situation. Participants re-played their past decisions with their current mindset and experience. They tended to play their present, as opposed to their past or future (e.g. cattle, improved pasture, and vegetable). They recognize that everything that had happened since that time influenced their decisions during the game. For example, their perception of the maize yield collapse risk is very different today as compared to the mid-2000 s. At that time, they thought they would grow maize forever with the same yields but now they know that a collapse can happen since they experienced it. Therefore, they are more eager today than in the past to take action on sustainable land management. In an attempt to avoid this time-lag effect, Ornetsmüller et al. (2018) sampled villages positioned at different stages of the land use trajectory at the time of the gaming sessions. The remoteness and accessibility issues of some villages allowed substituting distance for time. However, such a sampling design was not possible in the case of Cambodia as all villages are easily accessible. It was no longer possible to find villages in which agriculture resembled that of the last decade. Despite this constraint, our experience corroborates Ornetsmüller et al. (2018) observation that role play gaming allows investigating land use changes and farmers' decision making within a few weeks while non-participatory, survey-based research would take months to be completed and validated.

5.2. Revisiting innovation systems through participatory simulations

5.2.1. Opportunity windows for CA intervention

Gaming sessions confirmed that farmers did not perceive soil fertility issues at this time and were not yet ready to take action. We used the concept of opportunity windows (Castella et al. 2012) to draw practical lessons from these results. During debriefing sessions, we identified periods in local land use trajectories when the introduction of innovative systems was more likely to fail. This was especially the case at the beginning of the boom crop expansion, when the new crop allowed an impressive jump in economic returns and fertility depletion was not yet visible. The crop spread rapidly and easily with the support of agribusiness companies, and farmers largely ignored the messages promoting alternative cropping practices. This phenomenon was described in different agricultural contexts and with different crops (Hall, 2011, Mahanty and Milne, 2016, Cramb et al. 2017). We thus preconize targeting intervention during the periods preceding the boom to prevent its disastrous consequences, or in the aftermath of the boom to engage with communities in landscape restoration. The gaming approach has shown its relevance in rapidly identifying with local communities the most favorable time for intervention depending on their locations (Ornetsmüller et al. 2018).

5.2.2. From converting to transitioning to CA

The CA intervention incentivized the adoption of a full technical package including cover crop, no-till planter, free credit and yield insurance to convince farmers to test the new practices at the most difficult stages of the land use trajectory. Most farmers perceived CA as an innovative package that was technically complex and against their logic of crop management simplification with herbicides, fertilizers and mechanization. The large quantity of biomass produced by the cover crop to boost soil fertility and improve yields did not provide the short-term economic rewards expected by early adopters of the first period. Farmers, like some of the project's technicians, were still conceiving CA techniques in a logic of monocropping and did not envisage them as an element of wider agro-ecological transition based on diversified cropping systems and complex landscape mosaics. In addition, the agribusiness companies were promoting a one crop at a time (i.e. maize) strategy and thus the market for pulse crops was almost nonexistent. Finally, the project interventions failed to create the critical mass of CA farmers that would have raised the interest of private contractors to engage in a no-till sowing service. Retrospectively, playing the game at an earlier stage during the CA project could have identified these constraints, thus adjusting the intervention approach to the local reality more quickly.

During the second period (without subsidy), many farmers switched to cassava as an alternative to maize. Their main interest was to continue generating quick cash income with boom crops as they did with maize during the previous period, then to shift again to another commodity even with high risks and investment when profitability would decline. Cattle and off-farm and non-farm activities (local wage labor, migration work, and self-employment) were considered as safety nets when investing in risky boom crops such as cassava first and later orchards. Within such a context, as simulated during Round 5 of the game, the underlying logic of the CA package was no longer relevant. As a result, the CA team changed from a logic of conversion to CA, i.e. involving the full adoption of a technical-economic package, to a logic of transition to CA, considered as a stepwise process that would gradually include elements of CA within the existing cropping systems. This transition logic was combined with an objective of diversification. During the second period, the team provided innovation elements for all land use types (not focusing on maize only), for example orchards, pasture, cattle, cassava, etc., in an attempt to improve cropping systems within a larger perspective of sustainable landscape management and integration of all innovation system actors (including agribusinesses, NGOs, etc.) in the local development process. Impact was then measured in terms of individual behavioral changes, interactions among stakeholders, perceptions on soil fertility, management of wild fires, understanding of crop diversification, and no longer in a simple accounting of the number of project beneficiaries or the package adoption rate.

5.3. Exploring pathways toward sustainable agriculture

5.3.1. Enhancing social organizations to address technical constraints

The gaming approach pointed out a number of technical constraints to the larger adoption of sustainable land management practices such as the availability of equipment that enable CA alternatives cropping systems and the availability of seed of cover crops. So far, the CA team manages all equipment and services and the team members work with private contractors to increase the supply of no-till planters and mainstream CA services through market stakeholders and mechanisms. This turning point in the innovation process is reachable, although the game also revealed several organizational issues impeding overture to a larger network of stakeholders. During the debriefing sessions participants confirmed that the individualistic behaviors displayed during the game were similar to reality. They attributed these behaviors to the distance between farms, the large size of the villages which prevented people from knowing each other and the fact that people migrated from many different places and therefore did not share a common history of place. But more profoundly, the recent turmoil of war and conflicts profoundly disrupted social organization in Cambodia (Ledgerwood and Vijghen, 2002). In previous years, agriculture developed through pioneer front mechanisms (i.e. gradual forestland clearance by migrants – Kong et al. 2019) and therefore did not require strong social ties to expand. However, as land's end is reached local farmers realize that they have to shift from land rush to sustainable land management. They have to co-design a new agricultural paradigm.

5.3.2. Going to scale through social learning

One outcome of the game has been to create a deliberative process through which farmers could come up with a shared diagnosis of agricultural issues with which they have been grappling for 2 decades: land degradation, decline of agricultural income, simplification of agrarian landscape, etc. Farmers who played the game were rapidly convinced of the value of alternative practices and discussed the technical as well as organizational constraints to large-scale adoption. By doing so, the game helped consolidate a community of interest and practice around more sustainable land use practices.

The RADA game revealed subtle elements of collective learning that took place over the course of the project. For example, in the CT villages, several players were initially reluctant to adopt CA because they were afraid the fire hazard would be increased by the mulch in their CA plots. Their concerns were even greater with orchards which require higher upfront investment. In CA villages however, participants had acquired experience in fire control by devising firebreaks, for example, and explained the advantages of mulch to their children thus preventing them from burning it. This social learning was supported by the project yet had never been attributed to it until we played the game. These experiences were thus discussed during the game and options for collective management were proposed.

This brought the project proponents to discuss a number of interventions and approaches with local authorities in order to bring these results to scale. This approach would consist of working concomitantly on different aspects of this transition to CA: i.e. promoting the adoption of technical innovation, nurturing farmer-to-farmer learning as well as sharing and linking them to market actors. A gaming approach is likely to support such a multi-stakeholder process involving farmers, service providers, local administration and agribusiness representatives to pilot a territorial approach. It would consist of redesigning the landscapes and livelihoods from natural resource mining in a pioneer front to local land use planning conducive to complex agro-ecological assemblages in multifunctional landscapes (Duru et al., 2015a, 2015b).

6. Conclusions

We developed a gaming-simulation approach to analyze farmers' reactions to external interventions promoting sustainable land management practices. The game was designed as a process to elicit farmers' perception on land-use transitions and agricultural innovation introduced by a conservation agriculture project in a context of rapid land use changes. Including the non-CA villages in the game helped assess the project's impacts by comparing farmers' decisions 'in context' with or without CA interventions. We could also analyze how they solved the problems they were facing in the game in order to compare this with the solutions they had applied in reality. In addition, the players revealed how they perceived external interventions and articulated their needs for additional support, such as how to reach stable market prices or improving farm efficiency. Indeed, the farm types described in this paper have specific capacities and resources to engage in CA practices, e.g. family labor force, capital available, technical knowledge, activity portfolio. As these capacities are not evenly distributed across farm types, there is no one-size-fits- all alternative to unsustainable land management practices.

The second lesson from the RADA game is the need to coordinate efforts among farm types to foster their innovation capacities. Policy instruments supporting such coordination should therefore become a priority. They should create an enabling environment to strengthen farmers' organizations, such as informal communication groups or formal cooperatives, and connections with other actor networks along the food and feed crops value chains. Beyond revealing the necessary changes in local institutions and behaviors, the game may help enhance social learning. The RADA game showed the need to move from an individual crop approach to a more integrated farm-to-landscape one, which would involve nearly all farming system components. It also showed the need to enlarge the learning process circle of participants by engaging with multiple stakeholder groups thus up-scaling efforts already made at the local levels. Engaging stakeholders in agricultural innovation systems requires profound transformations of local institutions and social organizations.

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Appendixes. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2021.105404.

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