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AGROECOLOGICAL INTENSIFICATION OF INTEGRATED AGRICULTURE AQUACULTURE SYSTEMS: THE CASE OF SMALLHOLDER FARMS IN THE WESTERN DEMOCRATIC REPUBLIC OF CONGO

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Abstract

In the Democratic Republic of Congo (DRC) as in other sub-Saharan African (SSA) countries, small farms face the problem of low yields. To meet the challenge of stably and sustainably increasing production, some smallholders are turning to integrated agriculture aquaculture (IAA) production systems developed in South-East Asia. It is based on the exchange of nutrient flows between different subsystems among which fish ponds play a key role. It allows small farms to be less dependent on external resources, increasing profitability. However, the expected results are not yet visible in SSA. The objective of this thesis was to identify which levers can be used to optimize overall production at the farm level in the humid tropics in an African socio-economical context, using the periphery of Kinshasa as a case study. We hypothesized that the level of integration of flows determines the stability of IAA farms, focusing on nitrogen (N), both in terms of quantity and quality, as it is the major limiting factor in both terrestrial and aquatic production.

A survey of 150 integrated agricultural farms in two peri-urban and one rural area of Kinshasa helped to understand how ponds are managed in the integrated systems. A subsequent monitoring of 11 integrated agriculture aquaculture farms for eighteen months with at least two visits per month helped to understand the functioning, the strengths and the weaknesses in the technical and economic organization of IAA farms. In order to quantify and propose a more efficient use of N flows, a mathematical model has been developed. Finally, experiments with locally available resources were carried out to improve efficient use of N flow from pig at the farm level; namely by adding an insect larvae production subsystem in the IAA farms.

Results indicated that 79% of fish ponds in Kinshasa were located on farms integrating fish with livestock (mainly pigs) and/or vegetable farming. No striking difference in farm characteristics between urban and rural farms was denoted, except for fish feeding practices. IAA is generally applied in small farms with limited financial resources and some of them are unable to generate profits, although they all have a positive gross margin. Due to the lack of commercial feed for feeding fish, farm wastes and agro-industrial by-products are widely used as fish feed despite their low nutritional value, especially regarding the protein content and nutritive value of fish. At least eleven possible flows can be exploited with the three main subsystems, i.e. fish ponds, pigsties and vegetable beds, present on a farm with a relatively high use of pig manure as fertilizer for vegetable crops and as an indirect feed protein input through primary production in the fish food chain. The level of education and the involvement of the farm owner have proven to be crucial factors that can allow a better organization of the farm both technically and financially and take maximum advantage of the complementarity of flows between farm components. Losses of N due to poor management of some flows between components have been noted, especially during the harvesting and storage of pig manure which often requires additional labour. Nevertheless, a more appropriate management of N outflows from pigs, which were evaluated at 14gN/pig and 20gN/pig per day, for fecal and urinary forms respectively, by the mathematical model, can help farmers to reduce N losses. For instance, raising pigs above ponds

has been shown to be much more effective in minimizing N flow losses and handling requirements due to the natural collection of both feces and urine, which is often difficult in rural and peri-urban pigsties. It also allows farmers to reduce pond density per are of pond in the farm. Feces can also be harvested and used effectively as a substrate for the production of insect larvae, in mixture with agro-industrial wastes. Indeed, feces contain not only N but also undigested proteins and bacteria. They can be used more efficiently to produce a protein source and lead to the design of a new IAA system. In this system the natural production of flies larvae, whose growth limiting factor is probably lysine, could be improved by mixing pig manure with brewers' grains as locally available substrates. The produced larvae with a good amino acid profile can then be used as a complement to fish feed. At the farm level, a prototype infrastructure for maggot production was built directly on the ponds and allowed intensive production, natural harvesting of maggot in the ponds and reduced requirements for handling the manure by the farmers.

In conclusion, integrated agriculture aquaculture systems as applied in the humid tropics of the DRC are able to fulfill their promises of stabilizing production and turning farms profitable. This goal may be achieved if farmers apply a thoughtful strategy for labour management in the farm and get personally involved in the farm’s activities. Farmers need also to focus on reducing N losses through N flows management between subsystem in the farms. They can give particular attention to the pig density and the use of pig manure in the other subsystems. Finally farmers can use the solution proposed by the simulation model according to the available resources and its environment.

Keywords: livestock, fish pond, vegetable, agro-ecological, profitability, nitrogen modelling, maggot

Résumé

En République démocratique du Congo (RDC) comme dans les autres pays d'Afrique subsaharienne (ASS), les petites exploitations sont confrontées au problème des faibles rendements. Pour relever le défi d'une augmentation stable et durable de la production, certaines petites exploitations agricoles se tournent vers des systèmes de production de l'agriculture intégrée à l'aquaculture (IAA) développés en Asie du Sud-Est. Il est basé sur l'échange de flux de nutriments entre différents sous-systèmes parmi lesquels les étangs jouent un rôle clé. Il permet aux petites exploitations d'être moins dépendantes des ressources externes, ce qui augmente leur rentabilité. Toutefois, les résultats escomptés ne sont pas encore visibles en Afrique subsaharienne. L'objectif de cette thèse était de comprendre quels leviers peuvent être utilisés pour optimiser la production globale au niveau des exploitations agricoles sous les tropiques humides dans un contexte socio-économique africain, en utilisant la périphérie de Kinshasa comme étude de cas. Nous avons émis l'hypothèse que le niveau d'intégration des flux détermine la stabilité des fermes de l'IAA, en mettant l'accent sur l'azote (N), tant en quantité qu'en qualité, car c'est le principal facteur limitant de la production terrestre et aquatique.

Une enquête menée auprès de 150 exploitations agricoles intégrées dans deux zones périurbaines et une zone rurale de Kinshasa a permis de comprendre comment les étangs sont gérés dans les systèmes intégrés. Un suivi subséquent de 11 fermes d'agriculture intégré à l'aquaculture pendant dix-huit mois avec au moins deux visites par mois a permis de comprendre le fonctionnement, les forces et les faiblesses de l'organisation technique et économique des exploitation agricoles intégrées. Afin de quantifier et de proposer une utilisation plus efficace des flux d'azote, un modèle mathématique a été développé. Enfin, des expériences ont été menées avec les ressources disponibles localement pour améliorer l'utilisation du flux d'azote provenant des porcs à l'échelle de l'exploitation, notamment en ajoutant un sous-système de production de larves d'insectes dans les exploitations.

Les résultats indiquent que 79% des étangs piscicoles de Kinshasa étaient situés dans des fermes intégrant des poissons avec du bétail (principalement des porcs) et/ou des légumes. Aucune différence frappante dans les caractéristiques des fermes entre les fermes urbaines et rurales n'a été relevée, à l'exception des pratiques d'alimentation des poissons. L'IAA est généralement appliquée dans les petites exploitations agricoles aux ressources financières limitées et certaines d'entre elles ne sont pas en mesure de générer des bénéfices, bien qu'elles aient toutes une marge brute positive. En raison de l'absence d'aliments commerciaux pour l'alimentation des poissons, les déchets d'élevage et les sous-produits agro-industriels sont largement utilisés comme aliments pour poissons malgré leur faible valeur nutritionnelle, notamment en ce qui concerne la teneur en protéines et la valeur nutritive des poissons. Au moins onze flux possibles peuvent être exploités avec les trois principaux sous-systèmes, à savoir les étangs piscicoles, les porcheries et les cultures maraîchers, présents dans une exploitation. Le lisier de porc est relativement utilisé comme engrais pour les cultures maraîchères et comme apport indirect de

protéines alimentaires par la production primaire dans la chaîne alimentaire des poissons. Le niveau d'étude et l'implication du propriétaire de l'exploitation se sont avérés être des facteurs cruciaux qui peuvent permettre une meilleure organisation technique et financière de l'exploitation. Ils permettent aussi de tirer le meilleur parti de la complémentarité des flux au niveau des exploitations. Des pertes d'azote dues à une mauvaise gestion de certains flux entre les composants ont été constatées, en particulier lors de la récolte et du stockage du lisier de porc qui nécessite souvent du travail supplémentaire. Néanmoins, une gestion plus appropriée des sorties d'azote des porcs, qui sont évaluées quotidiennement à 14 gN/porc et 20 gN/porc respectivement, pour les formes fécales et urinaires par le modèle mathématique, peut aider les agriculteurs à réduire les pertes d'azote. Par exemple, l'élevage des porcs au-dessus des étangs s'est avéré beaucoup plus efficace pour minimiser les pertes de flux d'azote. Mais aussi pour minimiser les besoins de manipulation en raison de la collecte naturelle des excréments et de l'urine, qui est souvent difficile à collecter dans les porcheries rurales et péri-urbaines. Il permet également aux éleveurs de réduire la densité de porcs par étang dans l'exploitation. Les excréments peuvent également être récoltés et utilisés efficacement comme substrat pour la production de larves d'insectes, en mélange avec des déchets agro-industriels. En effet, les matières fécales contiennent non seulement de l'azote, mais aussi des protéines et des bactéries non digérées. Ils peuvent être utilisés plus efficacement pour produire une source de protéines et mènent à la conception d'un nouveau système de l'IAA. Dans ce système, la production naturelle de larves de mouches, dont le facteur limitant la croissance est la lysine, pourrait être améliorée en mélangeant du lisier de porc avec des grains de brasserie et/ou du sang de vache comme substrats disponibles localement. Les larves produites avec un bon profil d'acides aminés peuvent alors être utilisées en complément de l'alimentation des poissons. A l’échelle de la ferme, une infrastructure prototype pour la production d'asticots a été construite directement sur les étangs et a permis une production intensive, la récolte naturelle d'asticots dans les étangs et une réduction des besoins de manutention du fumier par les agriculteurs.

En conclusion, les systèmes d’agriculture intégrée à l’aquaculture tels qu'ils sont appliqués dans les régions tropicales humides de la RDC sont en mesure de tenir leurs promesses de stabilisation de la production et de rentabilité des exploitations. Cet objectif peut être atteint si les agriculteurs appliquent une stratégie réfléchie de gestion de la main d’œuvre à la ferme et s'impliquent personnellement dans les activités de l'exploitation. Les agriculteurs doivent également se concentrer sur la réduction des pertes d'azote par la gestion des flux d'azote entre les sous-systèmes des exploitations. Ils peuvent accorder une attention particulière à la densité des porcs et à l'utilisation du lisier de porc dans les autres sous-systèmes. Enfin, les agriculteurs peuvent utiliser la solution proposée par le modèle en fonction des ressources disponibles et de leur environnement.

Mots-clés : Elevage, étang, maraîchage, agro-écologie, rentabilité, modélisation de l'azote, asticot.

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SSA	Sub Saharan Africa
IAA	Integrated agriculture aquaculture
SSD	Sums of squared deviations
HFL	Housefly larvae
VAC	Vuon ao chuong
GDP	Gross domestic product
NGOs	Non-governmental organization
TLU	Tropical livestock unit
SD	Standard deviation
ICLS	Integrated crop-livestock system
DM	Dry matter
diOM	Digestibility of organic matter
AA	Amino acid
CP	Crude protein
ICBA	International Center for Biosaline Agriculture

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General introduction

General Introduction

1. Introduction

Africa is facing various issues. Its population with more than 950 million representing about 13% of the world's population is growing at an unprecedented pace, 2.7 percent per year. In 2050, Africans will represent nearly 22% of the world’s population, or 2.1 billion people (OECD/FAO, 2016). Climate change, soil degradation with severe nutrient depletion (nitrogen, phosphorus etc.) low crop yields, and poverty due to traditional farming methods (Gravel, 2016) does not help in answering the challenge posed by population growth. Most people in SSA are involved in agriculture as smallholder farmers with average parcels of land less than 2 hectares (FAO, 2017). They play a key role producing 80 per cent of the food supply of the continent (FAOSTAT, 2017). Nevertheless, to face these challenges, agriculture in SSA needs to be more productive and more efficient at using the available resource bases (Darnhofer et al., 2010; Garnett et al., 2013).

Intensification of agricultural production has been driven by a large use of non-renewable resources that often impairs environmental sustainability, as well as by a huge simplification of agricultural systems at all levels of organization (Lemaire et al., 2014). In the past 40 years yields have increased, resulting from greater inputs of fertiliser, water, pesticides, new crop varieties and other technologies of the well-known ‘Green Revolution’, increasing the global per capita food supply reducing hunger, improving nutrition (Tilman et al., 2002). However, intensification and specialization of agricultural systems in particular in industrialized countries came along with increasingly negative impacts on the environment (Pingali, 2012). According to Bommarco, Kleijn, & Potts (2013) these impacts decrease the provision of non-productive ecosystem services and, consequently, limit potential agricultural production in the long run.

Given the negative impacts of intensive agriculture, ecological intensification of food production is an urgent challenge for Sub Saharan Africa (Dey et al., 2010). Ecological intensification is a concept in agriculture that addresses the dual challenge of maintaining a sufficient level of production to meet the needs of human populations and to respect the environment in order to preserve the natural world and the quality of human life (Aubin et al., 2017). It aims to achieve high physical efficiency while reducing environmental impacts and reliance on non-renewable external resources (Leterme & Morvan, 2010).

Agricultural stakeholders are designing new sustainable food systems that can be seen as a response to farmers' and consumers' dissatisfaction with the negative impacts of industrial, agricultural intensification in developing countries (Dumont et al., 2013, Dorin, 2014). Mixed farming systems, which account for nearly half of current world food production and are present in almost all agro-ecological areas of the world, could provide solid alternatives to gradually achieve these goals (González-García et al., 2012). Especially in the humid tropics, where agriculture is often applied in a subsistence farming context by small farmers (Stark et al., 2018). Integrated crop-livestock systems (ICLS) for instance are considered as an effective concept for sustainable, ecological farming systems (Bonaudo et al., 2014). The sustainability and efficiency of ICLS relies on the complementarities between crops and livestock at the farm level.

Integrated agriculture-aquaculture (IAA) is one of such mixed farming system that strengthened the benefits of integrated crop-livestock in the tropic and particularly in East Asia, where it is traditionally practiced (Schneider et al., 2005). The presence of ponds coupled to agricultural activities involve many resource exchanges and cycle interactions between subsystems and answers the problem of increased competition for land and water (Ahmed et al., 2014). Adapted to different tropical conditions, and small-scale rural, as well as peri-urban farmers in developing countries with limited resources (Rajee & Mun, 2017), IAA involves to combine various types of perennial crop, vegetables and orchards to livestock and fish farming depending on where it is practiced. Expected benefits from IAA systems consist of greater autonomy, more efficiency and better integration using the available resource bases. It also increases the overall production stability of the system by reducing the magnitude of change after experiencing a disturbance (resistance) and increasing its ability to rapidly recover from disturbance (resilience) (Tracy et al., 2018), and thus, less vulnerable to hazards (Darnhofer et al., 2010; Garnett et al., 2013).

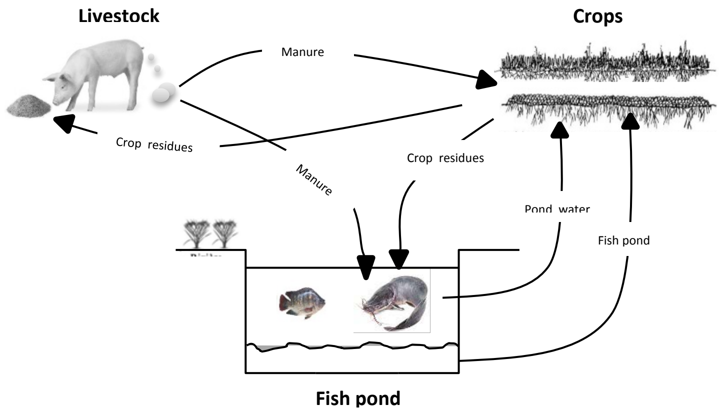

Figure 1. Nutrient cycle in an IAA system, adapted from Nhan et al. (2007).

As displayed in Figure 1, the system works in such a way that animals eat and convert products, by-products, and residues that are not suitable for human consumption; and produce feces and urines. Crops are produced by recycling feces (Taguchi & Makkar, 2015). Crop residues serve as feeds for fish and animal while fish pond sediments and pond water are respectively used as crop fertilisers and for soil irrigation purposes (Murshed-E-Jahan & Pemsl, 2011; Zajdband, 2011). In addition, pond dikes are also used for growing vegetables such as beans, cucumbers, and gourds (Ahmed et al., 2014). That may help provide income while rehabilitating soil through better on-farm nutrient recycling and retention (Tran et al., 2013). In this way the system helps to improve the efficient use of nutrients such as nitrogen (N) and phosphorus (P) which are the most important elements in the production process and in flows and balances of nutrients in agricultural systems. Since N is the most limiting nutrient in both aquatic and terrestrial production due to the large quantities harvested with crops, the ease of gaseous losses, leaching, runoff or erosion, the IAA systems should ideally allow N to be kept as much as possible and recycled on the farm, reducing external input requirements, increasing soil fertility and improving production (Nhan et al., 2007). IAA has been widely appreciated as an effective means for rural farmers to improve economic and production performance of their farming systems and strengthen livelihoods (Brummett and Jamu, 2011).

Several authors highlight successes of IAA systems in East Asian (Frei and Becker 2005; Nhan et al., 2007; Murshed-E-Jahan & Pemsl, 2011; Ahmed et al., 2014) on the one hand. Multiple benefits of the system can be summarized as follows: It is appropriate for resource-poor farmers, in order to maximize benefits from land, water, and labour making the most of scarce resources, since there are often synergistic benefits between the different enterprises. On the other hand, despite some individual success, IAA has done little to reduce poverty and malnutrition in SSA.

It is in this context that the University of Liège and the Catholic University of Louvain in collaboration with the University of Kinshasa and the National Pedagogical University in the Democratic Republic of Congo (DRC) have set up a project on the ecological intensification of integrated agricultural production systems with the aim to intensify and make sustainable the production systems within the framework of which our work was carried out.

Indeed, the Democratic Republic of Congo (DRC) is susceptible to host IAA systems due to its important hydrological resources. The food supply of Congo's cities is highly dependent on imports, especially for meat and fish products. However, in Kinshasa, in the valleys, along the Congo River more than 15,000 professionals and 100,000 occasional vegetables farmers exploit areas from 12 to 15 ares with orchards, medicinal plants associated to small livestock herds raised extensively and ponds that are not fully exploited. Farmers in these areas supplying Kinshasa cannot compete with imports because the productivity of their farms is too low. However, some study shows that IAA has been adopted in other SAA countries (Dey et al., 2010; Efole Ewoukem et al., 2012; Blythe, 2013) following successes in East Asia. Since the benefits of this system in terms of productivity, health risk, input needs and fertility have indeed been demonstrated in other tropical contexts eg Colombia and southeast Asia (Efole Ewoukem et al., 2012) with limited cash flow and pedoclimatic conditions similar to DRC, the presence of multiples subsystems (fish, vegetables and livestock) in DRC farms should be an asset to intensify the local production system. As the production of protein and animal-products is key to improved nutrition in the DRC and because N and/or amino acids are often the most limiting nutrients for both crop and animals, including fishes, a better integration of each subsystem of farms should be an alternative to improve production efficiency without excessive use of external inputs be closing N cycles at the farm level. However, the complexity of the system can become a trap for farmers because each

N transfer in the agricultural system carries a risk of inefficiency, due to losses that can occur between transfer steps from one subsystem to another. From the foregoing, it is clear that issues related to the development of this system in DRC are still a problem and considerable progress is still needed to increase the productivity of this system. As the advances of this system have not yet been clearly established in sub-Saharan Africa (DRC in particular) and as it is still poorly documented, this does not make easy improvement of IAA system in The DRC.

Hence the importance of being able to fully understand the functioning of IAA farms, to identify these weaknesses and to trace the N flows by identifying critical steps or N efficiency in the IAA systems in order to improve the system by enabling it to meet the production and productivity challenges and improve its stability in the DRC and SSA in general. To achieve this, we asked ourselves several questions that we aim to answer in this thesis:

- how do small farms involved in the IAA system work in the outskirts of Kinshasa?
- which components are present and how are they combined?
- do current IAA systems allow farms to be profitable and stable or do they offer opportunities for improvement?
- do types of system and management practices vary according to the location of the farms?
- which subsystems are actually involved in N flows between farm components and how are they managed?
- do N flows management allow to meet the needs of the animals (fish and terrestrial livestock) in terms of quantity and quality? Is there some room for improvement or innovative flows that would improve this efficiency?

2. Objective

The objective of this thesis is to understand which levers can be used to optimize overall production within small IAA farms in the tropics, using the periphery of Kinshasa as case study. We hypothesize that these goals can be achieved by through a better integration of N flows between subsystems at the farm level while predicting their evolution within the farm and making better use of local biodiversity.

3. Strategy

To perform this study, the answers to the main research questions are presented in in chapters based on the articles published or submitted for publication in different peer-reviewed journals. A literature review was conducted to provide an assessment of the current situation of IAA for smallholders in SSA. A survey of 150 small farms with at least one functional pond was subsequently conducted in Kinshasa's rural and peri-urban areas to quantify the extent of pond fish farming and to understand whether pond management depends on the integration of other subsystems. Based on this survey eleven IAA farms were monitored for up to two years to characterize technical and economic aspects in order to improve the understanding of the complexity of IAA systems and the impact of the integration of the different subsystems on the profitability of fish farms. A model has been developed in order to quantify the flow of nitrogen and predict its evolution within the system since it is the major limiting element in both aquatic and terrestrial productions in the tropic. This model envisages the possibility of preserving as much nitrogen as possible within farms. Finally, to improve N cycling at the farm level and address the question of quality of the N-source for the fish ponds, the addition of a new subsystem was tested through three experiments on complementary aspects of the production of housefly larvae (*Musca domestica*) with locally available substrates (industrial by-products, livestock waste) were conducted to use flies that are naturally present around farms in the tropics and produce proteins within the integrated farm.

This document is subdivided into 7 chapters as displayed hereafter. Beside the introduction, general discussion and perspectives, the remaining chapters have been submitted, published or under construction for publication and are adapted as published in the various journals.

Chapter 1: General introduction.

Chapter 2: Smallholders' Practices of Integrated Agriculture Aquaculture system in peri-urban and rural areas in Sub Saharan Africa.

Patrick Mafwila Kinkela, Bienvenu Kambashi Mutiaka, Denis Dochain, Xavier Rollin, Jacques Mafwila, Jérôme Bindelle

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Chapter 3: Diversity of farming systems integrating fish pond aquaculture in the province of Kinshasa in the Democratic Republic of the Congo.

Patrick Mafwila Kinkela, Bienvenu Kambashi Mutiaka, Thomas Dogot, Denis Dochain, Xavier Rollin, Roger Ntoto Mvubu, Charles Kinkela, Jacques Mafwila, Jérôme Bindelle.

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Chapter 4: Characterization of integrated agriculture aquaculture systems in smallholders' farm in peri-urban and rural areas of Kinshasa (DRC).

Patrick Mafwila Kinkela, Bienvenu Kambashi Mutiaka, Desiré Bisimwa Biamungu, Thomas Dogot, Denis Dochain, Xavier Rollin, Roger Ntoto Mvubu, Charles Kinkela, Jacques Mafwila, Jerome Bindelle.

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Chapter 5: Nitrogen prediction model in smallholder farming system integrating pig and fish farming in the urban and rural areas of Kinshasa.

Patrick Mafwila Kinkela, Denis Dochain, Bienvenu Kambashi Mutiaka, Xavier Rollin, Jacques Mafwila, Jérôme Bindelle.

Unpublished chapter

Chapter 6: Optimization of houseflies' larvae on pig wastes and brewers' grains for integrated fish and pig farms in the tropics

P Mafwila, D Bwabwa, N Nyongombe, B Kambashi, J Mafwila, D Dochain, J Bindelle and X Rollin.

Livestock Research for Rural Development, Volume 31, Number 2, February 2019

Chapter 7: General discussion and perspectives.

The following chapter focuses on the general concept of integrated agriculture aquaculture system. It defines the concept as perceived by different authors according to their location and experiences.

This chapter briefly describes the historical evolution of integrated agriculture aquaculture system in Sub Saharan Africa from its early adoption until today. It illustrates the different forms of uses of the integrated agriculture aquaculture systems by listing some examples in Sub Saharan Africa and highlighting their strengths, constraints and future prospects.

It aims to asses the current situation of smallholders practising integrated agriculture aquaculture systems in sub-Saharan Africa and assess the need for improvements that are addressed more extensively in Chapters 3 and 4 which use the contexte of periurban Kinshasa in DRC as a case study.

This chapter adress ata global regional level the first research question on the functioning of integrated systems in general in Africa before this question is addressed more specifically in the subsequent chapters of this thesis.

2

Smallholders’ Practices of IAA system in peri-urban and rural areas in SSA

Article 1

Smallholders' Practices of Integrated Agriculture Aquaculture system in peri-urban and rural areas in Sub Saharan Africa.

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Abstract

Sub Saharan African (SSA) population, which is expected to reach 1,998 million in 2050, is undergoing a demographic transition with an average annual growth rate of 3.7% and an increase in the agricultural population of 1.9%. During the same period, aggregate agricultural food production increased only 2.6%. Meeting food needs should therefore be achieved by improving the labour productivity of farmers in SSA. In the peri-urban and rural SSA, most of the people are smallholder farmers and are resource limited. They live on agriculture and to address the various challenges they face and increase productivity, several strategies have been developed in the search for a model of agricultural development that is more equitable, more ecological and more socially viable. The adoption of an integrated agriculture, aquaculture system (IAA) fits into this framework. The IAA system has been adopted in SSA from Asia based on its achievements. The adoption of IAA is particularly positive for farmers, whose topographical conditions allow for a variety of activities on the farm, including a fish pond. The variants of IAA system are various forms of adaptation to the agricultural practices of each tropical region. During its application in SSA, IAA system has presented advantages and disadvantages, but most importantly, it offers significant opportunities for improvement in the future. This chapter reviews the evolution of this integrated system since its adoption in SSA and elucidates the strengths, constraints and future opportunity of this system.

Keywords: IAA, livestock, vegetable, fish, farm

1. Introduction

Agriculture contributes immensely to the African economy because most of the population in SSA lives in rural areas living essentially from agriculture. Agriculture in SSA participates for about 15% of gross domestic product (GDP) and smallholder farms constitute approximately 80% of all farms in SSA, employing about 175 million people directly (FAO, 2016). Smallholder farms with an average area of 2 ha are seen as key actors in the search for a fairer, environmentally friendlier and more socially viable agricultural development model, since they are meeting about 70% of the food needs of the entire African continent and producing about 80% of the food consumed in Asia and SSA (FAO, 2016). However, SSA is facing various challenges among which the sharp population growth of the continent is not the least. In less than 35 years the population of SSA will have increased 2.6 times reaching 1.3 billion, a figure almost equal to China's projected population (Yeboah and Jayne, 2017). This problem is aggravated in some areas by the displacement of a large number of people, migration due to land pressure, but also to political turmoil and civil wars (FAO, 2016). Land degradation caused by deforestation or overgrazing that leads to nutrient depletion, soil erosion, salinization, pollution are also major issues in African agriculture (Jones et al., 2013). Many authors agree that low and declining soil fertility is a critical problem in Africa. Smallholders remove large quantities of nutrients from their soils without applying sufficient quantities of manure or fertilisers to replenish the soil (Billards, 2014). Depletion of soil fertility is a major biophysical cause of low per capita food production in Africa and constitutes a threat to about one quarter of the productive land of the continent. Sixty-five % of the soils on agricultural lands in Africa became degraded since the middle of the XXth century, as had 31 % of permanent pastures, and 19% of woodlands and forests (Jones et al., 2013). These different challenges tend to delay agriculture development in SSA.

Integrating livestock to crops in mixed farming systems is a key to sustainable agro-ecological production systems for its many ecological and agricultural added-values such as the preservation of soil biodiversity and soil fertility by the recycling of nutrients and organic matter, or the reduction of soil erosion. It also provides social and economic benefits to farmers: risk mitigation from diversification, reduced and more even use of labour across seasons, reduced dependence on external inputs, Assets that can be used to purchase farm inputs, increased added value to agricultural by-products as feed ingredients (Gliessman, 2015). In South-East Asia and China in particular agriculture has confronted similar challenges to those facing SSA and IAA came to play an important role in addressing some. Fish farming is common and fish supply about 30% of the total animal protein in the diet of Asians. Chinese farmers have developed the art of integrated fish farming to a high degree and about 80% of fish productions receive animal manure inputs (Hishamunda et al., 2011).

In addition to the benefits provided by the fish itself; highly nutritious and valuable traditional food in most of Asian and African countries, when it is included as a subsystem in mixed farms, IAA offers more others advantages. For example, fish pond plays a particularly effective role in the recycling of nutrients in the farm and, in processing waste materials without creating some problems associated with mulches and green manures such as weeds or insect pests (Brummett, 1999). Pond water can be used for crops watering and livestock wastes as feed and fertiliser for the fish pond. So IAA lead to increase employment opportunities, profitability of farm and minimizing pollution and use valuable resources (such as water) more efficiently and effectively (Edwards et al., 1988). The successful application of IAA systems has been reported in Asian and other tropical areas and impressive yields have been reported. These systems have been also applied in some SSA developing countries, but few results are documented.

The aim of this chapter is to thus assess the present situation of smallholders practicing IAA in SSA by questioning how this system is applied in SSA, what the existing experiences are, what the positive and negative impacts are, and what future possible progress of such systems in Africa are.

2. IAA SYSTEM DEFINITION, HISTORICAL BACKGROUND.

IAA production units refer to farms on which, besides a fish production unit, several other agricultural components, or subsystems, such as annual or perennial crops, pastures or livestock are present. The whole farm is organised in space and time in such a way that outputs from one subsystem become inputs for other subsystems in an attempt to optimise the flow of energy and the cycling of nutrients across the agro-ecosystem. In IAA, usually, a fish pond acts as fertility hub connecting with the other subsystems (Edwards, 1987).

IAA systems are characterized by their low reliance on external inputs, and a strong focus on recycling resources within the farm. The purpose is to preserve the availability of nutrients inside the farm through recycling while improving production to increase incomes and sustain the livelihoods of the farming households (Edwards, 1998).

IAA can be seen as systems in which at least three out of the five key principles of agro-ecology of animal farming systems are applied, namely (1). the decrease in inputs needed for production, (2). the decrease in pollution by optimising the metabolic functioning of the farming system and (3). the enhancement of diversity within the animal production systems to strengthen their resilience (Dumont et al., 2013).

IAA has been practiced traditionally for many years in South East Asia and Africa (Phong et al., 2010). In the 1850s most of Western Europe's agriculture was dominated by crops (food crops), and cattle was mainly kept as draft animals. Pigs and poultry were a source of meat and fallows were used to restore soil fertility. No integration was mentioned between the subsystems (Edwards et al., 1988). Between the 1850 and 1945, reducing and ultimately eliminating fallows and rotating cereal crops with growing pastures instead to restore soil fertility led to the development of true crop and livestock mixed farms in Western Europe and North America (Grigg, 1974). With the advent of the “green revolution” in 1943, based on industrial monoculture, mixed farm gave slowly way to the culture of specialized crops.

Nowadays the green revolution has shown its environmental limits (Pingali, 2012). And it is not adapted to smallholders' rural farms. Hence, mixed systems are seen as an alternative for sustainable agriculture. The expansion of aquaculture in the second half of the 1970s allowed South Asia to consider the integration of agriculture with aquaculture (Hishamunda et al., 2011). In Africa, research on small-scale aquaculture was widespread in the 1980s and 1990s (Blythe, 2013)

Integration of aquaculture into agriculture is more developed in Asia than in any other region of the world (Edwards et al., 1988). The IAA was explored especially in China, in the late 1970s due to wild fish stocks limited; limited land space and high human population to fulfil food requirements (Nhan et al., 2008). Thus, some companies intentionally selected species of fish, molluscs and crustaceans to increase the availability and production of protein from rice fields (Prein, 2002). The intentional stocking and culture of fish in rice field has increased in some developing countries such as China, Vietnam, etc., leading to an increase of rice yields through the inclusion of fish (Mishra and Mohanty, 2004). With this progress, integration has taken a commercial mode where farmers excavate ponds near rice field and rear ducks on the ponds (Srivastava et al., 2004). Most farmers also grow vegetables and fruit crops on the embankments of ponds using also harvested rainwater in the pond for rice field in drought period to enhance the productivity of the system. That is how the integrated fish farming system has attracted renewed interest over the past decade as a potentially viable means of producing additional food, especially protein, and increasing the overall incomes from an integrated farming system (Srivastava et al., 2004).

Since then, IAA becomes more appreciated by western countries due to a rapid increase in cost of high protein fish feed and inorganic fertiliser as well as the general concern for energy conservation (Shang and Costa, 1983). IAA increasingly being developed for more commercial, income generating purposes in both Asia and Western countries (Gooley and Gavine, 2003). For example in Israel, a very efficient, agro-industrial scale of IAA farming, incorporating various aquaculture and irrigated horticulture operations, is now well established. In Australia IAA is used as an integration of aquaculture and irrigated farming systems to optimize the economic and environmentally sustainable use of existing energy, resources and infrastructure (Gooley and Gavine, 2003). However IAA in SSA is generally developed on smallholder farms in earthen ponds, characterized by culture of mixed sex culture of Nile Tilapia (*Oreochomis niloticus*) and/or African catfish (*Clarias gariepinus*) with no or limited inputs, relying mainly on natural plankton, low stocking densities and usually low yields of 1 000 to 2 000 kg/ha/year. Products are oriented towards self-consumption or local markets (Brummett & Jamu, 2011).

3. TYPOLOGY OF IAA SYSTEM IN SSA

Although one or several ponds are found on IAA smallholder farms in SSA, many variants of such systems do exist. The particularity of different variants lies in factors such as the amount of subsystems associated with fish ponds, the intensity of fish culture, the area of the farm, the animal species reared and types of crop varieties used in association. The fish farming can differ in terms of pond type, size, fish species, and degree of intensification. Besides fish production, IAA farms can have various types of other agricultural activities including 2, 3 or even more subsystems.

i. Diversity of subsystems on IAA farms

Stand-alone fish farms can be risky ventures, especially for resource-poor farmers because of their environmental effects (e.g. pollution) and economic factors such as price volatility (Shoko et al., 2011). Hence, a survey conducted by (Kinkela et al., 2017) in the Democratic Republic of Congo revealed that, although 21% of the ponds are exploited alone, the combination of fish and vegetables is largely used (35%), followed by fish, vegetable and livestock (30%) and fish with livestock (14%). Based on the number of subsystems associated with fish ponds, different variants of IAA farming can be identified in SSA: IAA with two subsystems, including fish associate to crops or livestock (Shoko et al., 2011; Tabaro et al., 2012; Limbu et al., 2016) and IAA with three of more subsystems (Kinkela et al., 2017). Diverse fish species, crops and animals are used in such enterprise that will be developed in the next point.

Table 1. Subsystems and species found in IAA in different environments of SSA (% of surveyed farms)

Agroecological zone	Country	IAA subsystems	Fish	Crops	Livestock	Reference
Subhumid warm tropics	D.R. Congo	Fish (21%) Fish-Livestock (14%) Fish-Crops (35%) Fish-Crops-Livestock (30%)	Oreochromis niloticus (98%), Clarias gariepinus (28%)	Amaranthus hybridus (40%), Ipomoea batatas (38%), Hibiscus sabdariffa (25%), Solanum melongena (17%)	Pigs (95%) Chicken (6%)	Mafwila et al., 2017
Subhumid warm tropics	Tanzania	Fish-crops	Oreochromis niloticus, Clarias gariepinus	Brassica rapa chinensis	-	Limbu et al., 2016
Subhumid cool tropics	Rwanda	Fish-Livestock	Oreochromis niloticus	-	Rabbit	Tabaro et al., 2012
Semiarid warm tropics	Malawi	Fish-livestock-crop	Oreochromis niloticus, Oreochromis shiranus	Maize	Chickens, goat, pigs, rabbit, cattle	Blythe, 2013
Subhumid warm tropics	Tanzania	Fish – crops	Oreochromis niloticus	Kale Brassica Oleracea	-	Shoko et al., 2011
Subhumid cool tropics	Zambia	Fish-Livestock	O. andersonni, O. ossambicus, O. niloticus, Clarias gariepinus and Cyprinus carpio	-	Pigs and ducks.	Lally, 2000 in Gupta et al., 2004

ii. Fish

In SSA, aquaculture has recently developed with a 5-fold increase over the past 10 years reaching a production of 576,242 tons per year in 2015, out of which 97% were produced in inland waters of Eastern and Western Africa (FAO-FIGIS, 2018). The African catfish (*Clarias gariepinus*) and the Nile Tilapia (*Oreochromis niloticus*) are the main freshwater aquaculture species with 39 and 26% of the production volumes respectively (FAO-FIGIS, 2018). Carpe (*Cyprinus carpio*) is also cultivated in some areas but with 0.8%, and its share in SSA is much less than in Asia. These various species are generally cultured in earthen ponds by smallholder farmers. In 2004 over 90 per cent of cultured fish in SSA came from earthen ponds of 200 to 500 m^2 fed with locally available, low-cost agricultural byproducts. Containment or holding facilities such as: concrete tanks, raceways, pens, cages and racks are less common (Gupta et al., 2004).

Aquaculture in SSA is still facing various barriers despite the contribution of various governmental and NGO supported projects that have benefited smallholder farms and all the advances made in fish feed industry (Gupta et al., 2004). Some of these problems were identified in Uganda, especially and can be generalized to other SSA countries. The lack of essential inputs such as fish feeds, fertilisers, chemicals, the lack of access to high quality of fingerlings, fuel and spare parts or their volatile prices, severely restrict a farmer’s ability to predict yields and make any sort of reliable economic forecasts (Gupta et al., 2004). These problems result from an overzealous and unplanned technological introduction that does not sufficiently take into account the socio-economic, cultural and ecological conditions of traditional rural agricultural systems (COFAD, 1999).

IAA gives the opportunities to relieve some of big challenges such as price of fish feed and allow smallholder’s farm to produce fish cost that can be affordable for rural and peri-urban population. Hence, fish production mainly relies on the natural productivity of the ponds, as well as leftovers from family meals, livestock, crops wastes and some purchased industrial by-product such as brewer’s grains, wheat bran and other on-site natural resources as nutrient inputs (Kinkela et al., 2017). However, crop and livestock wastes can be used as feed for fish and is therefore an important source of food that can reduce the cost of production. For example (Muendo et al., 2006) obtained similar fish growth performance from ponds receiving manure or grass residues than formulated pellets under Egyptian condition. However to avoid sub-oxygenation issues in the ponds, the initial fish density was smaller leading to lower productivity per pond area. In Cameroun, (Brummett & Jamu, 2011) obtained satisfactory results concerning conversion index and specific growth rate respectively using agricultural by-products such as Cocoa shell (1.28; 2.16), Cockle shell (1.08; 2.28) Avocado leaf (2.49; 0.44) and *Chromolaena* (2.27; 2.51) in pond composters installed in extensive polyculture *Oreochromis niloticus-Clarias gariepinus* ponds. This way of using crops in pond generate fish production of 2.5 t/ha that remains low compared to that obtained with animal manure, it is verifiable by (44) that reported maximum daily low fish yields of 1.43 kg / ha / d and 2.35 kg / ha / d using plant residues (including fruit), compared to productions of 17.66 kg / ha / d obtained with animal manure in Mekong Delta.

Smallholders can also have the opportunity to produce high quality protein for feeding fish on the farms, using wastes such as pig manure, vegetable wastes and industrial by-product to produce fly larvae that are part of the natural diet of some farmed fish species (Nuov et al., 1995; Mafwila et al., 2017). Insect based protein meals offer an alternative to plant and animal-based fish food as ingredients in fish food for aquaculture to produce high value fish species. Insect species that may have potential (Black soldier fly, Yellow mealworm, Super worm and Housefly) can be reared wholly or partly on vegetable wastes such as carrots, green leaves, and plant stems (Ekman, 2014).

iii. Crops

Agricultural activities play an important role in providing food for enhancing household consumption and products for sale in local markets in SSA where smallholder farms constitute approximately 80% of all farms and employ about 175 million people directly (FAO, 2016). The major perennial and annual crops found in SSA with total production per tonne in 2016 are generally cassava (157,271,697) maize (62,370,245), rice (26,116,183), sweet potato (20,675,800), and potato (11,753,809). (FAOSTAT, 2018). Plantains, banana, various fruits, and vegetables such as *Amaranthus hybridus, Hibiscus sabdariffa, Solanum melongena, Brassica rapa chinensis, and Kale Brassica Oleracea* play also an important role in feeding the Africa population (FAO, 2016). Some of these crops directly concern IAA on smallholder farms since as in the Vietnamese VAC (VAC, "vuon, ao, chuong"; garden, pond, pigsty) crops in African IAA are essentially vegetables (Shoko et al., 2011, Blythe, 2013, Limbu et al., 2016; Kinkela et al., 20017).

As IAA is often practiced in urban and peri-urban area with a high pressure on the land, cropping is continuous, and a high supply in nutrients and organic matter is required to maintain production levels. Already in 1990, African crop production systems fell short of replenishing nutrient uptake by the crops per ha by approximately 20kg N, 10kg P_2O_5 and 20kg K_2O, up to a maximum of 40kg N, 20kg P_2O_5 and 40kg K_2O (Stoorvogel & Smaling, 1990). This situation remains until today a problem for SSA that see agricultural development and for smallholders in particular. Mineral fertiliser can be an alternative to solve soil depletion for agricultural development in SSA. This region sees agricultural use of mineral fertiliser progressing over the last years (2010 to 2015) from 1556981 to 1752379, from 723924 to 737252, and from 406934 to 450468, in tone of total nitrogen, total nutrient phosphate P_2O_5 and total nutrient potash K_2O, respectively (FAOSTAT, 2018). However, smallholders' farmers with limited resources may not always be able to afford these inputs, which are generally overpriced.

Moreover, production is to be maintained throughout the year even in the dry season when water is scarce as to be envisioned in countries such as Malawi, Rwanda, Burundi or Uganda that are under threat of a severe shortage. Water pond can also be a solution for smallholders in Africa and in the Lake Victoria basin in particular whose livelihoods depend on seasonal rain fed crops by availability of water inside the farm in dry water season since accessing water for productive agricultural use remains a challenge for millions of poor smallholder farmers in SSA (Shoko et al., 2011). The International Center for Biosaline Agriculture (ICBA) consider water scarcity and degradation due to soil nutrient depletion and soil salinization as the most potential threat to small-scale farming in sub-Saharan Africa (ICBA, 2015).

Increasing water availability across wet and dry seasons and the availability of mud are technical benefits, brought by fish pond although not directly related to fish culture profitability. They can increase economic resilience of farms by increasing the number of crop cycles per year with reduced requirements in fertilisers. Investing in a pond within the farm or modifying rice fields for raising fish ensures water availability for associated horticulture or cereal crops. Fish pond as a nutrient trap can play also an important role in nutrient cycling in mixed farming systems by trapping nutrients and re-distribute them to other parts of the farms (Shang and Costa, 1983). In IAA, sediments at accumulating at the bottom of the pond are rich in organic matter, nitrogen and phosphorus (Muendo et al., 2014). This sediment negatively impacts fish production in reducing the volume of water in the pond and affect fish yields due to the release of toxic compounds such as hydrogen sulfide and nitrites (Boyd &Tucker, 1995). High organic matter deposition may also increase biological oxygen demand, asphyxiating the fishes. Pond sediments can be recycled as fertilisers with production levels as high as 5 g C $m^{-2}d^{-1}$, corresponding to an equivalent production of 100 kg of dry manure ha^{-1} d^{-1} (Ogello et al., 2013). Muendo et al. (2006) have measured after a cultured period of *Oreochromis niloticus* in pond fertiliser with chicken manure the concentration at harvest, the quantity in accumulated sediment, and the quantity in accumulated sediment of nitrogen (1.9 g kg^{-1}, 5.89 kg $pond^{-1}$, 295 kg ha^{-1}, respectively), organic carbon (14.5 g kg^{-1}, 45.0 kg $pond^{-1}$, 2.3 tons ha^{-1}), available phosphorus (6.3 g kg^{-1}, 19 g $pond^{-1}$, 0.97 kg ha^{-1}) potassium (72 mg kg^{-1}, 2.23 kg $pond^{-1}$, 112 kg ha^{-1}) in pond sediment.

The quality of the pond outlet water used for watering varies according to the type and level of fertilization of the pond. Besides the provision of water allowing an extension of the growing season during the dry season when used for watering, it constitutes an extra source of nutrients for irrigated crops and vegetables. Pond outlet water contains both dissolved and suspended inorganic and organic matter from fish culture such as fertilisers and feeds, or other external nutrients, such as matter derived from soil erosion, run-off and leaching (Zajdband, 2011). In smallholder context, effluents from aquaculture may be used for terrestrial-crop and fruits while others are used by the family to dispose of waste water (FAO, 2009). Vegetables irrigated by water pond produce 1.8 times higher net yield than those irrigate with stream water, and pond water analysis show higher value in mgL^{-1} of nitrate (1.79), ammonium (1.13), total nitrogen(2.5) and total phosphorus (1.39) compare to stream water respectively (0.45, 0.25, 1.24, 0.14) (Limbu et al., 2016).

iv. Livestock

Livestock are essential for food security in sub-Saharan Africa. They serve multiple purposes and are economically important, contributing up to 40% of agricultural gross domestic product (GDP) in pastoral countries like Niger (Oosting et al., 2014). In livestock production in the tropics dominates the global scene when it comes to the number of animals, total output and number of beneficiaries; – that is, producers and consumers (Oosting et al., 2014). In SSA, livestock production is dominated in term of animal heads by chicken ($1,243,501 \times 10^3$), followed by goats ($337,679 \times 10^3$), cattle ($283,089 \times 10^3$), pigs ($36,597 \times 10^3$), and ducks ($11,160 \times 10^3$) (FAOSTAT, 2016). In Rwanda, DRC and Malawi, some small herbivores such as rabbits or Guinea pigs are also found (Tabaro et al., 2012; Blythe, 2013; Maass et al., 2014). Demand for livestock products in sub-Saharan Africa (SSA) is increasing rapidly driven by the expected high population growth in Africa and its changing food habits, and the trend of increased demand is currently not matched by a similar growth in local production (UNSIC, 2014).

This increase in livestock production will put higher pressure on livestock systems in terms of water or land availability, forage and feed management as well as disposal of livestock wastes. Conflicts might result between small crop farmers and livestock keepers in remote areas (Billards, 2014). Hence the question comes of which systems can sustain production in Africa while meeting the different challenges?

Integrating livestock into cropping systems is an important option for SSA because it is generally used by smallholder farms and can be considered as a local form of agro-ecological production system (Oosting et al., 2014). For instance, in Kenya, smallholder farmers in integrated systems contribute about 60% to 70% of the national milk output. Milk contributes 70% of the total livestock revenue and provides a livelihood for the majority of rural households (Herrero et al., 2014). Livestock in integrating livestock into cropping permit to meet increasing demand for crop production that requires managing nutrient cycles more efficiently through the use of animal manure as an important source of fertiliser in large part of African region (Herrero et al., 2014). In back cereal crop, straws and other crop residue, despite their low nutritional value in digestibility (<50 percent), hence low metabolizable energy content (<7.5 MJ/kg DM), low crude protein content (<60 g/kg DM), low intake (10-20 g/kg live weight daily) and low content of available minerals and vitamins are used to maintain adult ruminants in the context of smallholder farms (Antonio, 2010). For instance, discarded leaves of cabbages reaping that comprise up to 6 tons of edible dry matter per ha and carrots damaged at harvesting or discarded because of poor quality, is a good ruminant feed.

IAA strengthens the benefits of integrated livestock into the crop system and allows smallholder farmers to more resource-saving practices that aim to achieve acceptable profits and high and sustained production levels, while minimizing the negative effects of intensive farming and preserving the environment. The increasing demand for livestock product, increase availability of manure that increases pressure on the environment. Pond in IAA as another pillar among components offers possibility to use more manure as fertiliser and reduce environmental pressure. Water effluent is after effectively managed for multiple use including cleaning pigsties and watering the animals (Kinkela et al., 2017). In Mekong Delta, it is demonstrated that 40-50 kg of organic fertiliser can produce 1Kg of fish (Nhan et al., 2007), and despite the large use of crop wasted in aquaculture, the best fish yield is obtained by use of manure in the fish pond (>10 t/ha/year). Tabaro et al. (2012) give values of pond water in Rwanda with pond reared under 1200 rabbits ha^{-1} density in mgL^{-1}(nitrate = 2.40, ammonium = 1.12, total nitrogen = 6.19, total phosphorus = 0.64), and all the value remained within the favourable range required for *Oreochromis niloticus* and *Clarias gariepinus* species.

The discharge of manure into ponds provides a productive solution to animal waste management and allows more animals to be kept on farm besides the increase in fish yields (Nhan et al., 2008). Where fish is relatively expensive, or competition for livestock manure with crops is high, linkages between livestock and fish culture are weaker. Under such conditions, fish production may depend more on other feeds and fertilisers. Livestock waste may not always be used directly, especially if lack of space allows only the use of intensive ponds. It is possible in such case to consider the culture of intermediate organisms such as fly larvae, duckweed or biogas to process livestock wastes (Mafwila et al., 2017). Although little popular, this strategy of processing pig manure into live feeds for fish has been used successfully by (Nuov et al., 1995).

4. EFFICIENCY OF IAA SYSTEMS

Several studies explored how adding an aquaculture pond to existing farming operations could modify its efficiency. Benefits of the IAA system focus on the opportunity to generate cash, but three interrelated aspects of production, socio-economic and the environment are to be considered as well (Prein, 2002). Consequently, beyond the technical efficiency discussed in the previous section, the efficiency of IAA systems must also be evaluated under, environmental and socio-economic perspectives.

I. Economic efficiency and social impact of IAA system

The integration of various subsystems plays a central role in diversifying the outputs from an existing farming system, resulting in overall higher farm yields and incomes (Pant et al., 2004). Research in India and Sri Lanka has shown that productivity of integrated farm can be high and the cost and risk of production low (Murray, 2004). Economic efficiency and social impact are generally assessed based on farm productivity and income using overall technical efficiency, total farm productivity, profitability, total farm income realized and household welfare. A survey in Malawi conducted by Dey et al. (2010) showed that annual farm income of IAA farmers (185$) was on average 1.6 times higher than non IAA farmers (115$). Chimatiro and Scholz (1995) showed that with a Farmer-to-Scientist Research Partnership approach, average fish productivity of integrated Southern Malawian smallholdings (1650 kg $ha^{-1}yr^{-1}$) areas was greater than other productive fish farms (1350 kg $ha^{-1}yr^{-1}$). When facing severe droughts, Brummett (1999) report sustainability of the pond-vegetable systems that kept operating in Malawi when other farms involved in pilot research were badly affected. This demonstrates the increased resilience of small-scale farms with IAA while their yields were 11% higher than non-IAA farmers (Dey et al., 2010). In Tanzania the integration of fish ponds with vegetables produces 14 times higher net annual yields than fish alone (Limbu et al., 2016). Fish cultured under the integrated system exhibited higher growth rates than those in non-integrated systems (Ogello et al., 2013). In addition, in Egypt, Muendo et al. (2007) show that using chicken manure in fish pond provide besides a high net fish yield, possibility to have sediment as a good fertiliser for corn production.

II. Environmental efficiency of IAA system

The motivation for the practice of integrated fish farming is related to the fact that in addition to the added value provided to the farm, it contributes to the reduction of environmental impacts through the recycling of waste and allows a very efficient retention of nitrogen (Nhan et al., 2007). The environmental efficiency of the IAA system depends on two groups of elements: (i) the quantity and quality of fertilisers (nutrients profile) and feeds or feed ingredients, fish density, fish production system (monoculture or polyculture) and (ii) water management. The study carried out with 4 categories of farmers using manure and feed ingredients of different nature and in different proportions clearly shows that the oversupply of organic matter, nitrogen or phosphorus without taking into account the ability of fish to fix these elements can lead to the environmental pollution. Some of 4 Cameroon's categories IAA had eutrophication potential six times higher (kg $P0_4$-cq 908 *vs* 157) than the others. In addition, the Cameroon's ponds with low eutrophication potential were five times higher than those in Brazil (kg $P0_4$-cq 157 *vs* 23) (Efole et al., 2012). The appropriate polyculture increases the nutrient fixation in ponds (and improves the profit margins of aquaculture), hence decreasing the nutrient loading into natural water bodies that causes eutrophication (Xie et al., 2007). It can be concluded that biotechnological knowledge of this activity by SSA producers in this system is needed to make this activity environmentally more efficient.

The integrated production systems have also better water use efficiency and better water productivity. For instance, Abdul-Rahman et al. (2011) point out the fact that water use efficiency and water productivity in IAA treatments respectively (8.24 kgm^{-3}; 10.3m^{-3}) was higher than non-integrating treatment (6.83kgm^{-3}; 8.53m^{-3}) in the Bekaa plain in Lebanon conditions.

In China, the rice–fish-farming system reduces the emission of CH_4 by nearly 30% compared to traditional rice farming (Lu & Li, 2006). The results of Efole et al., (2012) on 4 different integrated systems in Cameroon are less positive. They show low the environment efficiency of IAA and have heavy impacts on climate change, acidification, energy use, eutrophication, and net primary production use, especially for the pond subsystem. Three hypotheses could explain these below average performances: (i) unsuitable association of fish species, (ii) poor water management or (iii) inaccurate determination of the fate of emitted nutrients. Nevertheless Cameroonian systems are more efficient in water dependence and land use. Based on simulation models of nutrient flows and balances in Kenyan farming systems, Muendo et al. (2006) show that fishponds can improve the nitrogen balance of farming systems in Africa.

5. ASSETS, CONSTRAINTS AND FUTURE PERSPECTIVE OF IAA ADOPTION IN SSA

The small-scale IAA system is one form of diversified agriculture mainly practiced in most of Asian countries (China, India, Indonesia, Malaysia, Thailand, Vietnam and Bangladesh) (Prein, 2002), in Southern Brazil and Colombia (Cavalett et al., 2006; Leterme et al., 2010) but not enough in SSA. This point stands out constraints and assets of the adoption IAA system in SSA.

A. ASSETS OF IAA ADOPTION IN SSA

Southeast Asia has a long tradition of integrated farming with fish, crops, and livestock to sustain the livelihoods of farming families. In the Mekong Delta of Vietnam, these farming systems have changed from self-sufficient systems, producing mainly rice with some fish and livestock for home consumption to more market-oriented IAA systems (Phong et al., 2010).

IAA system has been adapted in Africa in the context of African rural and peri-urban areas (Kinkela et al., 2017). Africa has a significant competitive advantage to use simultaneously two different strategies to increase aquaculture production; expansion of the area devoted to aquaculture and increased yields (Edwards, 1998).

As in Vietnam, small-scale IAA systems in Africa seem a relevant starting point for the development of a socially, ecologically and financially sustainable agriculture on family farms lacking resources or with few opportunities outside agriculture (Edwards et al., 1988). Usually applied by smallholders in rural and peri-urban area, with limited resource base this system in SSA needs to improve the efficiency of limited resources available, their diet, balance risks among various farming subsystems with optimized use of nutrient flow and provide full employment and generate surplus produce for sale.

Considering that sustainable agricultural intensification is needed for SSA, and that modernization of agriculture based on external inputs such as agrochemicals and improved high-yielding varieties may be out of reach for many African farmers in the near future (Dey et al., 2010), management of diverse on-farm resources and integration among various farm subsystems, should continue to receive high priority in SSA. Also, access to external inputs, such as mineral fertilisers as well as labour availability is also highly dependent on the size and resource endowment of the farming household (Giller et al., 2006).

B. CONSTRAINTS OF IAA ADOPTION IN SSA

Applications of the IAA system still stay within the limits of African pre-industrial societies, characterized by dense human populations with limited integration of crops, livestock and fish, and with most land under food crops for subsistence needs (Little & Edwards P, 2003). Financial capitals on smallholder farms with low agro industrial development in the regions where those farms are implemented in SSA are major constraints to fuel solvent demand. In SSA, most of small-scale farmers in the peri-urban and rural areas generally produce for self-consumption or poor community with little access to markets. This partly explains the low profitability of farms and non-use of external inputs such as mineral fertiliser and agro-industrial by-products for fish producing. This justifies the relevancy of IAA but at the same time, one might consider the risk with increasing incomes, that IAA farmers would abandon their complex systems and turn towards specialized but less sustainable production systems.

Improper management and technical skills still constrain in many developing countries for IAA in SSA (Edwards et al., 1988). High illiteracy among small-scale fish farmers combined with ignorance of the existence of IAA have been revealed as a major hindrance to the growth of integrated fish farming such as fish with *B. rapa chinensis* (Ogello et al., 2013). This is because IAA technology involves the provision of key management skills to farmers such that its successful application depends largely on the farmers' knowledge of the production systems involved in the farm.

Adoption of an IAA system in African countries and Tanzania in particular has been slow due to less rigorous empirical participatory research aimed at promoting IAA adoption in small-scale farmers' settings (Limbu et al., 2016).

IAA system has disadvantages to use more workforce than non IAA farmers and also a quality workforce (Pant et al., 2004; Muendo et al., 2007; Dey et al., 2010). The need of more workforces in integrated farm was also emphasized by Setboonsarng (2001) in Northeast Thailand. The surplus of workforce comes from fish production, collection and application of manure or crop residues, and extraction and use of pond sediment (Pant et al., 2004). Not many works undertaken in SSA have evaluated workforce requirements in IAA. (Muendo et al., 2007) for example did not give any detail about the cost of additional workforce in practice of IAA in the farm. It is probably because these workforce activities have only short-term demands, e.g. for pond maintenance, mud harvest and spreading and fish harvest that might be made by family workforce which are non-paid workforce.

C. FUTURE PERSPECTIVE

Farmers' decisions to adopt production systems such as fish with *B. rapa* chinensis integration are largely influenced by economic factors and dietary preferences (Xie et al., 2011). Consequently, approaches used to promote IAA in SSA, must involve smallholders using participatory approaches: on-farm research and demonstrations, identifying and training farmers with leadership potential through the formation of farmers' associations, etc. Earlier research however indicated that, short-term training was insufficient to enable farmers to successfully and independently practice IAA since it requires an in-depth understanding of particular aspects of the farming system (FAO, 2016).

Facing the competitive market, the challenge of increasing annual population in SSA, IAA need to migrate to diversification of resources and activities for producing simultaneously high quality products at an affordable cost in rural and peri-urban areas. In terms of resources smallholder farms in SSA can depend in part to external input combined with internal output to provide more efficiency of recycling nutrient in the farm and to produce high quality of fish as small-scale rice farmers in resource-poor North-east Thailand (Nhan et al., 2007). Being generally nutrient poor farms, any improvement in nutrient use efficiency is generally beneficial, even if according to Little & Edwards, P (2003), this strategy would tend to weaken the links between wastes of subsystems. It was the case for North-east Thailand where in the system rice-fish limiting fish production to the use of on-farm inputs alone, or limited amounts of off-farm nutrients did not always meet the needs of farming households (Little & Edwards P, 2003).

In terms of activities, SSA small-scale farms can diversify activities in the farm adding various subsystems, but as stated above labour cost remain major problem and some farmers tend to specialize, reducing the number of farming activities rather than increasing them. In such a situation further integration could be achieved between farms or even between groups of farms (Edwards, 1998). In this last case efficiency of resource use should to be assessed regionally, as an integrated resource flows occurs within complex networks than as simple linear linkages.

The profitability of IAA must be geared towards providing sufficient management skills to small-scale farmers by providing knowledge through training as it was done in the study of Limbu et al. (2016). The availability of industrial by-products and wastes in urban areas by industrialization of African societies can make cost-effective to recycle through pond fish culture (Nhan et al., 2007). Some research in Malawi and in Ghana has shown that a fish pond integrated into a farm in such a way that it recycles wastes from other agricultural and household enterprises can increase production and profitability (Chimatiro and Scholz, 1995).

It remains obvious that big challenges of IAAS such as ; lack of a comprehensive policy on aquaculture, poor information dissemination and technology transfer, low government funding, low investment by the private sector and incoherent promotion of aquaculture through many institutions, including government, universities, research institutes, non-governmental organizations (NGOs) and other national authorities, must be relieved for rapid development of IAA in SSA.

6. CONCLUSION

IAA system is a better strategy for on-farm waste management for farmers in SSA, in general and especially for smallholder farmers in rural and peri-urban areas, where resources are limited. This system has several advantages among others; the improvement of on-farm resource use, increase of farming income, environment safeguard and improvement nutrition for the family. However, it also has some disadvantages. Furthermore the benefits of IAA are not obvious because the efficiency of this system which is measured under three aspects (economic efficiency, technical efficiency and environmental efficiency) depends on several questions. This questions relates on the macro-level issues, including world trade, national development policy and goals, social aspects such as cultural attitudes to recycling, and input supply and marketing and micro-level issues mainly concerns the alternative use of resources. For example, whether IAAS are an appropriate use of resources and whether they can be linked synergistically with other farm and non-farm activities. If the IAA system has been successful in Asia and continues to show the benefits of its application, especially among farmers with a body of water allowing pond installation, its exploitation in Africa is far from a perfect success. This despite the various support whose systems have been beneficiaries.

Several issues need to be explored concerning IAAS in tropical areas and SSA in particular to contribute to the improvement of efficiency, productivity and ultimately higher income of farmers and additional environmental benefice. The slowness or delay in the development of the IAA system in SSA is probably related to, the lack of government policy to accompany innovations, lack of public and private investment in agriculture and aquaculture, weakness of research, lack of culture of waste recovery, recycling agricultural by-products or an unidentified factor. An anthropological study may be able to understand the phenomenon that slowed down the intensification of the IAA system in SSA.

The previous chapter showed that integrated aquaculture agriculture systems are a promising option for Sub Saharan Africa farmers. IAA is usually applied by smallholders in rural and peri-urban area of Africa, with limited resource base . They could thus seeks to design their own agricultural model, adapted to local conditions, to increase food production while meeting the conditions of ecological sustainability. However, efforts would still have to be made to have the system adopted in many African countries since the previous chapter shows a low enthusiasm from small farmers and a much less effective results compared to those of South East Asia, from where the system was adopted.

The reviwe of the literature showed also that evidence of success of the integrated agriculture aquaculture systems is not yet clear for Sub Saharan Africa and that a thorough review of the system needs to be done in order to highlight the lever that will drive the development of the system in Sub Saharan Africa.

Thus, in the following chapter we surveyed 150 farmers to examine in details the diversity of activities carried out by in pond fish farms with potential to integration with agriculture in the peri-urban and rural regions in the Province of Kinshasa in the Democratic Republic of Congo. We specifically focussed on the fluxes linking the different components because of their potential key role in increasing stability of production by entrapping nutrients such as nitrogen.

Photo 1. Surveyors interviewing a smallholder farmer in the municipality of Funa in the urban area of Kinshasa (DRC)

3

Diversity of farming systems integrating fish pond aquaculture in the province of Kinshasa in the Democratic Republic of the Congo

Article 2

Diversity of farming systems integrating fish pond aquaculture in the province of Kinshasa in the Democratic Republic of the Congo

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Abstract

Agriculture and aquaculture systems are used by many farmers in various tropical countries of Asia, America and Africa. They have proven their relevancy to increase the productivity of farms by optimising nutrient fluxes and reducing requirements for external fertilisers. This article analysed the current state of fish farming and the way it is integrated with other farm subsystems in the urban/peri-urban and rural areas of Kinshasa, Democratic Republic of Congo. More precisely, it examined the allocation of resources at the farm level, the recovery of helophytes plants, and the fate of fish production choices and it explored the possibility of intensifying these existing integrated farming systems. After a census of ponds in the urban and rural areas of Kinshasa, an on-site survey was conducted on 150 fish pond farms to assess the different activities practiced on farms, the impact of integrating crops and livestock to fish pond aquaculture and the constraints of the system. A total of three thousand and twenty (3020) fish ponds were recorded in the urban and rural areas of Kinshasa. Among these farms integrated aquaculture-agriculture systems exist with a wide diversity of practices (about 79% of farms combined fish with livestock and/or vegetable production). No striking differences between fish farms according to the allocation of resources, fish production method such as monoculture or polyculture, the recovery of helophytes plants and the fate of fish production choice were found depending on the location. However, fish farms were differently managed when combined with agriculture and/or livestock. Regarding the integration of the different subsystems through nutrient fluxes, 11 different movements of material between subsystems were found in integrated farms. However, not all fluxes are equally used in all farms and therefore improvements cannot be generalised. Improvements to be explored are such as making better use of manure pond mud and helophyte plants. For this purpose, proper training of farmers might be critical. Finally, bringing farmers together in cooperatives could also contribute to reduce the cost of purchase and transportation of fish fry and feed.

Keywords: crops, fish pond, integrated farm, livestock, rural, urban

1. Introduction

Faced with an overall annual population growth of 2.7%, low soil fertility, and low livestock and aquaculture production (Hishamunda & Ridler, 2006, Subasinghe et al., 2009), smallholder farmers in Sub-Saharan Africa (SSA) are facing a huge challenge of sustainable agricultural intensification to address their food security issues. They rely on low to no external inputs to maintain soil fertility. The sustainability of their production system heavily depends on the efficiency by which nutrients are kept and recycled in the farm (Rufino et al., 2006). Integrating several subsystems, such as crops and livestock, within a same farm is one possible way to promote the efficient use of nutrients within a given farm while increasing global productivity (Lemaire et al., 2014) in such a way outputs from one subsystem become inputs of another associated subsystem (Edwards, 1993; Rukera et al., 2012). In several humid tropical countries mainly in South-Eastern Asia and South America, this diversification includes aquaculture as a subsystem of farms, along with crops, livestock, or both to yield integrated agriculture-aquaculture (IAA) systems (Symoens & Micha, 1995; Phong et al, 2011; Preston & Rodriguez, 2014).

Based on the flow of nutrients between subsystems, integrated systems aim to improve the use efficiency of nutrients such as nitrogen and phosphorus to increase soil fertility and reduce external inputs while optimising agricultural resources for income generation and food supply at farm level (Nhan, 2007). For example, Poot-López et al. (2010) reported that IAA systems involving tilapia production in the Yucatan State of Mexico almost doubled economic returns in poor rural areas compared to plain crop production. The practice of integrated farming enables farm households to increase agricultural production while not depleting their base of natural resources. Tipraqsa et al. (2007) compared integrated farming systems (crops, pigs, poultry, trees, and fish) to commercial farming systems in north-eastern Thailand and concluded that the integrated farming system gave a more secure supply of food at the family level, it improved the resource base, created higher economic returns, and better matched the social needs of agriculture as a supplier of materials for food, medicines, local rituals, tools, and shading. In addition, the total output from integrated farms (3480 USD per farm) was significantly higher than of the commercial farms (2006 USD per farm).

Murshed-E-Jahan & Pemsl (2011) showed, that fish pond provided additional benefits besides nutrient recycling for an IAA system in Bangladesh, such as higher incomes from fish culture and an increase in water availability. They tested the hypothesis that IAA based on low cost aquaculture techniques led to improved productivity, profitability, efficiency and also human and social capital in Bangladesh. The net income of farmers practicing IAA grew at an average rate of 21.8% per year compared to the 5.8% income increase per year of farmers without IAA. Barbier et al. (1985) showed similar results in the marshes of Rwanda after the farming system was converted into dyke pond systems combining horticulture and aquaculture.

Despite their advantages depicted above and the possible role that integrated farming systems could play in the food security challenge, few data have been reported for Africa regarding integrated farming systems, especially when it comes to those including aquaculture. The result of the adoption of IAA systems including vegetables, fruits, livestock, irrigation and fish culture as subsystems in Malawi raised the productivity with 11%. Technical efficiency was increased by 134%, and total farm income by 60% (Dey et al., 2010). The results of Rukera et al. (2016) in a rabbit-fish-rice system showed clearly that although the productivity of individual subsystems is not always increased, the efficiency of the whole farm is improved. This illustrates the potential of IAA to contribute to poverty reduction and improvements in livelihoods in Malawi, Rwanda and Cameroon, as well as other countries in SSA with similar agro-ecological conditions, where IAA practices have recently been adopted.

In the Democratic Republic of Congo (DRC), fish holds a high share of the animal protein consumption (Brummett &Williams, 2000). Besides, Tollens (2004) showed that vegetable cropping is very important in urban and peri-urban areas with annual volumes consumed of 24.4kg/capita in 2000 in Kinshasa. Moreover, Kambashi et al. (2014) reported that residues such as root and leaves of some vegetable crops such as sweet potato and *Psophocarpus scandens* are commonly used to feed pigs, completing the available feed ingredients such as corn, cassava and potato tubers in urban and peri-urban areas of Kinshasa. In this way, vegetable crops have a great potential to support the development of livestock and fish pond aquaculture if grown in IAA systems by using crop residues to supplement fish and livestock feeds. Nonetheless, very little information is available on the present state of fish farming (Micha, 2015) and the way it is integrated with other farm subsystems in urban/peri-urban and rural areas of Kinshasa. The success of an IAA farming system not only depends on its subsystems but, more importantly, on the appropriate combination of the different subsystems and the management of nutrient flows between these subsystems. Therefore, the aim of this research was to quantify the extent of fish pond farming and to understand whether the management of the ponds depends on the integration of other subsystems (e.g. market gardening and livestock) in urban/peri-urban and rural areas of Kinshasa (DRC).

For this purpose, a large scale survey has been conducted to address the following research questions:

- Do IAA systems exist in urban/peri-urban and rural areas of Kinshasa in the DRC?
- Are fish ponds differently managed when combined with agriculture or livestock?
- Which subsystems are actually integrated through nutrient fluxes between the components and how these are managed?

2. Materials and methods

2.1. Pond density assessment

Given that no recent data are available in the literature on the number of fish farms in Kinshasa, a preliminary pond census was performed in order to quantify the density of ponds in the urban/peri-urban area of Kinshasa and to set-up an appropriate sampling procedure for the following survey. For this purpose, satellite images available from Google Maps were used (Google Maps, viewed on 17/12/2012 map version, DigitalGlobe). The urban territory of the city was divided into 4 areas (North West, North East, South West, South East), in which fish ponds were counted. This work enabled the selection of sites to conduct the survey.

2.2. Survey

A survey was conducted from March to May 2013 in two urban/peri-urban areas with a high density of ponds (N'djili Brasserie and Funa), and one rural area (Mbankana) of Kinshasa (Figure 2). Both urban/peri-urban areas are located in the city of Kinshasa in the municipality of Mont Ngafula (4° 25′ 35″ S 15° 17′ 44″ E), where the population density is 727 inh.km^{-2}. Mbankana is located in the eastern part of Kinshasa, 145 km from the capital, on the Batékés' plateau, in the municipality of Maluku (4° 26' 48.9'' S; 16°11'30.8'' E). The city covers an area of 1,500 km², with a population density of 23inh.km^{-2}.

Based on the list of farms obtained from farming organisations operating in the areas of the selected sites (Figure 2), farms holding at least one active pond were randomly selected, after on fields verification. For this purpose, Bernoulli's equation (Ancellet, 2008) was used to determine the lowest number of farms per sites required for representativeness, homogeneity and sample accuracy for a confidence level of 95%. In total, 150 farms with at least one pond were surveyed in the three selected sites: 51 in Funa (Urban 1), 45 in N'djili Brasserie (Urban 2), and 54 in Mbankana (Rural).

The survey comprised six main sections: one per farm subsystem (livestock, fish, and crops), one for farm management, another focused on the characteristics of the farms (farm area, land type and so on), and the last section comprised socio-economic questions to characterise the farm manager. In the "fish" section, questions were directed towards the characterisation of ponds, feeding practices, fish species, method of manure and fertilisation in ponds. In the "livestock" and "crops" sections, key information was collected on animal and vegetable species, animal housing systems, livestock and vegetable management, manure and vegetable waste flows, as well as methods used for soil fertilisation. In few cases, farmers reported to own some fields far from the ponds where some staple crops such as cassava were cultivated. Since those crops were not managed in integration with the other components, they were considered an external component of the farm. The survey was completed after a draft version of the questionnaire had been tested on some farms in the urban area.

The questionnaire was handled in a single pass during an interview with the farm manager. The technique for data collection consisted of questions followed by a discussion when needed for clarity. The interviews were conducted in Lingala or French. Measurements of the total area of the farm were undertaken when necessary; pond area, mean depth, width of the dike, and cultivated area were measured at the end of the interviews. As the survey was conducted in areas known for endemic epizooties such as the African swine fever, pigsties were measured by the farmers to avoid contamination between farms; the interviewers did not touch any animal and a quarantine period was observed before going from one survey site to the other.

Farms were divided into four types according to the encountered subsystems on the visited piece of land: fish farming solely (F), fish and livestock farming (FL), fish and vegetable farming (FV), and fish, livestock and vegetable farming (FLV).

The mixed procedure of SAS was used to compare mean values of quantitative data between farm types after testing distributions for normality. The chi-square test was applied to analyse the dependence of frequency variables on the farm types. Association between farm types (F, FL, FV or FLV), farm location (urban/peri-urban or rural), the different farm characteristics measured and quantitative variables in the survey was assessed by using the Pearson correlation procedure in SAS.

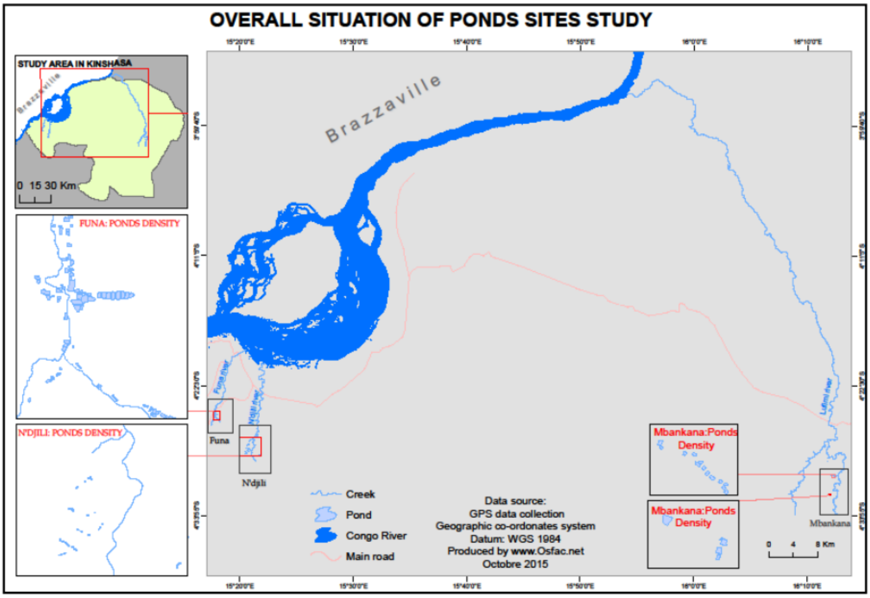

Figure 2. Map of Kinshasa (upper left) showing the location of study sites. The “ponds density” squares display enlargements of the three areas were the survey was conducted: N’djili and Funa are urban/peri-urban areas and Mbankana is a rural area. Data source: GPD data collection geographic co-ordinates system. Datum: WGS1984. Directed by www.osfac.net. October 2015.

3. Results

3.1. Pond density in Kinshasa

Three thousand and twenty (3020) fish ponds were spotted on the urban/peri-urban territory of Kinshasa. This number largely exceeds the latest statistics which mentioned only 769 fish ponds in Kinshasa (Kombozi, 2006). The highest number of fish ponds was found in the South-West area (1427 fish ponds) concentrated along rivers, specifically the Funa and N'djili rivers. Therefore, this area was selected for the urban/peri-urban survey. The South East area accounted for 922 fish ponds while 602 ponds were counted in the North West area and 69 in the North East area. The latter had fish ponds which were mainly located close to the international airport of N'djili, in the alluvial plain of the Congo River.

3.2. Farm activities according to location

Results of the on-farm survey showed that association of fish ponds with agriculture is commonly practiced by pond holders. The combination of fish and vegetables (FV) is largely used (35%). Fish, vegetable and livestock (FVL) are also quite common (30%). Fewer pond holders associate fish with livestock (FL) (14%). Finally, only 21% of the pond owners do not practice any association with fish farming (F).

Analyses showed that there is no striking difference in farm characteristics between the locations (Table 2). Although some differences were observed between the two urban sites, farms share the same general characteristics, whether they were located in urban or rural sites for their production cycle, the type of ponds, the choice of fish species the use of manure, and the fate of fish production. One notable exception has been observed, however, which concerns the habit of feeding the fish. In rural areas, only 50% of the farmers feed their fish, while this percentage was as high as 80 to 90% in urban areas. Moreover, more farmers who feed their fish use purchased feed ingredients in urban areas than in rural areas (Table 2). Finally, in urban areas, the recovery of sludge and helophytes vegetation (e.g. *Nymphaea alba*, *Eicchornia crassipes*) are also more practiced ($P < 0.01$).

Table 2. Pond characteristics and management according to location. (n=numbers of farms by site).

	Urban 1	Urban 2	Rural
n (number of farms by site)	51	45	54
Total farm area (are)	4.7±3.5*	7±7.4	6.3±7.1
Operational ponds (N)	1.9±1.1b	3.0±1.7a	1.8±1.2b
Non-operational ponds (N)	0.3±0.8	0.9±1.9	0.7±1.2
Production cycle (month)	9.4±6.8	8.9±4.0	8.0±2.7
Average age of fish farm (years)	12.7±11.9	10.1±8.6	14.3±9.1
Types of ponds on the farms (%**) (χ2, ***P = 0.58)			
Growth	100	98	100
Pre-growth	0	2	0
Nursery	2	4	0
Storage	10	2	0
Spawning	2	0	2
Fish production method (%) (χ^2, $P < 0.01$)			
Monoculture	67	64	89
Polyculture	33	36	11

Table 2. Continued

	Urban 1	Urban 2	Rural
Fish species (%) (χ^2, P = 0.05)			
Oreochromis niloticus	96	100	98
Clarias gariepinus	35	38	11
Heterotis niloticus	2	9	2
Parachanna obscura	8	4	2
Practice of fish feeding (%)	94[a]	84[a]	48[b]
Using on-farm resources (%)	6[c]	20[b]	39[a]
Using purchased ingredients (%)	94[a]	78[b]	31[c]
Fate of fish production (%) (χ^2, P = 0.09)			
Quantities sold	74	56	44
Quantities consumed	26	42	56
Recovery of sludge (%)	90[a]	64[b]	50[b]
Recovery of helophytes vegetation (%)	76[a]	56[b]	44[b]
Farm subsystems (%) (χ^2, P = 0.09)			
Fish only (F)	6	29	29
Fish and livestock (FL)	10	16	17
Fish and vegetables (FV)	51	22	30
Fish and livestock and vegetables (FLV)	33	33	24
Ponds water supply (%)(χ^2, P < 0.01)			
River	6	38	54
Groundwater	76	29	22
Water source	18	36	24
Sex control (%)	0b	2b	22a
Use of manure (%)	67a	49b	39c

* Means±standard deviation , ** Percentage of farms for a given location
***P-value: Chi-square tests, probability between sites
[a b c]: if main effects are significant, then means in the same row are followed by different superscript letters

3.3. Farm organisation according to subsystem

Most farms relied on unpaid family labour with some engagement of paid workers but with no significant differences between farm types (Table 3). Very few integrated farms used a paid workforce only and many farmers had complementary activities to generate income. FLV farms provided more work to family members than all other types of farms and displayed the longest experience in agriculture in general (13.4 years); however the difference is not statistically significant. On FL and FLV farms, managers had the highest education levels ($P<0.01$).

On IAA farms, vegetables or livestock, in this sequence, contributed more to farm income than fish. Aquaculture was always considered a secondary contributor to income. Vegetable production was generally the first farming subsystem, as famers practising this have around 12 years of experience. On IAA farms, the fish farming and livestock subsystems followed later (Table 3). However, the integration with other subsystems did not influence the purpose of fish production, i.e. self-consumption or selling. In all types of farms, about half of the production is sold and half is consumed by the farmers' families. No farmer ever raised the issue of preservation or transformation of agricultural products during the interviews, meaning that everything that was sold was sold fresh.

Table 3. Farm characteristics according to the diversity of subsystems (n=number of farms by subsystem, Means ± standard deviation)

	Subsystems				P-value*
	F	FL	FV	FLV	
N (number of farms)	32	21	52	45	
Household size	7.3 ± 3.5**	5.3 ± 2.9	6.5 ± 3.8	7.1 ± 3.6	0.22
Family members work (FTE)	1.4 ± 0.9	1.0 ± 0.9	1.9 ± 2.0	2.1 ± 2.0	0.07
Average age of farm (years)	10.7 ± 9.4	10.9 ± 8.5	13.5 ±11.5	13.4 ± 9.4	0.52
Years of Experience in farming system (years)					
Fish pond	10.7 ± 9.4	8.8 ± 8.0	11.5 ± 10.9	11.4 ± 9.0	0.73
Livestock	-	6.8±6.8	-	9.1 ± 9.6	0.32
Vegetables crops	-	-	12.4±11.7	11.7±9.7	0.77
Workforce (%)					χ^2, 0.17
Unpaid family labour	38	24	46	22	
Paid workers only	16	29	14	29	
Combination of paid and unpaid	47	47	40	49	
Off-farm activities	44	76	52	62	χ^2, 0.09
Level of education (%)					χ^2<0.01
No education	0	5	4	2	
Elementary school	34	5	25	16	
High school	56	38	54	38	
Post-secondary education	9	52	17	44	
Share of farm income (%)					χ^2 <0.01
Livestock	-	57	-	37	
Fishes	100	43	35.5	24	
Vegetables	-	-	64.5	39	
Fate of fish production (%)					χ^2, 0.79
Quantities sold	47	58	67	56	
Quantities consumed	53	42	33	44	

*P-value: ANOVA test, Chi-square tests, probability between subsystems.** Means±standard deviation. F: Fish farming solely, FL: fish and livestock farming, FV: fish and vegetable farming, FLV: fish, livestock and vegetable farming.

3.4. Farm subsystems and management

Ponds are typically small in size and cover most of the areas of the farms, with an average of 2.5 are per fish pond and a total pond area of 4 to 7 are per farm (Table 4). No effect of farm type was found related to pond area. Livestock species were present on 44% of the farms. Tropical Livestock Unit (TLU) densities varied from 2.5 to 5.3. Although no significant differences were found whether vegetables were present or not in the integrated system due to high variability FL farms had twice as many more animals (in TLU) as FLV farms. On the farms rearing livestock, reared animals species were pigs (95.3%), chicken (6.1%), goats (3%), ducks (1.5%) and rabbits (1.5%). Activities on the farm are very often associated with vegetable crops (65%). The average area dedicated to cropping is 96 m² and 67 m² for FLV and FV, which represents approximately 10 and 7 vegetable beds per farm. No effect of integration was found according to vegetable area. Amaranth (*Amaranthus hybridus*) (40%), potato leaves (*Ipomoea batatas*) (38%), roselle (*Hibiscus sabdariffa*) (25%), and eggplant (*Solanum melongena*) (17%) were the most cultivated species. Other vegetables such as cabbage, onion, bean, spinach, cucumber, tomato, pepper were less represented.

Almost all farms had growth ponds with sometimes other types of specialised ponds, for example nursery or storage ponds, existing on fewer farms. Most farms were growing *Oreochromis niloticus* in monoculture (64 to 81%) regardless of the farm type. Farms with fish only (F) tended (P=0.10) to declare longer fish growing periods than farms associating fish production with livestock and/or vegetables, as they did not practice intermediate harvests. F farms seemed to rely more than the other types on the natural productivity of the ponds and on freely available feed such as plants harvested outside the farm or leftovers from family meals (31% vs. 19 to 29%) and less on purchased ingredients (53% vs. 62 to 75%; P<0.01). Reported on-farm feeds included *Manihot esculenta* leaves and peelings, *Elaeis guineensis* nuts, and leaves of *Ipomoea batatas*, *Moringa oleifera*, *Chromolaena odorata* and *Eicchornia crassipes* while commercial feeds ingredients included mainly brewer's grains followed by wheat bran, fish meal, blood meal, and rice bran. Collected manure was mainly used as fertiliser for the pond on farms associating livestock to fish ponds (67 to 73%), followed by FV farms (42%) and F farms (25%). Farmers who did not have livestock declared that manure was purchased. Recovery of pond sludge was higher in farms with vegetables, with 79 and 84% for FV and FLV, respectively, than in FL and F farms, with 52 and 38% respectively (P<0.01). Pond sludge was mostly used by farmers for fertilising and/or compacting pond dikes. Helophytes plants were used for feed animals and piled in the compost. They were also recovered for no actual intended use, except to avoid the cluttering of fish ponds.

Table 4. Size or area allocated to each subsystem in the different types of farms (n=number of farm, Means ± standard deviation)

	Subsystems				P-value*
	F	FL	FV	FLV	
n (number of farms)	32	21	52	45	
Total farm area (are)	6.6 ± 8.0	7 ± 6.9	4.7 ± 3.9	6.4 ± 6.7	0.35
Pond area (%)	100 ± 0	94 ± 98	86 ± 94	86 ± 95	0.19
Vegetable area (%)	N/A†	N/A	14 ± 34	15 ± 31	0.42
Operational ponds (N)	2.4 ± 1.9	2.5 ± 1.9	1.8 ± 1.0	2.4 ± 1.3	0.13
Non-operational ponds (N)	0.7 ± 1.6	1.0 ± 2.1	0.5 ± 1.2	0.6 ± 1.2	0.73
Livestock density (TLU)	N/A	5.3 ± 16	N/A	2.6 ± 2.8	0.26

*P-value: ANOVA test, probability between subsystems
†N/A : not applicable. F: Fish farming solely, FL: fish and livestock farming, FV: fish and vegetable farming, FLV: fish, livestock and vegetable farming.

3.5. Fluxes inventory between subsystems

Possible fluxes of material (dotted boxes) between subsystems (full boxes) of the farming system due to management actions are shown in Figure 3. Farmers with all subsystems on their farms (fish, livestock and vegetables) showed the highest percentage of flux use between subsystems, whatever the material that could be transferred between subsystems (Table 5). One exception lays in the use of pond water to water the vegetables during the dry season. Due to a lack of space or soil characteristics, some farmers have relocated one activity further away from the farm land. This is the case for FL systems which use manure for composting and vegetable farming. In some farms, benefits from fluxes between these activities are negatively impacted by the costs of moving manure towards remote subsystems that are not actually present on the same farm site.

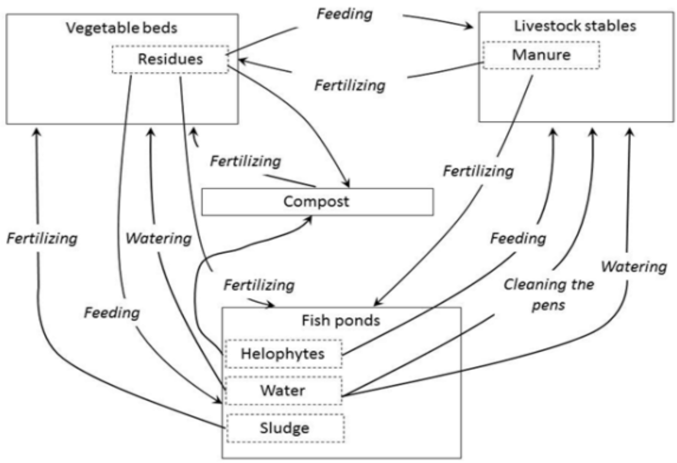

Figure 3. Description of the fluxes between subsystems mentioned by the farmers. Arrows represent the movement of the fluxes between subsystems

Table 5. Inventory of fluxes between subsystems mentioned by the farmers according to the farm type. (% of farms in the category using the fluxes)(N=number of farm, Means ± standard deviation)

	Subsystems			P-value*
	FL	FV	FLV	
n (number of farms)	20	52	45	
Pond used for:				
Fertilising vegetables with sludge	N/A**	10	20	χ^2, < 0.01
Composting of helophytes plants	N/A	21	22	χ^2, 0.89
Feeding helophytes plants to livestock	14	N/A	16	χ^2, 0.74
Watering animals	10	N/A	31	χ^2, <0.01
Cleaning pigsties	10	N/A	18	χ^2, <0.01
Watering plants	N/A	64	49	χ^2, <0.01
Manure used for:				
Pond fertilisation	57	N/A	64	χ^2, <0.01
Vegetable farming	19	N/A	80	χ^2, <0.01
Composting	5	N/A	4	χ^2, 0.11
Vegetable wastes used as:				
Animal feed (pig, fish)	N/A	6	33	χ^2, <0.01
Pond fertiliser	N/A	2	4	χ^2, <0.01

*P-value: Chi-square tests, probability between subsystems. ** N/A: not applicable. FL: fish and livestock farming, FV: fish and vegetable farming, FLV: fish, livestock and vegetable farming.

4. Discussion

Results of the present study showed that Integrated Aquaculture-Agriculture systems exist in different forms, combining fish ponds with vegetables (FV), livestock (FL) or both subsystems (FLV) within farms in urban/peri-urban and rural areas of Kinshasa. Compared to the very diverse systems developed in tropical Asia where the system is usually built around a paddy field with rice as the main crop associated with fish and livestock (Symoens & Micha, 1995; Edwards, 1998; Ahmad, 2001; Micha, 2005), emphasis in Kinshasa is given to vegetable crops such as amaranth, sweet potato leaves, roselle and eggplant, and to raising small livestock such as pigs, chickens, ducks, and goats associated with fish. Crops such as cassava, peanut, corn and soybeans can be found in few farms and are generally grown in rural areas. Because of their requirement for space (flat and wide land), soil characteristics (less clay) and water, these crops are often located outside of the farm and managed without integration with ponds. Under these conditions, even when it is practiced by the same farmer, those crops have little influence on the pond farming because flows are never really exchanged with components outside the immediate vicinity of the pond due to factors such as transportation issues and a lack of manpower to carry the manure, for example. Integration with ponds is therefore basically related to vegetables in Kinshasa like in the Vuon-Ao-Chuong system (VAC, literally meaning “garden/pond/livestock pen” in Vietnamese), which is practiced by a large number of small-scale farmers in Vietnam (Chung et al., 1995; Long et al., 2002; Micha, 2005) or systems associating fruit and vegetable farming on fish pond dikes in India (Tripathi, 2001). Practices in fish farming in Kinshasa are different between rural and urban areas only for some aspects. For example, the short distance that separates farms and the city centre of Kinshasa in urban areas offers some advantages. Farmers close to the city centre use more commercial feed ingredients to feed the fishes and other animals. They have better access to markets and can therefore more easily support high TLU densities on small areas by purchasing feed ingredients for their livestock and mixing with on-farm resources, as shown by Kambashi et al. (2014) in the same area. This practice is also noticeable for the management of the ponds. Regarding fish feeds, the high proportion of farmers reporting the use of purchased fish feeds in urban areas hides the fact that very few of them actually used commercial well-balanced feeds. They purchased any kind of agro-industrial wastes such as wheat bran or brewers’ grains and throw them in their ponds thinking that they feed the fishes. Moreover, they don’t do it regularly, but only when these ingredients are available. Such feed ingredients have little values for fishes and are rather acting as fertilisers for the ponds and also possibly supplying some maggots from flies that lay eggs on the brewers’ grains during storage. Urban farmers have an easier access to purchased fingerlings from Congo River and commercial fingerlings producers, allowing polyculture instead of monoculture more easily as fish production method (35% urban vs. 11% rural). Conversely, rural farmers rely on the exchange of fingerlings between farmers by donations or purchase, lowering the diversity of fish species when stocking ponds.

Having more than one species of fish together in the same pond (polyculture) has generally been regarded as more productive than raising individual species separately (monoculture) (Edwards, 1998; Long et al., 2002). Over half of the fish produced is sold. Customers are predominantly resellers who carry the products to the markets. The farmers therefore wait to have sufficient customers before making the decision to sell the production by emptying the ponds. This situation has an influence on the production cycle, which varies greatly from one farm to another in urban area (high variability of SD table 2). This situation is very similar to that observed by Efole Ewoukem et al. (2012), where the duration of production cycles varied from 9 to 18 months. In contrast, fish production in rural area is more oriented towards self-consumption (Table 2), with a higher use of on-farm resources to feed the animals. The decision to sell the production is taken by farmers when thinking it's ready for consumption. Since over 60% of farmers live on or near their farms, they are very much present on the farm to care of and expect result from the farm. Considering the growing demand for fish, there is an opportunity for smallholder farms to evolve towards partly or completely commercial systems in the future. Major use of purchased ingredients by urban famers hides the fact that brewer's grains are the main purchased ingredients provided by two breweries located in Kinshasa. For rural farmers the cost of transportation is very high and exceeds the cost of acquisition of brewer's grain. This also hides a strong dependence of the urban farms on the breweries.

Regarding the impact of integration, farmers practicing integrated farming generally have more experience in agriculture and have the highest level of education. These farms require high monitoring, involving the highest workforce who are usually family members in Kinshasa. Generally, increased subsystem diversity for more nutrient linkage requires additional labour (Prein, 2002). The paid workforce is normally used for operations that require abundant labour such as harvesting, preparing flowerbeds and transporting farm production if necessary. In this study, an exception lies in FL farms because livestock require more paid labour. FL farms are bigger and contain twice as many animals (in TLU) as FLV; some farmers made big investments and intensive use of the purchased ingredients. The use of paid workforce allows also some farmers to make off-farm activities. Although they are considered a secondary activity contributing only secondarily to the income, ponds play an important role in integrated farms. Ponds are typically small in size, probably due to construction costs, and the lack of appropriate construction materials. The size of the ponds on the farms is correlated with the total area of farm ($P<0.01$, $r=0.97$) and tends to be correlated with the length of the production cycle ($P=0.14$, $r=0.06$). Also, the larger the ponds, the more they display economic importance since pond area is negatively correlated with the contribution of vegetables to the income ($P=0.01$, $r=-0.20$). Results showed that the total amount of harvested fish tends to be correlated with TLU ($P=0.14$, $r=0.07$) and total cost of materials ($P=0.11$, $r=0.14$). Therefore, it seems that the productivity of the animal subsystems is linked with the production of the ponds, possibly due to nutrient transfer through the manure that sustains pond productivity.

The degree of integration and intensification in IAA systems varies with the variation in the pattern of bio-resource flows among various enterprises (Pant, 2005). In urban/peri-urban and rural areas of Kinshasa, 11 fluxes were identified within integrated farms with different degrees of intensification. Integrated farms showed a greater use of manure and sludge for fertilising ponds and vegetables. Manure is directly used in ponds or vegetable farming. Table 5 also shows that only a few integrated farms make full use of the entire range of possible fluxes and require further guidance on the benefits of, for example, a moderate eutrophication of ponds or the use of helophytes in combination with manure to produce compost; this intensifies the positive flows between subsystems, without any deterioration of environmental conditions, in order to derive more profit, as reported by Murshed-E-Jahan & Pemsl (2011) in Bangladesh.

In addition to the fact that this study shows that integrated system exists in rural and urban areas in DRC, it also reveals the fact that the management of the fish pond is not the same when it is alone or associated with other sub-systems in the farm; also there is a tendency for greater efficiency following the management of a greater number of flows for farms with multiple subsystems. However, to confirm this last statement, a proper technical economic analysis or a life cycle assessment would be necessary to show which combination of sub-systems provides high economic return and improves the farmers' socioeconomic conditions.

Chapter 3 allowed us to observe that the integrated system that is practiced in the D.R.Congo is close to that practiced in China and Vietnam.

This chapter helps to understand that the system is generally practiced by small farms in rural and peri-urban areas. The practice of this system does not show a great difference between rural and peri-urban areas except for the practice of food. This chapter has shown that farmers focus on nitrogen management by using techniques to maintain a maximum amount of nitrogen on farms such as using pig manure to boost primary production in fish ponds but also as a crop fertilizer.

Many problems have been highlighted in the previous chapter in particular: (1) low integration of flows between some components (2) lack of commercial feed for fish growth (3) use of industrial by-products of low nutritional quality for fish feed, (4) high use of family labour which is not taken into account in profitability calculations.

Nevertheless, we did not determine the increase in efficiency as a result of greater integration of components within the farm and profitability of IAA. This is probably due to the weakness of the quantitative data collected during the survey and the lack of an appropriate technical and economic analysis method.

Hence, Chapter 4 focuses on the study of the performance of integrated farms based on technical and economic indicators. It provides information on whether these farms are profitable in their current state, whether the highest the integration of flows the better the efficiency on the farm.

Photo 2: Physical and chemical parameters of ponds collection during farm monitoring in urban 1 area

4

Characterisation of integrated agriculture aquaculture systems in smallholder farms in rural and peri-urban areas of Kinshasa (Democratic Republic of Congo)

Article 3

Characterisation of integrated agriculture aquaculture systems in smallholder farms in rural and peri-urban areas of Kinshasa (Democratic Republic of Congo)

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Abstract

In the humid and subhumid tropics, integrated agriculture aquaculture (IAA) production systems reduce the dependence of farmers on external inputs as opposed to producing fish or crops separately. Exploiting the complementarity in fluxes between components in an agro-ecological manner enhances stability in economic and environmental stresses. In sub-Saharan Africa (SSA), a wide diversity in the way different subsystems are integrated within a farm results in large differences in performance. This study combines analysis of technical and economic aspects of IAA farms in order to improve the understanding of the complexity of IAA systems and the effect of integration of the different subsystems on the profitability of fish farms. To perform this study, monitoring of 11 IAA farms with two or three subsystems was conducted during at least one fish pond production cycle in the Province of Kinshasa in the Democratic Republic of Congo (DRC). Results show that, although IAA farms have a positive net margin, some fail to generate profit. Good performance of an IAA farm is only possible under an efficient combination of flow management and allocation of farm expenses and not just by having the highest possible number of integrated flows. Such studies serve as the basis for a much more complex study of IAA performance that considers both the socioeconomic and environmental context and helps IAA farms to make judicious decisions for improving profitability in global activities.

Keywords: agro-ecological, fish, livestock, profitability, technical, vegetable.

1. Introduction

Global fish production has grown steadily in the past decade (3.2%), twice as fast as the world population (1.6%; FAO, 2016). Production of capture fisheries has been relatively stable since the end of the 1980s. Aquaculture, which accounted for only 7% of total fish supplies in 1974, increased to 50% in 2014 (FAO, 2016), partly in response to the decline in natural fish stocks caused by excessive and uncontrolled fishing (Pauly et al., 2002). Asian countries provide most of the total world production (89.3%). Africa holds only a small share of the global supply (2.3%), behind the Americas (4.3%) and Europe (3.9%; FAO, 2017). Several factors, such as the lack of social and economic considerations of the farmers, the lack of judicious choice of technique according to the characteristics of the farms, the lack of food for fish, can be at the root of the difference in fish production between African and Asian countries. This is despite most African aquaculturists using technologies imported from Asia, Europe and North America as part of rural development projects (Gupta et al., 2004).

IAA promotes nutrient linkages between two or more farming activities, one of which is aquaculture (Dumont et al., 2013). IAA is an important technology developed in South and South-East Asia, in particular Bangladesh, China, India, Indonesia, Malaysia, Thailand and Vietnam. It has been promoted as a way of increasing food production and security in a resource limited environment (Edwards, 1993; Symones and Micha, 1995; Mathias et al., 1998; Prein, 2002; Zajdband, 2011). IAA became important in Asia after the limitations of green revolution were observed, especially regarding its negative environmental impact and its incapacity to solve the problem of malnutrition (Matson et al., 1997). In Asia, IAA is a practice that is well-accepted by the local communities because of the higher profit and the lower waste it generates compared to non-IAA farms (Tipraqsa et al., 2007; Murshed-E-Jahan & Pemsl, 2011). As such, IAA could help increase aquaculture productivity in SSA where financial resources, limited cash flow and pedoclimatic conditions similar to South-East Asia prevail.

However, IAA has not yet produced the expected results in SSA smallholder farms (Brummett, 1999). For instance, from the 1970s to the mid-1990s, several donor organisations attempted to introduce aquaculture to rural farms in Malawi, but with little success (Dey et al., 2010). Despite all attempts, fish production in Africa (1,682,000 tons) remains far less than fish production in Asia (40,3120,000 tons; FAO, 2016). Hence, IAA still has significant progress to make in terms of increasing food production and food security in SSA.

Key features of sustainable integrated crop-livestock systems (ICLS), under which IAA systems may fall, involve complex resource exchanges and cycle interactions between crop and livestock production sub-systems. Such interactions are at the heart of the metabolic and immune functions of the agroecosystem (Bonaudo et al., 2014) and should be optimised to sustain the production function from an agro-ecological perspective. Stark et al. (2016; 2018) stressed the importance of flow exchanges between the different subsystems of an integrated farm and showed that the greater the exchange possibilities, the more sustained and stable the production of the farm was. However, how such a complexity in network flows impacts on the economic sustainability of IAA farms is unknown, although this could be critical to the adoption of this technology in SSA. A proper implementation of IAA should lead to low dependence of farms on external inputs due to good management of the complexity of internal flows. That can result in high performance of IAA farms ascertainable through economic and technical indicators which contribute to the farm performance. Some studies that compared IAA with conventional farms demonstrated that IAA is more profitable (Dey et al., 2010; Blythe, 2013; Limbu et al., 2016). However, the contribution of each subsystem to profitability is still poorly documented. Hence, farmers still lack information on how they could optimise their IAA systems, considering the compromises to be made between the subsystems in order to maintain the overall balance of the IAA system.

In a recent survey of more than 150 aquaculture farms in the Western provinces of the DRC, about 79% of farms combined fish with livestock and/or vegetable production. However, huge differences were observed in the way integration of the different subsystems in the fish farms was managed, with 11 possible nutrient fluxes being identified (Kinkela et al., 2017). Hence, this paper proposes a characterisation of some technical and economic aspects in order to asses IAA farm performance with a view to improving the understanding of the complexity of IAA systems and the effect of the integration of different subsystems on profitability. The study used integrated fish farms from urban/peri-urban and rural areas of the province of Kinshasa in DRC as case-studies.

This research, beyond understanding the functioning of IAA, also provides insights into weaknesses in the technical and economic organisation of IAA farms, which may be the basis of improvements in IAA in humid and subhumid SSA. This could serve 'as the basis for much more complex IAA performance studies that consider both the socio-economic and environmental context.

2. Material and methods

Based on the survey conducted by Kinkela et al. (2017) of aquaculture farms in the Province of Kinshasa, DRC, 11 IAA farms with two (fish plus crops or livestock) or three (fish plus crops and livestock) subsystems were monitored for at least one fish pond production cycle, lasting from 6 to 18 months, for technical and economic characterisation. These IAA farms were located in Funa (urban 1/peri-urban), N'djili Brasserie (urban 2) and Mbankana (rural), all in the province of Kinshasa, DRC.

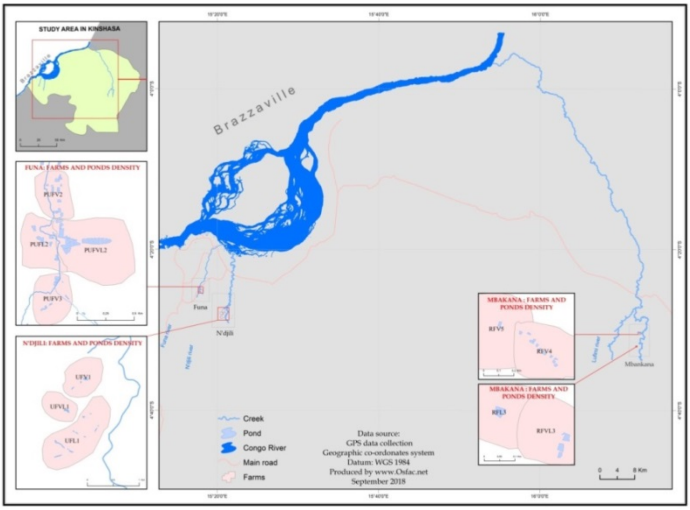

Figure 4. Map of Kinshasa (upper left) showing the location of study sites. The "farms and ponds density" squares display enlargements of the three areas where selected farms were monitored: N'djili and Funa are urban/peri-urban areas with UFVL1, UFV1, UFL1, PUFV2, PUFV3, PUFVL2, PUFL2 selected farms and Mbankana is a rural area with RFV4, RFV5, RFVL3, RFL3 selected farms. Data source: GPS data collection geographic coordinates system. Datum: WGS 1984. Obtained from www.osfac.net. September 2001.

In addition to criteria such as the number of subsystems and site location (urban and rural sites), the selection of the IAA farms was based on stability and regularity of their activity, i.e. farms must have already carried out more than one fish production cycle and have access to the market. Other criteria were diversity in farm size, the owner's involvement in the day-to-day work and relative importance of aquaculture; these were used to establish the diversity of situations observed in the area. Hence two exploitation groups were monitored. The first group consisted of holdings with large areas (>1 ha) but only a small part was exploited as farming was considered as a secondary occupation, and the second group with a small area of which almost all it was exploited, truly making a living from this activity (Table 6). Farmers from the second group were very much involved in farm activities, while the first group used a farm manager and paid labour to do most of the manual work on the farm. The farms reared *Oreochromis niloticus* and *Clarias gariepinus* fish species in monoculture or polyculture systems. Livestock consisted exclusively of pigs. Crops were mainly vegetables, such us Amaranth (*Amaranthus hybridus*), potato leaves (*Ipomoea batatas*), roselle (*Hibiscus sabdariffa*) and eggplant (*Solanum melongena*), which were grown in rotation in the same plots.

The resulting farm sample was as follows: three farms (UFVL1, PUFVL2, RFVL3) with fish, vegetable and livestock production (FLV), five farms (UFV1, PUFV2, PUFV3, RFV4, RFV5) with fish and vegetable production (FV) and three farms (UFL1, PUFL2, RFL3) with fish and livestock production (FL) (Table 6 and Figure 4).

Table 6. Farms characterisation in different peri-urban and rural areas of Kinshasa

Study area	Subsystems in farm	Farm identity	Farm size (a)	*UAA (a)	Vegetables plots (N)	Average plot size (a)	Ponds (N)	Pond area (a)	Pigs on farm (TLU)
Urban 2	**FVL	UFVL1	300	6.3	44	0.2	1	7	4.2
Urban 2	***FV	UFV1	250	10.9	71	0.2	2	3	N/A
Urban 2	[||]FL	UFL1	50	N/A	N/A	N/A	4	8	4.8
Urban 1	FV	PUFV2	24.9	2.3	9	0.2	2	18	N/A
Urban 1	FV	PUFV3	29.2	3.4	13	0.3	1	1	N/A
Urban 1	FVL	PUFVL2	57.6	9.1	27	0.3	4	23	6.4
Urban 1	FL	PUFL2	76	N/A	N/A	N/A	2	4	2.4
Rural	FV	RFV4	500	3.8	20	0.2	4	16	N/A
Rural	FV	RFV5	500	2.4	17	N/A	2	7	N/A
Rural	FVL	RFVL3	500	19	81	0.2	3	11	2.4
Rural	FL	RFL3	150	N/A	18	N/A	1	3	0.8

*UAA: utilised agricultural area for vegetables, **FVL: fish, vegetable and livestock farming, ***FV: fish and vegetable farming, [||]FL: fish and livestock farming, N/A: not applicable. TLU: tropical livestock unit (conversion of pigs to TLU), according to Jahnke et al. (1988).

Two farms visits were organised per month for a maximum of 18 months from May 2014 to January 2016. During the visits, technical and economic information recorded by farm managers according to the survey instructions, were discussed and collected for further analysis. Also, some additional technical measurements and samplings were conducted by the surveyors. An exception was made for the four rural farms where only economic data were collected due to the remoteness of these properties.

Economic data were recorded by the farmers on a daily basis in the form of a list of sales (outputs) and purchases (inputs), with prices, quantities where relevant and ascription to one subsystem (fish, crop or livestock). This list was checked and collected by the surveyors during the visits. It was used to calculate variable costs, fixed costs, agricultural gross margin, total production and total revenue for the farm.

Technical data, collected on a fortnightly basis from the seven urban/peri-urban farms, focused on changes in herd structure (number of animals in the different categories), animal weights, quantities of feed distributed, sales, purchases or deaths, as well as any type of operation carried out, related to the livestock, i.e. the pig subsystem. Only young growing pigs were weighed twice a month. Adult animals were weighed at the beginning and at the end of the monitoring period because of the heavier equipment that was required. To prevent transmission of diseases between farms, farm managers weighed the animals themselves. In regard to the vegetable subsystem, technical information focused on the type of crops, area and quantities produced by plots, quantity of fertiliser used, as well as irrigation. In the case of the fish subsystem, data such as, quantity of fertiliser and feed distributed to the pond, was recorded by the farmer. Water temperature, hydrogen potential (pH) and dissolved oxygen (DO) were directly measured in ponds at each farm by the surveyors at approximately 6 am using a HQ40D Kit digital multi meter (Hach, Düsseldorf, Germany). Water samples (200 ml) were also collected and analyzed for total nitrogen (TAN), ammonium (NH_4^+) nitrate (NO_3^-) and nitrite (NO_2^-) contents by spectrophotometry using the dedicated NANOCOLOR kits in a NANOCOLOR 500D spectrometer (Macherey-Nagel, Germany) following the manufacturer's instructions. Briefly, the determination of total nitrogen is made after oxidative mineralization in a heating block followed by interference compensation and determination using 2.6-dimethylphenol in a mixture of sulphuric and phosphoric acid. Ammonium is measured after indophenol: ammonium reacts at a pH of about 12.6 with hypochlorite and salicylate, in the presence of sodium nitroprussiate as catalyst, to form indophenol blue. Nitrate is measured using 2.6-dimethylphenol in a mixture of sulphuric and phosphoric acid. Nitrite is measured using sulphanilic acid and 1-naphthylamine.

2.1. Calculations

The operating account method or results account described by Cerrada et al. (2008) was used to analyse the economic performance of each subsystem within the integrated farms. This method summarises the expenditure and income of a farm for a given period, called the "accounting period", corresponding to the monitoring period. In this study, the monitoring period was reduced to one year, which corresponds to a full cycle of the longest subsystem, namely fish farming, and more than one cycle of livestock and vegetable production.

In this study, the generated operating account enabled calculation of economic indicators, such as gross margin, farm income and profit or loss, that were used with technical indicators to evaluate farm performance. The parameters calculated to determine the profitability of subsystems on the farms were as follows: total production, total revenue, agricultural gross margin, variable and fixed costs, and profit or loss.

Due to succession of multiple crops in the same plot during a period and the farmer’s difficulty in reporting the exact quantity of crops produced by the plot, as well as the presence of different fish species in the same pond, it was difficult to calculate the breakeven point for the vegetable and fish farming subsystems. Total production for these two subsystems was recorded in value without any distinction in crop or fish species by the farmer. The following equations were used to calculate the required parameters:

1. Variables and fixed costs (VC and FC)

$VC = \sum X_i$ and $FC = \sum Y_i$

Where VC is variable cost, FC is fixed cost, Xi represents all expenditure related to the acquisition of inputs and Yi represents all expenditure of the farm not related to the volume of production.

2. Total production (TP)

$TP = \sum$ product (sold and consumed (kg) x price of product ($\$kg^{-1}$)

Where TP represents the total production in the farm

3. Total revenue (TR)

TR = TP (\$) – SC (\$)

Where TP is the total production in the farm and SC is self-consumption

4. Agricultural Gross Margin

GM = TP – TCV

Where GM is gross margin, TP is total production and TCS is total cost variables

2.2. Statistical analysis

The multivariate and univariate tests for repeated measures analysis of variance were used to compare mean values of water parameters for the seven selected farms in urban1 (peri-urban) and urban 2 areas of Kinshasa. Ponds on each farm were considered to be the experimental units and the sampling dates as repeated measurement. Principal component analysis (PCA) in SAS was used to assess economic and technical indicators and expenses for the seven selected farms (urban/peri-urban) and to investigate correlation between farms. Finally, Pearson’s correlation was use to assess expenses and economic indicators for eleven farms selected (urban/peri-urban and rural).

3. Results

3.1. Economic aspects of IAA farms

The highest gross margin was observed for PUFVL2 farm which has a full integration of subsystems, while the lowest was for RFL3 farm with only two subsystems present, fish and livestock (Figure 5). Farm income was negative for two IAA farms, the two farms with the lowest gross margin value. Among the monitored farms, six made profits at the level of the farm's overall activities; the five remaining farms did not make any profit. The farms making profits and those not making profits belonged to the three types of subsystem associations (FV, FL and FVL).

Separate analysis of the subsystems shows that all subsystems had positive gross margins except the fish subsystem on one farm (UFV1; Table 7). According to farm income, eight IAA farms involving different subsystems had negative values. According to farm income, eight IAA farms involving different subsystems had negative values. The subsystems that had negative values were essentially fish and livestock farming, but never vegetable farming. Two farms were profitable in all subsystems (PUFVL2 and UFL1), while two did not make profit with any subsystems (UFVL1 and PUFV2) and seven had at least one subsystem with profit, whereas the other subsystems present were in deficit. Although in a very diversified way, all the agricultural subsystems of the IAA have contributed significantly to farmers' self-consumption through different farm products since the percentage of total revenue (Total production – Total revenue) was less than 100%. The difference represents unsold value that is mainly self-consumed. Vegetable farming contributed to self-consumption with an average percentage of 7.2 ± 1.6%, fish farming with 24.3 ± 13.2% and livestock farming with 33.1 ± 13.3%.

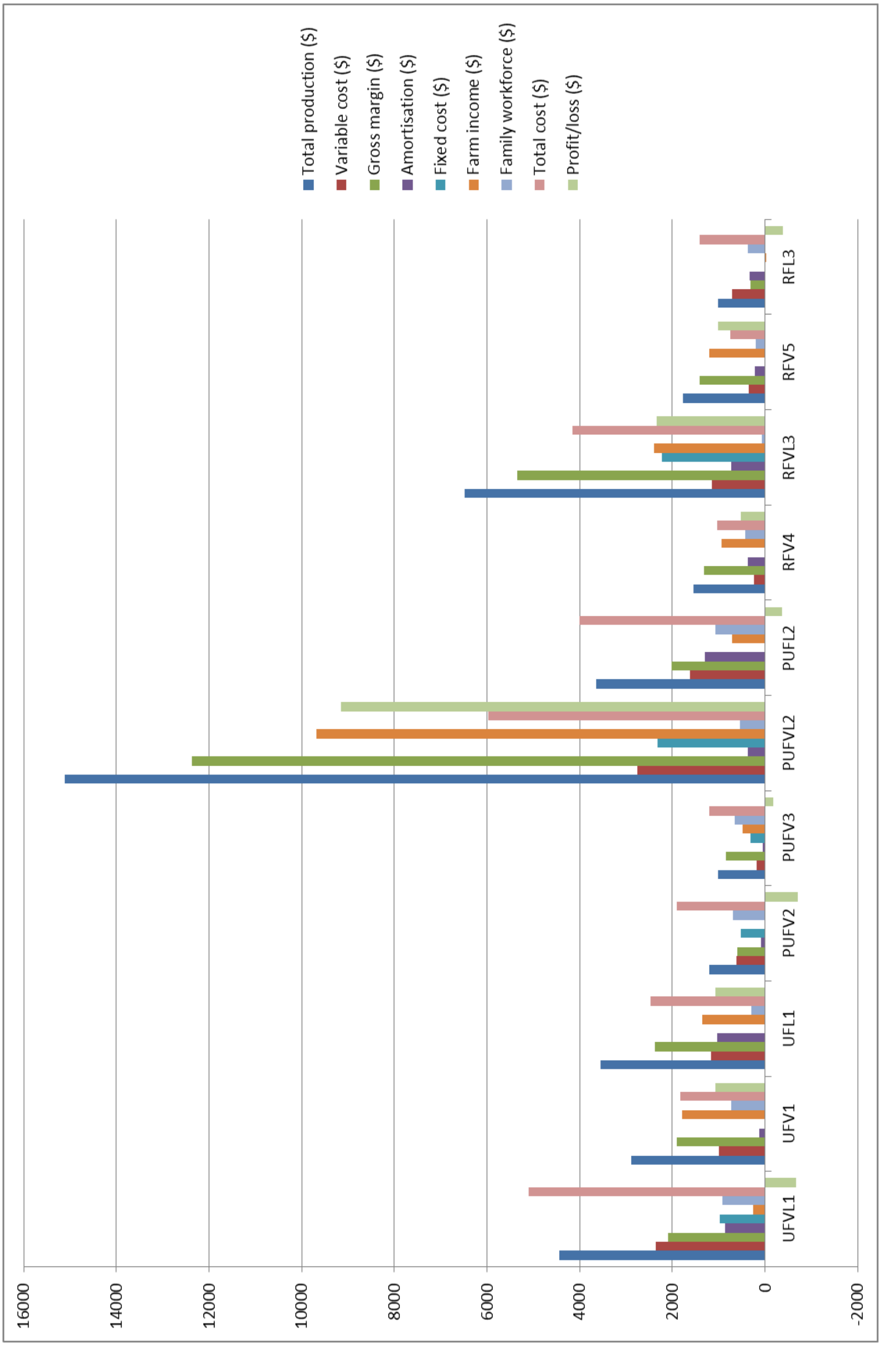

Figure 5. Global profitability of IAA farms in rural and peri-urban areas of Kinshasa

Table 7. Profitability of IAA farms with fish (F), vegetables (V) and livestock (i.e. pigs) (L) subsystems.

Farm identity	UFVL1			PUFVL2			RFVL3			UFV1		PUFV2		PUFV3		RFV4		RFV5		UFL1		PUFL2		RFL3	
Subsystems	F	V	L	F	V	L	F	V	L	F	V	F	V	F	V	F	V	F	V	F	L	F	L	F	L
Pond size (a), UAA (a), pigs (TLU)	7	6.3	4.2	23	9.1	6.4	11	19.1	2.4	3	10.9	18	2.3	1	3.4	16	3.8	7	2.43	8	4.8	4	2.4	4	0.8
TP($)	293	1676	2474	4301	3161	7658	351	5192	942	126	2759	344	856	178	835	79	1464	41	1720	799	2746	457	3177	139	882
TR (% of TP)	79	90	87	93	93	60	76	94	N/A	82	90	79	93	81	93	71	94	46	94	92	N/A	66	61	67	59
GM($)	242	1063	787	3659	2968	5733	141	4917	287	-183	2080	71	523	162	672	62	1249	36	1381	765	1617	431	1582	135	172
Farm income ($)	94	801	-641	2821	2928	3936	-84	2663	-184	-252	2036	-258	255	-7	481	-267	1201	-110	1317	594	757	343	365	72	-96
Profit /loss ($)	-11	-17	-641	3054	2457	3936	-134	2663	-184	-263	1327	-229	-376	12	-166	-262	790	-117	11323	582	493	319	-685	65	-4512

F: fish farming; V: vegetable farming; L: livestock farming; N/A: not applicable; UAA: utilised agricultural area for vegetable; TP: total production; TI: total income; GM: gross margin; BCR: benefit cost ratio.

The overall profitability of IAA farms hides the individual level of performance of each subsystem. For instance, vegetable farming seemed to be the most profitable subsystem of the investigated IAA farms ahead of fish and livestock farming. Among the eight farms involved in vegetable farming, all had a positive gross margin and farm income value and five made a profit with this activity (Table 7). Profit ranged from 789.98$ (RFV4) to 2662.64$ (RFVL3). As per sample constitution, all 11 IAA farms had fish farming as one of subsystem in the farm. This subsystem generated profits only in five farms and one of them had a negative farm income (Table 7). Profit with this subsystem ranged from 11.65$ (PUFV3) to 3053.55$ (PUFVL2). In the case of two subsystem IAA farms, fish farming generally generated a profit when it was associated with livestock farming and hardly ever when it was associated with vegetable farming (Table 7).

Livestock farming appeared to be the less profitable subsystem in IAA farms. Only activities in two farms (UFL1 and PUFVL2) gave rise to profit among the six selected IAA farms with pigs (Table 7). However, all of the six farms had positive gross margins and three farms had positive farm incomes.

Table 8. Expenditure for vegetable farming in IAA farms in USD ($). Values in parentheses indicate expenditure as a share of the total cost (%).

Farm system	FVL			FV				
Farm identity	UFVL1	PUFVL2	RFVL3	UFV1	PUFV2	PUFV3	RFV4	RFV5
Total area (acres)	6.2	9.1	19	10.9	2.3	3.4	3.8	2.4
Total production	1676	3161	5192	2759	856	835	1464	1720
Production value /area	270	347	273	253	372	246	385	717
Seeds	49 (3)	27(4)	117(5)	114(8)	182(15)	21(2)	48(7)	69(12)
Mineral fertiliser	119 (7)	30(4)	41(2)	165(12)	59(5)	20(2)	44(7)	44(8)
Organic fertiliser	100(6)	4(1)	84(3)	333 (23)	18(1)	57(6)	47 (7)	77(13)
Phytosanitary products	39(2)	6(1)	12(1)	25(2)	8(1)	0	5(1)	19(3)
Temporary workforce	225(13)	120(17)	0	43(3)	67(5)	53(5)	62(9)	104(18)
Others charges	83(5)	7(1)	21(1)	0	0	13(1)	9(1)	27(5)
Amortisation	8(0.5)	40(6)	112(4)	44 (3)	30(3)	19(2)	47(7)	63(11)
Rent amount	0	0	0	0	237(19)	171(17)	0	0
Permanent workforce	254(15)	0	2143(85)	0	0	0	0	0
Family workforce value	818(48)	470(67)	0	709(50)	632(51)	647(65)	411(61)	185(31)
Total cost	1692	704	2529	1432	1232	1001	674	588
Profit/loss	-17	2457	2663	1327	-376	-166	790	1133

FVL: Fish, vegetable and livestock farming; FV: Fish and vegetable farming

Table 9. Expenditure for livestock farming in IAA farms in USD ($). Values in parentheses indicate the expenditure as a share of the total cost (%).

Farm system	FVL			FL		
Farm identity	UFVL1	PUFVL2	RFVL3	UFL1	PUFL2	RFL3
Pigs (TLU)	4.2	6.4	2.4	4.8	2.4	0.8
Total production	2474	7658	942	2746	3177	882
Production (TLU)	589	1197	393	572	1324	1103
Average BWG (g/day)	44	103	48	86	111	-
Temporary workforce	0	57(2)	0	19(1)	69(2)	83(6)
Veterinary products	59(2)	135(4)	60(5)	60(3)	84(2)	74(6)
Feed	1522(49)	1655(45)	580(52)	1022(45)	1231(40)	493(37)
Other charges	106(3)	77(2)	16(1)	29(1)	211(6)	60(5)
Amortisation	702(23)	48(1)	391(35)	860(38)	1217(32)	269 (20)
Rent amount	0	1274(34)	0	0	0	0
Permanent workforce	725(23)	475(13)	79(7)	0	0	0
Family workforce value	0	0	0	264(12)	1050(27)	356(26)
Total cost	3115	3721	1126	2253	3862	1334
Profit/loss	-641	3936	-184	493	-685	-452

FVL: Fish, vegetable and livestock farming; FL: Fish and livestock farming

Expenditure for the farms, shown in Table 8, 9 and 10 as well as its distribution according to the total cost of the farm in each subsystem clearly shows that some expenses absorbed the profit and had a marked influence on the profitability of farms. In vegetable farming, the unpaid family workforce represented a very high theoretical cost for almost all farms, although this remained unnoticed by farmers because it was unpaid (Table 8). This value varied from 31.4% up to 67% of total costs and had a major impact on farm profitability.

In livestock farming, feed costs represented the biggest expense, even when vegetables were grown on the farm (Table 9). The amount ranged from 37% to 52% of total costs. Amortisation for the pig housing was a particularly significant cost in the livestock subsystem, except for the PUFVL2 farm. In fish farming, amortisation seemed to be the greatest expense due to the cost of pond construction. However, it varied from one farm to another (from 7 to 92% of the total cost for the farm) and was very low in peri-urban areas where farmers rented ponds. Some IAA farms spent a significant amount of money on purchasing fish feed, but not all of the farms (Table 10). These two categories include, on the one hand, farms that invest a lot in fish feed which also use fertilisation with vegetable waste and/or pig manure for growing fish (UFVL1, PUFVL2, RFVL3, UFV1, PUFV2 and PUFV3) and, on the other hand, those for which relies only on natural productivity of the ponds using vegetable waste or pig manure (RFV4, RFV5, UFL1, PUFL2 and RFL3). Despite the lack of purchased feed, farms with fish and livestock farming (UFL1, PUFL2 and RFL3) of the latter category all generated profit from fish farming activities.

Expenses related to mineral and organic fertiliser were quite low in IAA farms involving three subsystems (fish, vegetable and livestock farming) (Table 8). The exception was UFVL1 farm in which, in spite of the presence of livestock, 8% of the total cost was spent in buying mineral and organic fertilisers. PUFV2 and PUFV3 are notable in that land for the plots was rented (representing 17% and 19% of total cost, respectively) and this expense affected the profit.

Table 10. Expenditure for fish farming in IAA farms in USD ($).Values in parentheses indicate expenditure as a share of the total cost (%)

	FVL			FV					FL		
Farms	UFVL1	PUFVL2	RFVL3	UFV1	PUFV2	PUFV3	RFV4	RFV5	UFL1	PUFL2	RFL3
Area (a)	7	23	11	3	18	1	16	7	8	4	4
Total production	293	4301	351	126	344	178	79	43	799	457	139
Production/area	42	187	32	42	19	178	5	6	100	114	35
Temporary workforce	31(10)	40(3)	0	0	0	0	0	0	26(12)	0	0
Stocked fish	7(2)	24(2)	12(2)	3(1)	19(3)	1(1)	17(5)	7(4)	8(4)	4(3)	3(4)
Pond fertilisation	0	0	0	0	32(5)	0	0	0	0	0	0
Feeds	9(3)	578(37)	198(40)	306 (78)	222(33)	15(8)	0	0	0	0	0
Other charges	4(1)	0	0	0	0	0	0	0	0	22(15)	0
Amortisation	148(49)	272(18)	226(46)	70(18)	45(7)	28(14)	329(92)	145(87)	171(76)	89(62)	63(83)
Fish pond rental	0	566(36)	0	0	283(42)	142(73)	0	0	0	0	0
Family workforce value	105(34)	64 (4)	61(12)	14(3)	68(10)	10(5)	12(3)	14(9)	20(9)	28(19)	10(13)
Total cost	303	1544	496	393	669	195	358	167	226	142	77
Profit/loss	-11	3054	-134	-263	-229	12	-262	-117	582	319	65

FVL: Fish, vegetable and livestock farming, FL: Fish and livestock farming, FV: Fish and vegetable farming.

3.2. Technical aspects of ponds on IAA farms

During the monitored period, water quality of fish ponds on integrated farms showed significant difference in pH (P<0.0001), dissolved oxygen (P<0.0001) and nitrate as NO_3^- (P<0.0001) parameters between farms (Table 11). Water temperature reached an average value of 25.6°C, but decreased down to 20.7°C during the dry season from the end of June until the beginning of October. pH values of fish ponds on all farms were within an acceptable range for the culture of *Oreochromis niloticus* and *Clarias gariepinus* (Table 11), species that were cultivated the most on farms in this study. The two farms, UFVL1 and PUFVL2, each involving three subsystems (FVL) had high pH values (6.6 and 6.6, respectively) with no significant difference between them. The lowest pH value was observed on the PUFV2 farm, one of the farms with a FV system (5.2). The remainder of fish ponds in the FV or FL systems did not show any significant differences.

Level of DO greatly fluctuated during the monitored period, from 1.2 mg l^{-1} to 6.4 mg l^{-1}. As for the pH value, IAA farms with three subsystems (UFVL1 and PUFVL2) had the highest DO value for the fish pond water (6.4 mg l^{-1}). Statistical analysis showed a striking difference between DO values for farms in FVL systems and those in FV/FL systems. Generally, the farms in FL systems displayed low DO values. The lowest DO value was recorded for PUFV2 farm; this had a particularly low DO value compared to others one in the FV system. Nitrate data are the only ones presented as an eutrophication indicator in Table 11. The remainder of the data related to ammonium and nitrite is presented in the appendix 3 since due to the failure of the analytical kite not all the samples could be analysed and the analysed samples do not provide more information than the information provided by the nitrate analysis. Nitrate values for pond water were within the acceptable range for fish species in ponds. The values ranged between the minimum value of 0.4 mg l^{-1} and the maximum value of 1.2 mg l^{-1}. The highest value was reported for PUFV2, followed by the two farms using FVL and FV systems. The lowest values occurred in the two farms of the FL system.

. **Table 11.** Dissolved O_2 (mg l^{-1}), nitrate (NO_3^-) (mg l^{-1}) and hydrogen potential (pH) of pond water on IAA farms according to different systems (means ± SD).

Systems	FVL		FV			FL	
Farms	UFVL1	PUFVL2	UFV1	PUFV2	PUFV3	UFL1	PUFL2
Number of ponds	4	4	4	1	2	2	2
Number of observations	96	96	96	24	48	48	48
pH	6.6a ± 2.9	6.6a ± 0.9	6b ± 0.5	5.2c ± 0.9	6.1b ± 0.7	6.1b ± 0.4	5.9b ± 0.6
O_2	6.4a ± 2.9	6.4a ± 2.9	1.2e ± 0.9	4.8b ± 1.5	3.9c ± 2.8	2d ±1.1	2.1d ± 1.8
NO_3^-	0.9b ± 0.6	0.8cb ± 0.6	0.6cd ± 0.4	1.2a ± 0.7	0.6ed ± 0.5	0.4e ± 0.3	0.5ed ± 0.3
Production/unit ($)	41.8	187.0	42.0	19.1	177.8	99.9	114.4

a, b, c, d and e: Mean values in the same row without common letter are different at $P<0.05$

FVL: Fish, vegetable and livestock farming, FL: Fish and livestock farming, FV: Fish and vegetable farming.

3.3. Performance of IAA farms

Figure 6 presents results of a PCA which combines technical, economic indicators and expenses of IAA farms in the same analysis to determine the performance of IAA farms in urban/peri-urban areas of DRC. The Figure shows that the first axis concerns variables related to farm performance, including indicators and expenses that contribute to farm profitability. Axis 2 relates to expenses and technical indicators that negatively impact on farm performance. With the exception of the PUFVL2 farm (Figure 7) which, despite these expenses enhances the overall production of the farm, the remaining farms faced either high expenditure that negatively affects farm performance (UFV1, UFVL1 and PUFV2) or low expenditure with low capacity to promote production of the farm (PUFV3, UFL1 and PUFL2).

Representation of variables axis2 * axis1

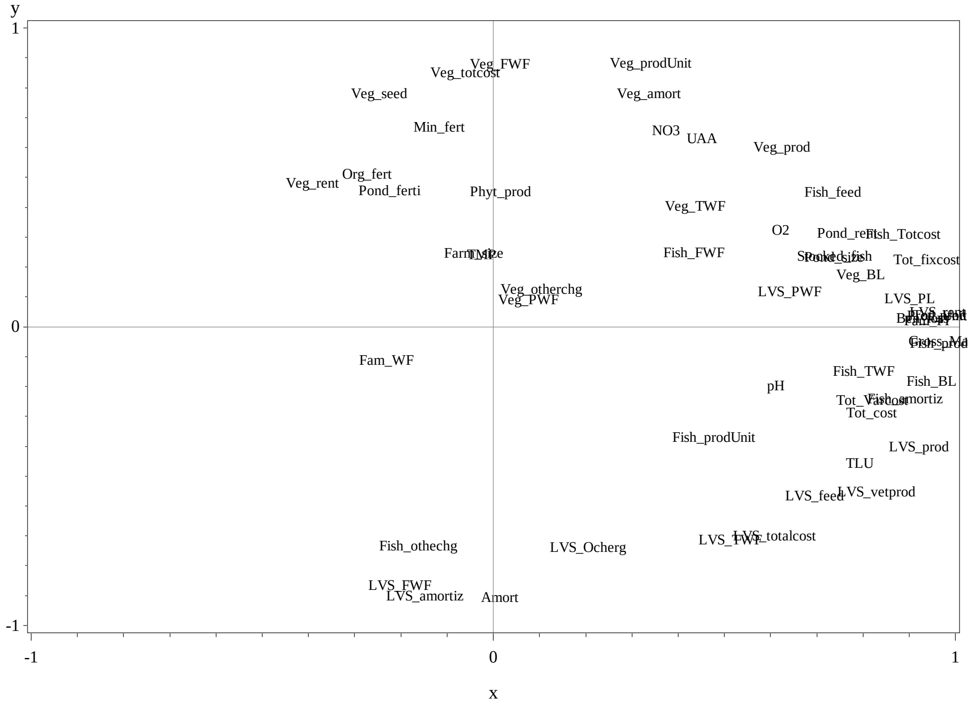

Figure 6. Results of the principal component analysis on the three first dimensions (explaining 80% of variability). Distribution of individual integrated farms that were studied according to the indicators considered.

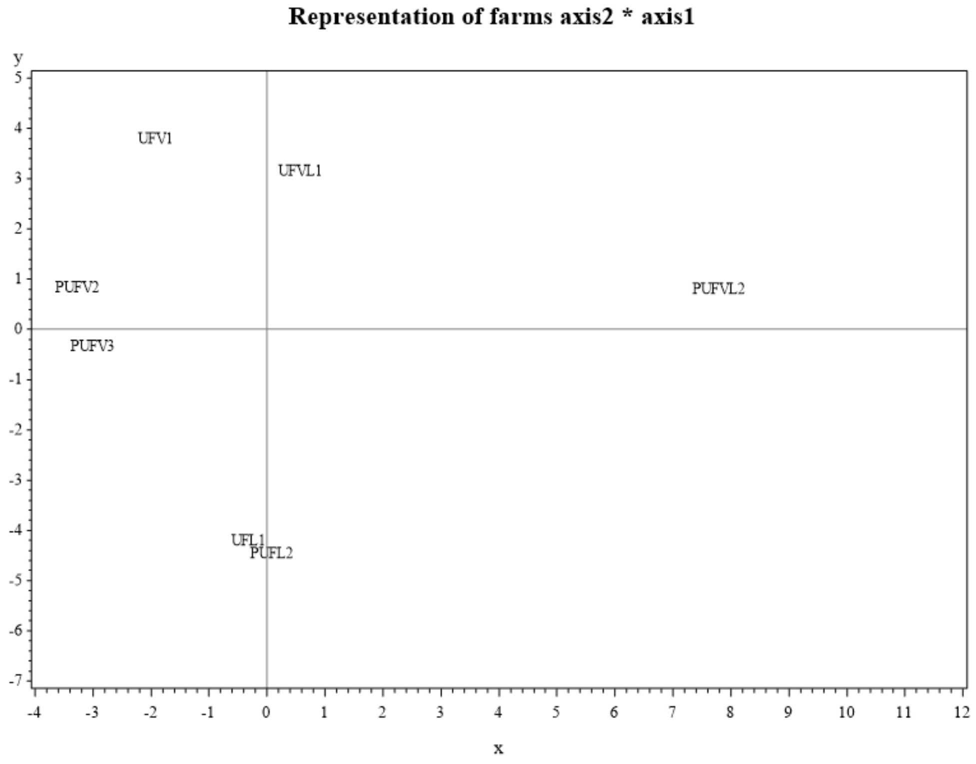

Figure 7. Distribution and correlation of variables for urban 1 and urban 2 (peri-urban) integrated farms studied. Results of the principal component analysis on the three first dimensions (explaining 80% of variability).

4. Discussion

Economic results of the present study show that only two IAA farms had a negative farm income while all were able to cover variable costs with a positive gross margin. However, most of them failed to generate a profit (Figure 5). There are two major reasons for the paradox of why unprofitable farms continue their activities: (1) they do not properly evaluate the family workforce and the immobilisations of assets; and (2) they consider the farm as an investment that they can liquidise in case of problems by the one-off sale of animals, vegetables or fish. This behaviour is in contrast with what was observed with non-IAA Congolese smallholder pig producers who were strongly market oriented (Kambashi et al., 2014), although the profitability of the activity was not necessarily guaranteed. In addition, monitoring data indicate that the area of the farm land was not correlated with the level of investment or the intensity of farm activities. In contrast to IAA farms in Bangladesh, the size of farm in rural and peri-urban areas of Kinshasa may not reflect the availability of capital or managerial ability, or the potential to operate or use resources efficiently (Ahmed et al., 2007). This explains why the correspondence analysis showed negative correlation between farm size and the three economic performance indicators, namely gross margin (P=-0.13), farm income (P=-0.16) and profit or loss (P=-0.19). A farm such as UFVL1, for example, which has a large area (3 ha) but only exploits a small part of it and the owner does not rely on the farm revenue.

Most farms in rural and peri-urban areas have poor financial resources, do not receive government subsidies and do not have access to agricultural credit, as shown, coupled with limited access to a skilled workforce. Therefore, the utilisation of a family workforce over the year by smallholders with an integrated system is a great opportunity for reducing farm costs and contributing to increased production inside the farm, as well as creating employment opportunity for income generation for family members who do not have an opportunity for outside work (Alam et al., 2009). This explains a much greater use of the family workforce on some farms. Previously, Dey et al. (2010) pointed out that the productivity of the family workforce in IAA activities is higher than alternative opportunities for using the family workforce in off-farm activities. However in this case, the income from this employment opportunity is not comparable to off-farm work which, moreover, is not easy to obtain but enables the farm to progress and contributes to family food requirements. The value of a family workforce is usually disregarded in the daily accounting for the farm in rural and peri-urban areas of Kinshasa. Conversion of this resource in a cash equivalent, therefore, significantly affects the profitability of the farm. So, the family workforce is negatively correlated with the farm profit (P= 0.45, r=-0.25).

The studied farms presented a strong variability in the subsystems used, as well as in the factors that drove the profitability. Such diversity probably originates from differences in farming practices and location of the farm. Hence, it seems highly desirable to understand what makes one farm more profitable than another, in order to provide advice on practices that are best suited according farm location in other to pull all farmers towards increased sustainability as suggested by Gerber et al. (2013).

The involvement of a dense network in IAA farms which combine fish, vegetable and livestock farming (FVL), which is expected to be more sustainable and stable due to the high score of flux between the subsystems, seems not to be a sufficient and necessary condition for financial viability. It still seems clear that the capacity of farmer to take advantage of the presence of large flows on the farm trough skilled flow management is needed (Stark et al., 2018). Among the three selected FVL farms, only one was financially viable (PUFVL2).

In general, the two farms that stood out from the others in terms of profitability (PUFVL2 and RFV5) showed judicious decision-making with regard to the allocation of expenses, the management of flows, and the involvement of the farmer in farming activities. One specific farm, PUFVL2, showed good economic and technical conditions in all subsystems and for this reason should be further examined. There are several reasons for this situation. Firstly, in vegetable farming where PUFVL2 scores the highest profit (2457$) and the second production value per unit area (347$); this farm minimises the expenses related to mineral and organic fertilisers (only 5% of the total cost in the farm) while maximising inputs from pig manure and pond water for this purpose. Mineral (P=0.21) and organic (P=0.26) fertiliser was not correlated with vegetable profit; minimising these expenses enabled the farm to make a profit. RFVL3 used the same strategy, however, its finances were burdened by a permanent workforce, representing 85% of the total cost compared to zero cost in PUFVL2, which was committed to using the family workforce, representing 67% of the total cost. PUFVL2 used a temporary workforce when the work in the field became too important (17% of the total cost) and for work that did not require a skilled workforce (harvesting, weeding and transporting vegetables) and, therefore, had a lower cost than a permanent workforce. And so, the farmer spent much of his time, together with the family, carrying out routine work. Secondly, with regard to livestock farming, PUFVL2 seemed to have good control of expenses coupled with high value of the product. In PUFVL2, the livestock building was rented which significantly reduced the cost of amortisation on the farm because both tend to be negatively correlated (P=-0.0945) and a permanent workforce was used for routine animal work on the farm, representing 13% of the total costs. On occasions, veterinarians or livestock technicians were used on a temporary basis (2% of total costs), which was an additional cost, but with good results because the farm benefitted from the advice of livestock experts. This farm used a feeding strategy that combined purchased animal feed with harvested crops; this led, not only to a high average body weight gain (but not the highest), but also to minimised feed cost. This represented a good way of enhancing production by minimising total cost while maximising production. Thirdly, this farm had the largest pond area of its category and used fertilisers combined with purchased fish feed for the growing fish. Similar to the livestock system, amortisation was particularly low because the farm rented the ponds. This farm was the most market oriented, selling 93% of total farm production. In addition to these aspects, this farm was particularly well organised on a daily basis; the activities were organised in such a way that each subsystem benefitted from a workforce that was competent and had a reasonable cost. This is probably a consequence of the personal involvement of the farmer, as well as his level of education which is above that of the other farmers. Finally, in terms of technical indicators, PUFVL2 had the largest production value per unit area (187$), which was four times more than UFVL1 (41.83$) 'which involved three subsystems and was located in an urban area. In addition pond water had a pH of 6.6, close to 6.5 which represents the optimum for freshwater species (Ivoke et al., 2007), an acceptable level of DO in water (6.4 mgl^{-1}) and low nitrate levels (0.8 mgl^{-1}) which were well within the limit for fresh water species.

It also appears that in the remaining farms, some subsystems, although not profitable, positively affected other subsystems by significantly reducing the cost of the latter subsystem through transfer of nutrients. Kinkela et al. (2017) identified fluxes between subsystems and pointed out the heavy use of effluents from livestock in fish and vegetable farming. In economic terms in this study, livestock appeared to be the least profitable subsystem but was underestimated. The livestock subsystems shared their effluents with the fish and vegetable subsystems. The valorisation of these effluents would increase the total production of the livestock activity since they are "sold" in some way to the fish and vegetable subsystems which will then be subject to an additional charge. At the overall level of the farm, the value of internal transfer is cancelled, but in an analysis by activity it cannot be disregarded. Livestock farming enabled fish farming to be particularly profitable whenever they were associated together (UFL1, PUFL2 and RFL3), even without the use of any fish feed and additional expenditure on fertilisation. It is probably the influence of the amount of nitrogen from pigs that is used in the fish food chain in the pond. Although there is still the question of whether nitrogen provided as fecal is an efficient use of this nitrogen source because it provides not only nitrogen but also organic matter and phosphorus etc. However, pig manure competed with crops if the herd was too small to produce enough manure for both subsystems. It was probably one of the crucial problems of fish farming in UFVL1 and RFVL3 farms where manure was more oriented to vegetable farming instead of fish farming to reduce the cost of organic and mineral fertiliser (Table 8). This led to increased expenditure on fish feed by up to 40% of total cost for RFVL3 farm at the expense of direct use of manure.

The association of fish and vegetable farming did not lead to fish farming becoming more profitable. This is despite fish ponds allowing the cultivation of a wide variety of crops on the farm over the year due to the higher water availability in areas where water scarcity is a limiting factor (Blythe, 2013). Crops do not provide sufficient waste to serve as a feed for animals over a long period. Moreover, their contribution to fish growth is negligible due to their low nutritional value (Muendo et al., 2011). Similarly, crops cultivated on the IAA farms that were investigated did not provide pigs with enough waste of good nutritional value (Kambashi et al., 2016) for use as a dietary supplement which could significantly reduce the cost of animal feed. Animal feed costs were correlated with the total cost of farm operations ($P<0.001$, $r=0.82$). Fish feed still represent a major issue, however albeit weakly, vegetable wastes contribute to pond fertiliser (Kinkela et al. 2017) and can lead to acceptable pH and non-negligible nitrate value in the pond as the case for farms in this system (Table 11). In general, using fertilisers in vegetable production systems was not an effective way to make IAA farms profitable, since gross margins precluded the use of fertiliser on the first axes of the principal component analysis.

This study also showed that more than 50% of products (vegetables, animals and fish) from small-scale IAA farms were intended to be sold. Contrarily to old acquaintance that IAA prioritise self-consumption especially for the fish farming sub-system (Dey et al., 2010), this study showed that IAA can quickly move towards a much more commercial system if farmers have access to the market.

5. Conclusion

This study showed that diversifying fluxes in IAA is an important factor for sustainability which can lead to high performance of farms. Nevertheless, this strategy must be coupled with additional conditions for the success of this system depending to the economic, environmental and social context of the region. In the context of limited financial resources and cash flow in smallholder IAA farms, involvement of the farmer in farm activities and their level of education are crucial factors that can result in a well-organised farm with good management of flows, and can lead to profitability.

Moreover, wise choices and compromises need to be made in IAA in terms of trade-offs between subsystems to maintain the overall balance in IAA. In these conditions, emphasis should be placed on livestock effluents due to their direct involvement in the food chain of pond and vegetable fertilisation and their ability to positively influence the other subsystems through their nutrient richness.

As animal feed is one of the biggest expenses, it is crucial to adopt a strategy for minimising feed costs while maintaining high animal performance on the farm. This could be achieved by supplementation of pig feed with crops and direct use of manure in fish pond or production of intermediate organisms using agro-industrial by-products available on the farm, such as maggots.

Finally, judicious decisions concerning the make-up of the workforce can also positively impact on the profitability of smallholder farms. In SSA, where employment opportunities are scarce, unskilled family workers can be used for simple tasks, while a paid permanent or temporary workforce should be used for complex operations or during periods of heavy work on the farm.

6. Acknowledgements

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Chapter 4 focused on analysing the technical and economic performance of integrated farms in aquaculture in order to improve the understanding of the complexity of IAA systems and the effect of the integration of different subsystems on profitability and the quality of the pond water for fish production, focussing on the different forms of N. Although the method used did not allow an assessment of the overall profitability of the system, since we studied the system in a compartmentalized way, this analysis revealed several additional elements.

The economic and technical indicators studied in this chapter have shown that integrated farms may not always be profitable and the performance of these farms was linked to several factors that need to be combined for to reach good result.

An important fact that this chapter highlights is the positive impact of livestock manure on other subsystems involved in the farm trough nutrient flows and possibly nitrogen. However, these nitrogen flows must be quantified in order to optimize its management by limiting losses as much as possible and efficiently directing its use towards the other components

Thus, Chapter 5 proposes a mathematical model to estimate the amount of nitrogen from livestock avalaible for other subsystems of the integrated farm and the impact of N flows from livestock to the fish pond on pond productivity.

5

Nitrogen prediction in smallholder farming system integrating pig and fish farming in the urban and rural areas of Kinshasa

Unsubmitted article

Nitrogen prediction model in smallholder farming system integrating pig and fish farming in the peri-urban and rural areas of Kinshasa.

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Abstract

The modelling of nitrogen (N) pools and flows within and between the subsystems present on pig and aquaculture integrated farms allows the *in silico* assessment of the impact of management on the evolution of production levels. This is one of the important ways to test improvements in production in small integrated agricultural aquaculture farms in the peri-urban and rural areas of Kinshasa with limited financial resources. IN this chapter, we developed a model that simulates the use of nitrogen produced by pigs for fertilizing fish farming ponds. The pig module was calibrated and validated, contrary to the fish module which is not validated due to the lack of appropriate experience data. Results of pig module prediction, gives the cumulative N amount of the fattening period. The model shows that changes in feed composition alter the fecal and urinary N production of pigs. Combined to the N from pig, N water in the fish pond is sensitive to N from pig addition and fish biomass. Change in factors that affect pig intake and pig density per pond area lead to a variation in both N production by a pig and N dynamics in the pond as well as fish production.

Keywords: IAA, pond, modeling, nitrogen, feces, urine

1. Introduction

Most developing countries in Sub-Saharan Africa are facing problems of low farm productivity. To address this problem, some smallholder farms in the rural and peri-urban areas of Kinshasa are turning to integrated systems combining aquaculture with pig farming (Kinkela et al., 2017). This system imported from South Asia offers several advantages to smallholder agricultural farming characterized by limited resources. Several studies on the impact of the integrated agriculture show that benefits are perceptible in terms of food security, environment, economy and social issues (Efole Ewoukem et al, 2012; Murshed-E-Jahan and Pemsl, 2011; Phong et al, 2010; Poot-López et al, 2010). From an environmental point of view, integrated systems based on the exchange of nutrient flows between farm components offer a more efficient and ecologically sustainable use of resources as wastes from one agricultural component are used as inputs to another (Prein, 2002).

It contributes to improving the efficiency of nutrient use, such as nitrogen, phosphorus, at the farm level by maintaining nutrients on the farm, increasing soil fertility and reducing input requirements (Nhan et al., 2007). Since N is one of the determining factors on farms, it is important to focus efforts on N conservation on the farm to increase the productivity of small farms (Rufino et al., 2006). Due to the complexity of integrated systems, several authors have used modeling to quantify the different nutrient flows (especially N) and to predict its evolution on the farm. Many studies propose prediction models for N fluxes in fish (Jamu and Piedrahita, 2002; Jiménez-Montealegre et al., 2002; Li and Yakupitiyage, 2003), pigs (Aubry et al., 2004; Vu, Prapaspongsa et al., 2009), integrated crop into livestock or crop into aquaculture (Rufino et al., 2007). Most of these models are built on the basis of either European or Asian realities and cannot be applied in the context of Sub-Saharan African countries without some adaptation. A mathematical model can improve the understanding of the different physical, chemical and biological processes involved in the use of wastes from one farm subsystem as input to another subsystem. In this way, models can predict the evolution of N pools, which is the major limiting element in both aquatic and terrestrial productions of agricultural in integrated farming and help in designing new integrated systems with improve their stability to various external factors, freeing farmers from testing innovation by feeling, which usually puts them at risk of deceptive results. In Sub Saharan Africa countries, very few models are established to predict the N evolution in both pig farming and fish earthen ponds in the context of smallholder farms.

The objective of this study is to develop a mathematical model adapted to the biological functioning of integrated farming combining pig to fish in the context of rural and peri-urban areas of the humid tropics of Africa using Kinshasa as case study. Specific objectives are to:

- develop an appropriate simulation of total N accumulation in integrated farming;
- evaluate the sensitivity of the fish ponds environment and productivity to management options influencing N flows and quality;

- identify the processes that need further documentation from the field.

This study uses preexisting models of the fish and pig subsystems to build a model combining N evolution in both subsystems on the farm.

2. Material and methods

2.1. Model description

The model includes two modules: the pig and the pond module (Figure 8). The pig module focuses on modeling the growth of fattening pigs and estimates cumulative feed consumption as a function of animal weight. This module provides an estimate of the accumulation of the amount of N excreted daily by the pigs through feces and urine during the predicted period. It is built on various empirical equations, established by previous work carried out in Europe (Aubry et al., 2009 and Dourmad et al., 203) and Asia Prapaspongsa et al. (2009). To run, the model calls on driving variables and inputs: the composition of the pigs feed, the weight of the pigs at the beginning of the breeding as well as the estimated weight at the end of the breeding.

The pond module which is a set of mechanistic equations focuses on: (1) the variation of the total N content in the water column of the pond, (2) the use of N from the pond water column for phytoplankton growth and (3) the use of phytoplankton biomass for fish growth. The amount of fecal N produced by the pig is the main input source of N in the pond module making the connection between both submodels. Urinary nitrogen was considered as a loss in this model since most farmers do not collect it under peri-urban and rural farm conditions (Kinkela et al., 2017). The module was built on the basis of conditions in tropical areas, especially in Sub-Saharan Africa. The module includes nitrogen input and output terms in the fish pond. To simplify the equations, the module focused only on parameters that have a strong influence on the evolution of total nitrogen in the pond water. State variables of the model is given by table 12.

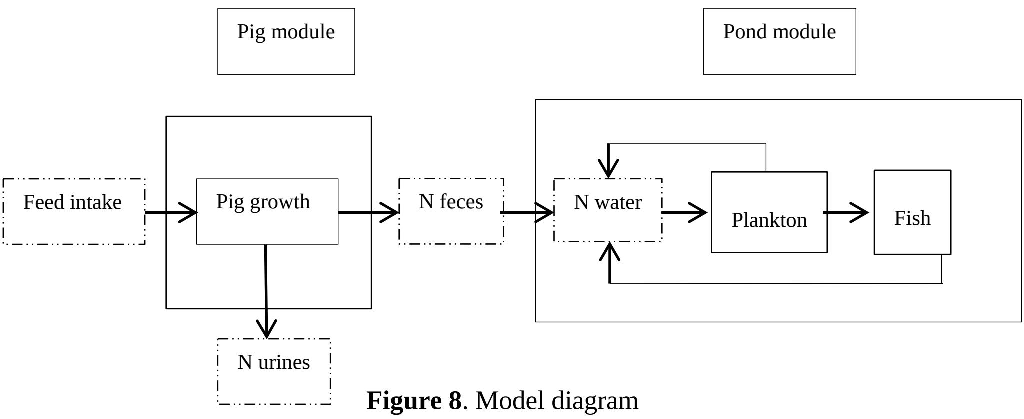


Figure 8. Model diagram

Table 12. State variables used in the model

State variables	Dimensions	Symbol
Pig module		
Live weight	kg	*LW*
Feed intake	kg	*Feedintake*
Fecal nitrogen	g	*Nfeces*
Urinary nitrogen	g	*Nurine*
Fish module		
Total nitrogen in water	g/m3	*Nw*
Phytoplankton concentration in water	g/m3	*Xph*
Fish biomass	g/m3	*Fishbiom*

2.2. Pig module

The model is based on four state variables (*LW, Feedintake, Nfeces, Nurine*) with feed quality as the major general input. Thus chemical composition of different feeds must be known before running model.

Pig growth is an empirical equation used by Aubry et al. (2009). The equation was calibrated using an experiment monitoring 308 pigs from birth to slaughter in order to model the evolution of live weight as a function of age. The purpose of this study was to determine the growth and quality performance of pig meat (standard and heavy) from Large White x Landrace French cross sows inseminated with Piétrain x Large White cross boars.

The selected individual data were analyzed using a non-linear regression and applied to a Gompertz function. The growth equation whose coefficients of the original equation have been adapted after calibration with local data in order to meet tropical breeding conditions is given by:

$$LW = 120\left(\frac{LW2}{LW1}\right)^{\left(\frac{0.356-e^{(-0.00798\times\, time+0.775)}}{0.644}\right)} \quad (1)$$

where *LW* is the pig weights (kg), *LW1* and *LW2* are pig weights. Equation (1) is subsequently used to determine the cumulated feed intake of pigs during predicted period.

The feed intake equation is built on experiments of feeding growing-finishing pigs with 285 different diets used in digestibility and balance experiment covering a broad variety of feedstuffs used both in Europe and Asia (Prapaspongsa et al., 2009). The initial equation used to determine the cumulative consumption of pigs, whose coefficients were modified for our study, is given by the following empirical equation:

$$Feedintake = -24.9236 + 1.9227 \times LW + 0.00948 \times LW^2 \quad (2)$$

where *Feedintake* is the cumulated feed consumption in fresh matter (kg), LW is the weight considered for the calculation of consumption. In this case LW is generated by the growth curve determined by equation (1).

After estimating the amount of feed consumed over the modeled period, the estimation of the cumulative amount of N produced by the pig during this period through urine and feces based on feed characteristics becomes possible. For N fecal and N urine determination, 285 diets were fed to Danish growing pigs weighing from 28 to 94 kg for a period of 12 days, including initial 5–7 days for adaptation to feed, metabolic cage and environmental conditions. Daily feces and urine were collected quantitatively during the last 5–7 experimental days of each replicate. N fecal and N urine are determinate by following empirical equations with new equation coefficient modified:

$$Nfeces = 7.611 - 46.9 \times diOM + 0.0163 \times CP + 5.1458 \times Feedintake \quad (3)$$

$$Nurine = -29368 + 0.0804 \times CP + 9.135 \times Feedintake \quad (4)$$

where *diOM* is the coefficient of the digestibility of the organic matter, *CP* is crude protein content of feed (g/kg) and *Feedintake* is cumulated feed consumption expressed in dry matter (g/kg DM), *Nfeces* is the amount of N in the pig feces (g) and *Nurine* is the amount N in the pig urine. The digestibility of the organic matter is estimated using the equation proposed by Dourmad et al. (2003):

$$diOM = (-0.128 + ((7.80 \times DE + 0.87 * CP))/DM)/CP/DM \quad (5)$$

where *DE* is the digestible energy content (MJ/kg), *DM* is the dry matter content (g/kg), CP is the crude protein (g/kg).

The total N produced by the pig through the feces and urine (*Np*, g) is given by the following simple addition relation:

$$Np = Nurine + Nfeces \quad (6)$$

2.3. Pond Module

The pond module equations are built on the basis three state variables: N water column evolution in the fish pond (*Nw*), phytoplankton growth in the pond (*Xph*) and fish growth in the pond (*Fishbiom*). The main source of N input is N fecal from pigs since we observed on the field that urinary N is difficult to collect by farmers. Fish excretion and mortality are also providing inner source of nitrogen for the pool of N in the water column. Phytoplankton growth in the pond uses the nitrogen from the water. Since fish uses phytoplankton in the food chain, the N consumed by fish for growth eaten from the phytoplankton pool. Fish feeding was not considered in this model because most fish farmers use manure as the main source of feed in ponds (Kinkela et al., 2017). Other N inputs and outputs are not included in this model because they are considered to be negligible. The model equation describing changes of Nw over time is built, on the one hand, of positive terms that are considered as nitrogen input to the pond water through external inputs (nitrogen from pigs) and inner exchanges from sediments and fish and phytoplankton mortality and, on the other hand, of negative terms (water renewal and consumption by phytoplankton):

$$v \times \left(\frac{dNw}{dt}\right) = \alpha fl \times dailyNfeces \times dens + fishintake \times 0.05 \times \left(1 - \frac{1}{IC}\right) + seddepth \times kls \times \left(\frac{Ns - Nw}{24 \times waterdepth}\right) - q \times Nw - (\mu max \times lighlim \times Nw \times 0.0075 - mrphyto) \times Xph \quad (7)$$

where v is the pond water volume (m^3), Nw is N concentration in pond water column (gN/m^3), *αfl* is the rate of N release from pig feces, *dailyNfeces* is the daily amount of N from pig dumped into the pond (gN/m^3×d) calculated from the results of the pig module, *dens* is pig density, *fishintake* is the phytoplankton eaten by fish (g/d), *IC* is the conversion index, *seddepth* is the sediment thickness (cm), *kls* is the liquid-solid transfer constant (diffusion coefficient), *Ns* is the soil N concentration (gN/m^3), *waterdepth* is the water depth (m), *q* is the renewal water flow (l/s), *µmax* is the phytoplankton growth rate (1/h), lighlim is a light limitation factor, *mrphyto* is the phytoplankton mortality rate (1/h) and *Xph* the phytoplankton concentration in the pond water (g/m^3).

The following set of equations is used to determine the consumption of phytoplankton by fishes in the ponds, depending on the availability of plankton for fishes to eat. If plankton mass is lower than what fishes would eat, it is considered that fishes lose weight (negative growth) and no plankton is eaten at all. If the mass of plankton is enough to satisfy the daily feed requirements of the fishes, then , fish intake is positive as well as fish growth. This minimum amount of phytoplankton that must be available in the pond is estimated at 10% because tropical fish can consume 10% of their biomass daily (NRC, 1993). Otherwise the fish consumption is zero and this leads to a weight loss on the initial fish biomass of about 1% per day (Pouomogne, 1995). Since phytoplankton contains at least 15% dry matter (Kiorboe, 1989), the fish intake is given by the following equations:

$$if\ \ Xph \leq (0.10/0.15) \times fishbiom$$

$$fishintake = 0$$
$$fishgrowth = -0.01 \times fishbiom$$

$$else\ fishintake = 0.10\ \times fishbiom/0.15$$

$fishgrowth = 0.10 \times fishbiom/IC$ (8)

Where *fishintake* (g/d) is the phytoplankton eaten by fish and *fishbiom* is the fish biomass in the pond.

The evolution of phytoplankton, whose growth is proportional to the amount of N available in the pond water column and disappearance is related to fish intake, is given by the following equation:

$$\frac{dXph}{dt} = (\mu max \times lighlim \times Nw \times 0.0075 - mrphyto) \times Xph - fishintake \quad (9)$$

where Xph is the phytoplankton concentration in water (g/m^3), μmax is the phytoplankton growth rate (1/h), *lighlim* is a light limitation factor (0-1), mrphyto is the phytoplankton mortality rate (1/h) and *fishintake* is the phytoplankton eaten by fish (g/d).

The fish growth is modeled by the equation:

$$\frac{dFishbiom}{dt} = fishgrowth \quad (10)$$

and *fishgrowth is* previously given by equation 8

where *fishgrowth* is the fish growth (g/m^3) and $Fishbiom$ is the fish biomass (g/m^3).

The pond module use variables from preexisting model in the literature. Theses variable are given by table 13.

Table 13. Initial conditions of variables used for pond module simulation

Variables	Symbol	Units	Value	Initial source
Phytoplankton growth rate coefficient	*μmax*	h^{-1}	0.104	Scavia, 1980
Phytoplankton mortality rate coefficient	*mrphyto*	h^{-1}	2.08e-4	Jorgensen et al., 1978
Gram of amino acids for 1 mole ATP	*Aaatp*	G amino acid (mole ATP)$^{-1}$	4.76	Van Dam and Penning de Vries, 1995
Amino acid oxidation rate (glycogenesis rate)	*AAgluc*	md AA/l/day	0	Jiménez-Montealegre et al., 2002
Light limitation factor (0-1)	*lighlim*	-	0.3	Jiménez-Montealegre et al., 2002
Water depth	*waterdepth*	m	1.2	Jiménez-Montealegre et al., 2002
Sediment thickness	*seddepth*	cm	5	Jiménez-Montealegre et al., 2002
Diffusion coefficient	*kls*	$m^2 h^{-1}$	-1	Jiménez-Montealegre et al., 2002
N concentration in the soil at the bottom of the pond	*Ns*	mgl^{-1}	0.105	Jiménez-Montealegre et al., 2002

2.4. Model calibration

Data for the calibration and validation of the pig module using local data were collected during two experiments carried out by Kambashi et al. (2014) on the growth and digestibility of pigs (Large White x Duroc), feed with a local commercial corn and soybean based diet (basal diet) and that same diet substituted (25%) with foliage from three different local legume forage species: *Psophocarpus scandens*, *Stylosanthes guianensis* and *Vigna unguiculata*. In this dataset, twelve pigs were fattened for 90 days per group of two pigs per box (N=6). The age of the pigs at the beginning of the experiment was 70 days and at the end of the experiment 160 days. Pig's weight and voluntary intake of feed diet were determined. Experiment diets were used for 5 days digestibility where apparent digestibility, N retention and N excretion were measured. Model calibration used data from a commercial corn and soybean-based diet (basal diet) displayed in Table 14, which ones correspond to state variable values measured in the field for basal diet. Since on day zero of the experiment the cumulated intake is zero, the quantity of food consumed on the first day is corrected by adding the cumulative quantity proposed by the model at this growth stage (30.2 kg).

Table 14. Experimental data collected to perform calibration of the pig module

	States variables			
Days	Cumulated LW (kg)	Cumulated Feed intake (kgDM)	Cumulated excreted in N feces (g)	Cumulated excreted in N urine (g)
80	27.9	30.2	180.7	206.0
90	31.8	41.4	247.8	282.5
100	35.8	54.4	325.6	371.3
110	42.6	71.5	428.1	488.1
120	48.0	91.5	547.9	624.6
130	53.9	111.5	667.7	761.2
140	61.6	137.9	826.1	941.9
150	70.1	166.2	995.4	1134.8
160	79.0	195.1	1169.1	1332.9

Source: Kambashi et al. (2014)

Chemical analysis data from different diets used by Kambashi et al (2014) are summarized in Table 15. For model calibration, only data from basal diet are used.

Table 15. Chemical composition of experimental diets used to calibrate and validate the model

	Basal diet (corn and soybean	Basal diet + *Psophocarpus scandens 25 %*	Basal diet + *Stylosanthes guianensis 25 %*	Basal diet + *Vigna unguiculata 25 %*
Digestible energy (MJ/kg)	13.8	13.4	13.2	13.4
Neutral detergent fiber (g/kg)	228	256	273	244
Ash (g/kg)	69.0	71.9	72.7	76.6
Dry matter (g/kg)	885	807	777	796
Crude protein (N × 6.25) (g/kg)	192	196	192	194

Source: Kambashi et al. (2014)

For the calibration of parameters related to the pig module, some coefficients of the equations (1), (2), (3) and (4) have been adjusted (decrement and increment) from values proposed in the literature (Aubry et al., 2009, Prapaspongsa et al., 2009), in order to perform the fitting of simulated to observed data (basal diet data only). Only coefficients with sensitive impact on the prediction responses were adjusted, the remainders were kept as proposed in the literature because of their small influence on the model's prediction. The adjustment was made in ±10% steps until the difference between the measured and predicted values was minimized. The values of the coefficients used are those that gave the lowest value of sum of the squares deviation (SSD) between predictive and measured curve (Table 16). This method of adjustment also used by Jiménez-Montealegre et al. (2002) allow adaptation of different predicted equation to the tropical breeding conditions.

Table 16. Sum of the squares of the deviations

Model equations	SSD before adjustment	SSD after adjustment
$LW = 120\left(\frac{LW2}{LW1}\right)^{\left(\frac{0.356-e^{(-0.00798\times time+0.775)}}{0.644}\right)}$	9183	89
$Feedintake == -24.9236 + 1.9227 \times LW + 0.00948 \times LW^2$	7161	764
$Nfeces = 32.981 - 6.7 \times diOM + 0.00326 \times CP + 6.0814 \times Feedintake$	263343	37730
$Nurine = -29.68 + 0.0804 \times CP + 9.135 \times Feedintake$	118122	30354

2.4.1. Evolution of animal growth and cumulative food consumption

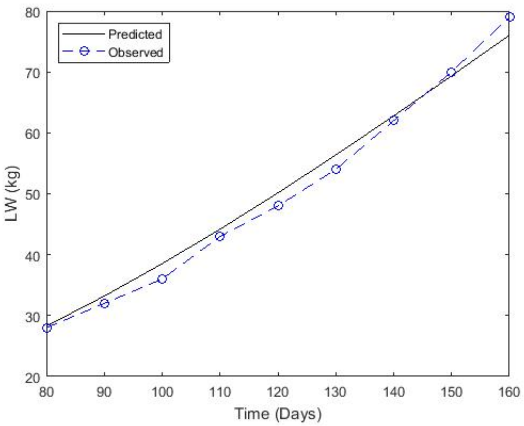


Figure 9. Pig growing during predicted time

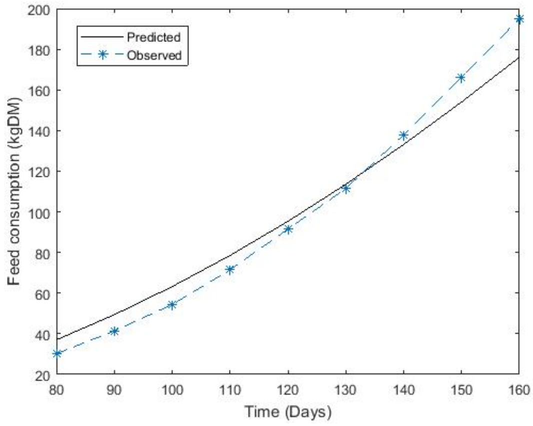


Figure 10. Cumulative simulated and observed feed consumption

Over the course of the simulation, the prediction of pig weight in the model tends to fit well to that of the observations, but after 150 days, the model underestimates pig growth (Figure 9). Since this is an exponential growth phase in the Gompertz curve, the prediction and simulation curves possibly eventually meet at some time beyond the simulated period. For the cumulative intake of feed, the model tends to underestimates the consumption most of the time (Figure 10). However, after 140 days of growth, the model tends to overestimate food consumption.

2.4.2. **Cumulative N feces and urine production**

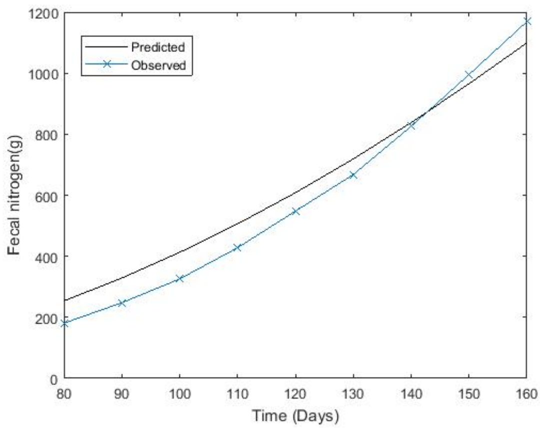


Figure 11. Cumulative simulated and observed fecal N production

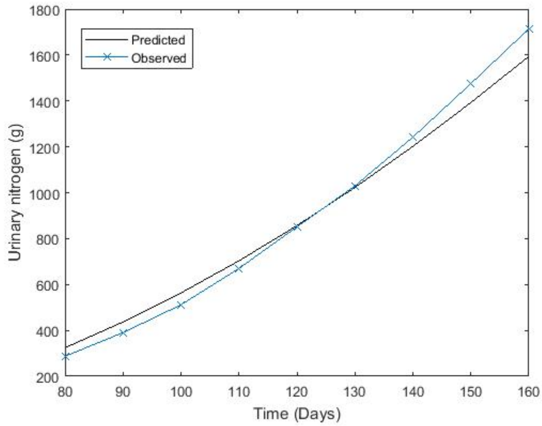


Figure 12. Cumulative simulated and observed urinary N production

The model tends to slightly overestimate fecal N production (Figure 11). However at the end of the prediction time, the difference between the cumulative values of measured (1169 gN/pigs) and predicted (1099 gN/pigs) is not large. The same trend is observed for the prediction of urinary N (Figure 12). For the whole simulation, the urinary N predicted amounted to 1594 gN/pig and the measured one amounted to 1715gN/pig.

Due to the lack of experimental, the pond module has not been calibrated. However, we used the values from the literature presented in the table 14 to make simulations to allow us to get an idea of the different processes at the farm level.

2.5. Pig module validation

After calibrating with the basal diet, an independent set of data from Kambashi et al.'s (2014) experiment was used to validate the pig module (Table 17). This data used three types of feed containing commercial feed basal diet (corn and soybean) substituted by 25% of three different forages. Thirty-six pigs were raised in groups of three corresponding to the different types of feed with two pigs per box.

Since the forage used have limited differences in crude protein, ash, digestible energy and dry matter contents, the results of the N fecal and urinary prediction showed a difference that was not great. The amount of N fecal (N urinary) produced was estimated to 1184 gN/pig (1721gN/pig), 1174gN/pig (1706 gN/pig), 1162 gN/pig (1688 gN/pig), respectively for *Basal diet* + 25% *Psophocarpus scandens*, *Basal diet* + 25% *Stylosanthes guianensis* and *Basal diet* + 25% *Vigna unguiculata*. The total N produced from pig, for the predicted period was 2905gN/pig, 2880gN/pig and 2849 gN/pig for the three diets respectively.

Table 17. Experiment data used to validate the model

Days	*Basal diet + Psophocarpus scandens 25 %*				*Basal diet + Stylosanthes guianensis 25 %*				*Basal diet + Vigna unguiculata 25 %*			
States variables	PV (kg)	Feed intake(kgDM)	N feces (g)	N urine(g)	PV(kg)	Feed intake(kgDM)	N feces(g)	N urine (g)	PV (kg)	Feed intake (kgDM)	N feces(g)	N urine (g)
80	46.8	30.0	287.9	321.9	29.2	30.0	268.3	253.6	28.1	30.0	260.1	365.5
90	49.2	40.7	390.2	436.3	32.5	40.8	364.7	344.8	31.5	40.1	348.2	489.4
100	51.7	53.3	511.4	571.8	35.9	53.5	478.3	452.1	35	52.4	544.5	638.8
110	54.7	69.9	669.9	749.0	41.5	70.5	629.2	594.8	40.1	68.3	592.4	832.6
120	57.6	88.8	851.0	951.5	47.1	90.1	804.0	760.1	45.5	86.9	753.2	1058.5
130	60.8	107.4	1029.8	1151.3	52.4	110.1	982.9	929.2	50.3	105.7	916.4	1287.8
140	64.4	129.6	1242.2	1388.8	59.8	135.1	1205.5	1139.6	58.9	128.8	1116.9	1569.7
150	67.8	154.0	1475.7	1649.9	66.6	161.2	1438.6	1360.0	65.6	154.1	1335.6	1877.0
160	71.2	179.0	1714.8	1917.3	73.5	187.5	1673.7	1582.2	73.3	180.5	1564.4	2198.5

Source: Kambashi et al. (2014)

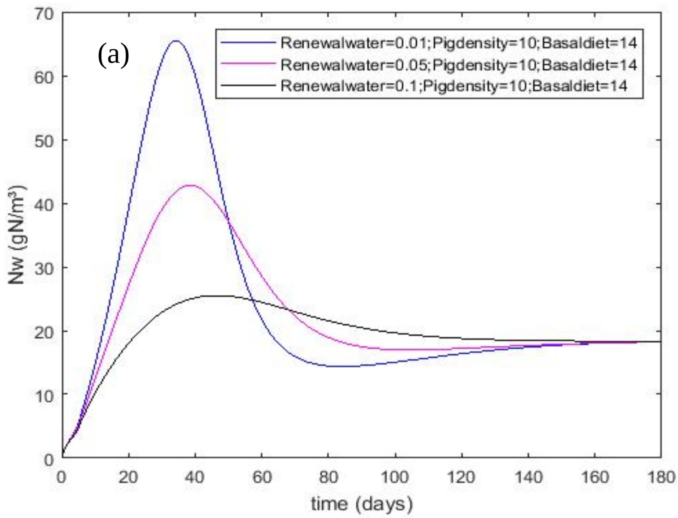
2.6. Pond module simulation

Since the fish module uses the feces from pig as N source, cumulated amount of fecal N produced by the pig module was used in simulation of pond N dynamics (1099 gN/pig, 1184 gN/pig, 1174 gN/pig and 1162 gN/pig respectively for Basal diet, Basal diet + *Psophocarpus scandens*, Basal diet + *Stylosanthes guianensis* and Basal diet + *Vigna unguiculata*). These results represent a daily fecal nitrogen production of 14, 15, 15 and 15 g/day/pig, respectively. The quantity of N produced by pig is brought into a pond of 1 are and a depth of 1 m for the simulation of pond module. The pond module requires initial conditions of state variables. Thus model is run with initial values:

- *Nw* = 0.1gN/m^3 (0.1mgN/l), since the desirable range of total N is 0-2 mgN/l and acceptable limit range less than 4 mgN/l (Stone NM and Thormforde, 2003);
- *Xph* = 100gN/m^3 of wet phytoplankton with dry matter of phytoplankton and body N body weights is respectively estimated to 15 % and 5% by Kiorboe (1989);
- and the initial fish biomass (*Fishbiom*) is set at 20g/m^3.

To assess the possibility from farmers to optimize fish pond productivity over one production cycle of 180 d, three management levers were tested: pig density per are of pond (1, 10 and 50 pigs), renewal of water (1, 5 and 10% per day) and the feeding of pigs the different diets of Kambashi et al. (2014). These management options tested in different simulations reflected situations observed on the field during the survey and the monitoring of farms (see previous chapters), pushing some conditions to some extremes.

3.2.1. **Influence of water renewal in the pond**



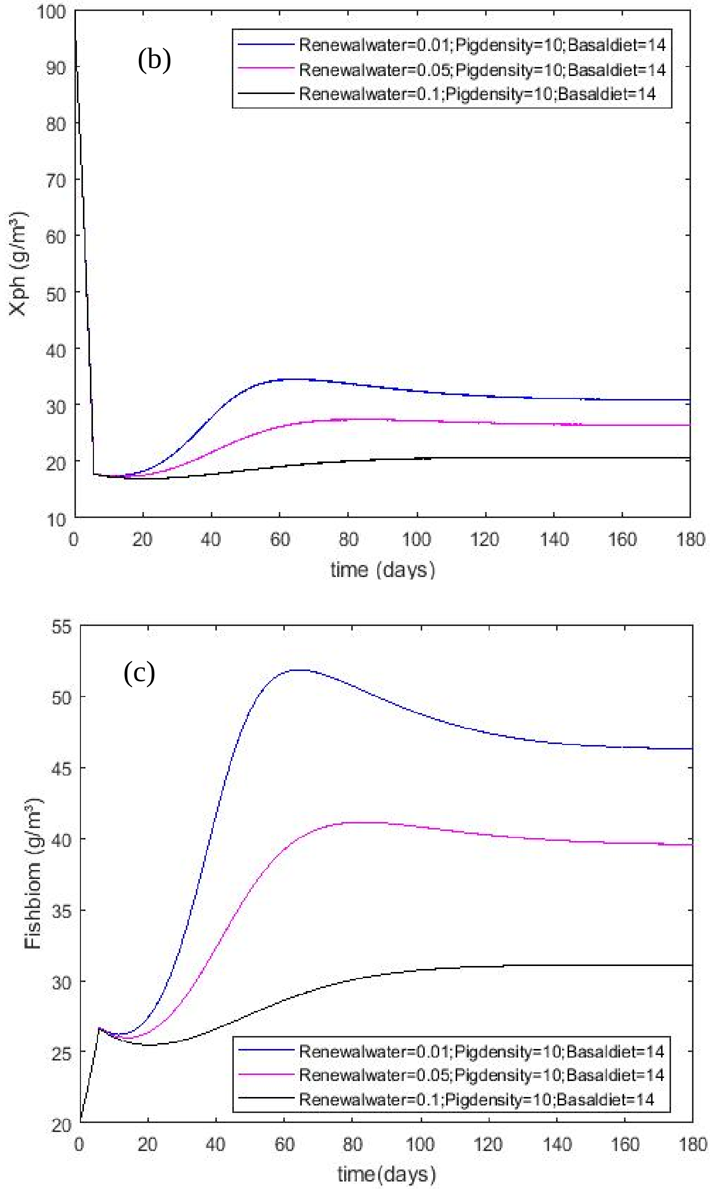
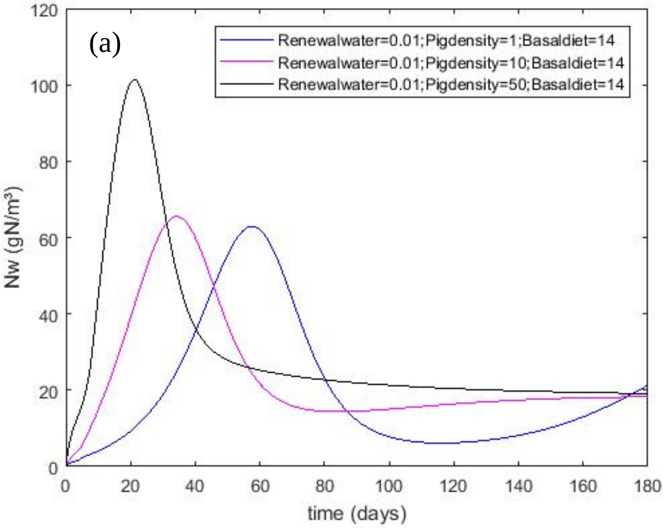
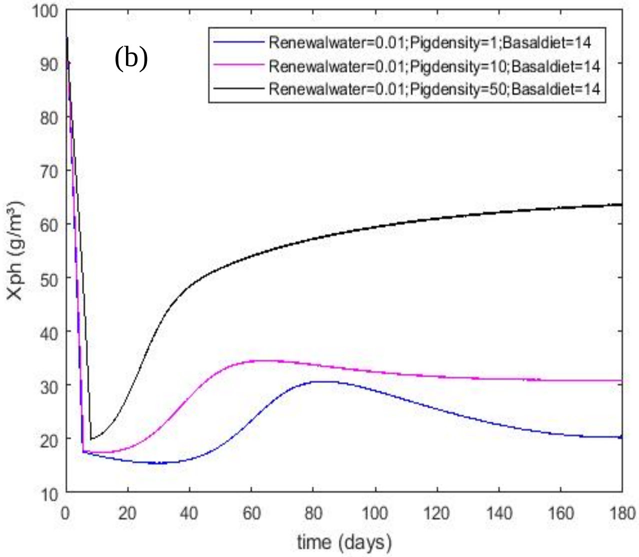


Figure 13. Evolution of N water (a), phytoplankton (b), and fish biomass (c) in the fish pond according to the renewal water level.

Figure 13 shows the evolution of the three state variables in the pond with different water renewal rates in the pond, with constant density of 10 pigs per are and diet providing (14gN/pigs/day). The N content in the pond water, which is initially low (0.1mgN/l), gradually increases during the first week with the addition of nitrogen from the pig and reaches a peak around the fourth week. The amount of renewal water determines the height of the peak reached. The N content of pond water decreases around 80 days and remains fairly stable until the one hundred and eightieth day. The initial mass of phytoplankton in the pond first perishes. It stabilizes for a few moments and resumes its growth but at masses much lower than the initial mass. The amount of renewal water brought in influences the growth of phytoplankton in the pond. Figure 13c shows that high renewal water flows in the pond result in low fish biomass as a consequence of too little phytoplankton growth.





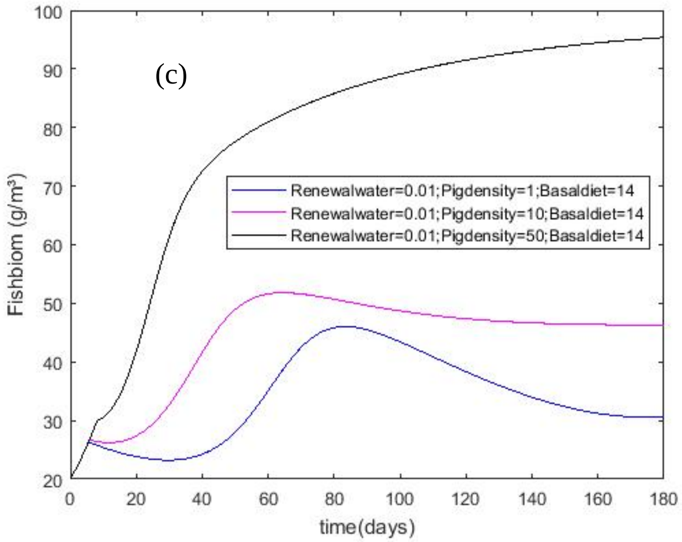
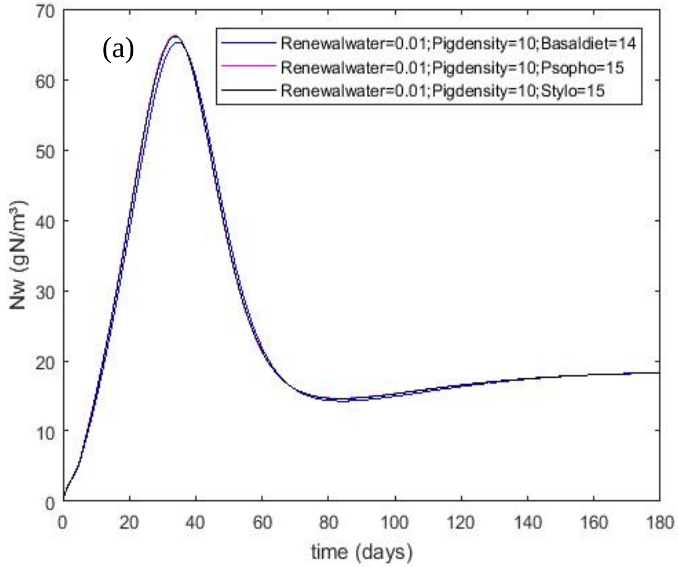
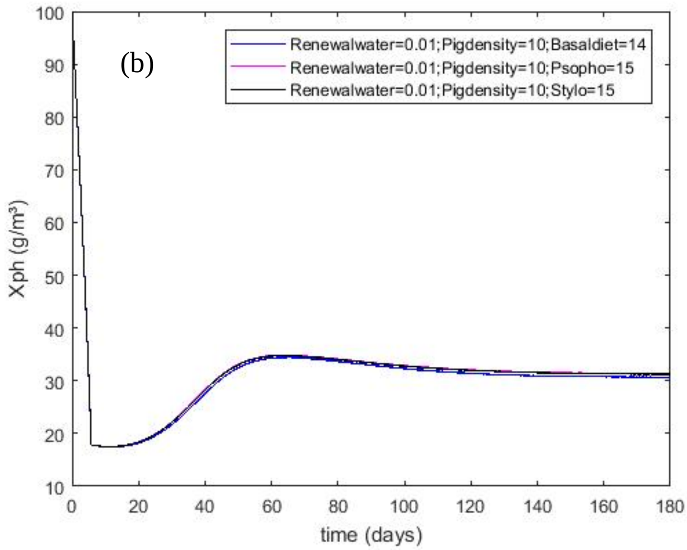


Figure 14. Evolution of N water (a), phytoplankton (b), and fish biomass (c) in the fish pond according to pig density.

Figure 14 shows the N evolution of the three state variable in the pond with different pig density (1, 10 and 50 pig/are), the renewal rate and the quantity of Nfeces being constant. With densities of 1 and 5 pigs for a 1 are pond, the N peaks in the water are lower and arrive much later in the pond. Nitrogen falls are much higher and tend to stabilize later on in the same way as the density of 50 pigs. With a high pig density of pigs beside the pond (50 pigs on 1 are of pond), phytoplankton mass falls for a short time and then quickly returns and continues to increase during the fish farming cycle compared to other densities (1 and 10 pigs per are). As a consequence, low pig densities do not support the growth of fish in the pond.


(a)
Renewalwater=0.01;Pigdensity=10;Basaldiet=14
Renewalwater=0.01;Pigdensity=10;Psopho=15
Renewalwater=0.01;Pigdensity=10;Stylo=15
Nw (gN/m³)
time (days)


(b)
Renewalwater=0.01;Pigdensity=10;Basaldiet=14
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Renewalwater=0.01;Pigdensity=10;Stylo=15
Xph (g/m³)
time (days)

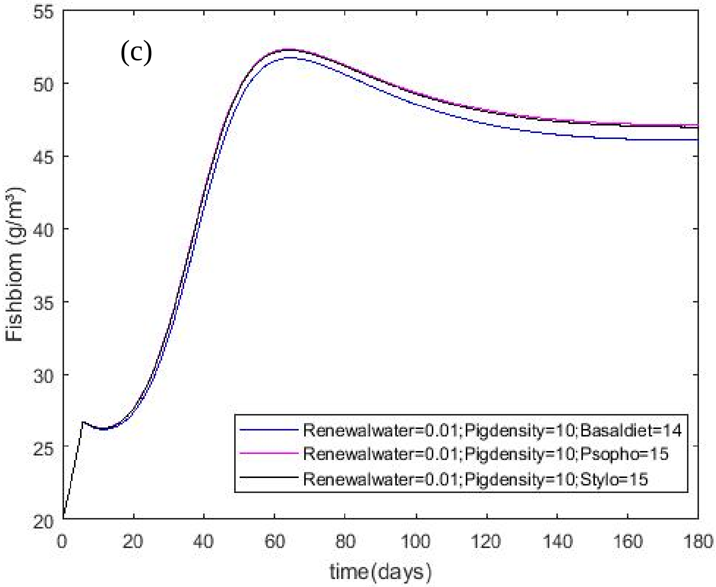

Figure 15. Evolution of N water (a), phytoplankton (b), and fish biomass (c) in the fish pond according to fecal N production of pigs fed different diets

Figure 15 shows that the different diets used to feed pigs and which generate slightly different amounts of nitrogen in the feces, have little impact on nitrogen dynamics in the pond as well as on phytoplankton. Nevertheless, forage-based diet supported higher fish growth.

3. Discussion

Several models have been proposed in the literature on N flows and cycles in pig and fish farming. The particularity of this model is that, it combines N flows from pig farming to fish ponds. The model provides a fairly accurate estimation of the weight of growing pigs.

The estimation of N fecal excretion in pigs is strongly related to the estimation of digestibility from the empirical equation given by Dourmad et al. (2003). This equation provides an accuracy of 83% of the actual *in vivo* digestibility. N fecal excretion depends on the pig diet content and its digestibility (Prapaspongsa et al., 2009). However it should be noted that the digestibility prediction equation proposed by Dourmad et al. (2003) and used in the pig module does not take into account the amount of fiber in pig feeds (NDF), which tends to bias the N fecal estimation, especially in our case in which forage-based diets are used. Nevertheless, any change in the quality of feed leads to change in N excretion pathways both in feces and urine (Bindelle et al., 2019). In more details, N excretion pathways depend on the digestible energy content, protein content and digestibility of the diet, as well as fermentable fibre factions.

The value of total N excretion from pig obtained in the predicted time with basal diet by this model (2.7 kg/pig) is close to the amount of N obtained in pig slurry 2.53 ± 0.26 kg/pig for predicting model and 2.56 ± 0.22kg/pig for measuring value on fattening pig in France developed by Dourmad et al. (2003). It should be noted that the database used to calibrate and validate the pig module consisted of very few animal numbers (N=6) compared to those used to conceptualize the equations in the literature. Nevertheless, it was possible to contextualize the equation for application in rural and peri-urban tropical areas and to simulate the evolution of nitrogen in an integrated system for aquaculture agriculture.

The fish module still needs to be calibrated and validated with appropriate experimental data so that the values obtained for the state variables can be considered as reliable. However, the model can already be explored to observe the behavior of state variables to various changes in IAA farm management.

Since the state variables of the pig and pond modules of the prediction model are linked, any change in pig feed, not only leads to a change in the amount of fecal and urinary N produced, but also to a change in the evolution of N in the pond water column, in phytoplankton growth and in fish biomass growth.

The three types of diets used to feed pigs (basal diet, basal diet + 25 % *Stylosanthes guianensis* and basal diet +25 % *Psophocarpus scandens*) generate according to the model 14, 15 and 15 gN/day of fecal N and 20, 21 and 22 gN/day of urinary N respectively.

Since pigs are often raised on the side of the ponds and urinary N is difficult to collect, the model assumes that the entire flow of N harvested is brought to the ponds through the feces. Thus, Figure 14 shows that by providing an amount of N equivalent to 14 gN/pig with a density of 1 pig for pond of one are, a much slower increase in the initial amount of N in the pool and much lower peaks than those using densities of 10 and 50 pigs for a pond of one are. After 80 days, nitrogen in the water tends to stabilize for the rest of the fish farming cycle. High N peaks in water can be reduced by increasing the water renewal rate that dilutes the N in the water (Figure 13a). Since the initial amount of N in the water is low (0.1 mg/L), the planktonic mass of our ponds first dies in all simulations (Figures 13b, 14b and 15b). It stabilizes after a few days with the gradual increase of nitrogen in the water. The decrease of N peaks in the pond water corresponds to a resumption of phytoplankton mass growth. However, this N consumption does not allow the initial mass in the pond to be reached even with very high pig densities (50 pigs per pond area) because phytoplankton is consumed in the meantime by fish in the pond. The increase in the flow of renewal water negatively affects the development of the phytoplankton mass while the increase in pig density positively affects phytoplankton mass in pond.

The growth of fish in the pond is linked, all things being equal to the density of pigs on the farm (amount of nitrogen provided by the feces of the pigs), the rate of renewal water flow and the quality of feed provided to feed the pigs. The low density does not support the growth of fish in the pond (Figure 14c) which after 180 days does not manage to double their initial weight. With 5 pigs per are of pond, the weight of the fishes more than doubled and almost quintupled with 50 pigs after 180 days. Considering urinary nitrogen in the model, the density of pigs should be reduced by maintaining good results on fish growth because they produce much more nitrogen in the urine than in the feces. Moreover, reducing the number of pigs for a same N supply to ponds by adding urine would also reduce the organic matter load in the ponds that is provided mainly by feces. This would positively reduce the biological oxygen demand (BDO5), increasing the quality of the pond water. The renewal water that dilutes nitrogen in the pond and reduces the mass of phytoplankton leads to much lower fish biomass in the pond (Figure 13c). Since the diets used to feed pigs do not present huge difference in ingredient contents, the difference in fish biomass in the pond is therefore small (Figure15c). It is also important to note that the food provides nitrogen, phosphorus which plays an important role in the primary production of the pond. In rural and peri-urban tropical conditions, the contribution of plants to pig feed enriches feces and urine with phosphorus.

The farmer will have to choose the best management strategy to adopt to maximize production on the IAA farm. By setting specific objectives (optimization of fish and/or pig production, etc.), she will be able to decide on the quality of the food according to the expenses he incurs and the results he can obtain.

This model can be improved in its pig module by reducing the difference between the prediction values of fecal and urinary N and those measured in the field. Apart from the calibration and validation of the pond module, the model can be improved by directly incorporating the nitrogen produced progressively from the pig to the ponds. Thus instead of splitting the amount of Nfeces from the pig, the state variable Nfeces can be incorporated into the pond module as a function. The breeding time should be the fish and pigs that are raised on the ponds as presented by Kinkela et al. (2017) in integrated agriculture, aquaculture system. The pond module can also be improved by incorporating fish feed as some farmers use ingredients such as brewers' grains, etc. as fish feed. Finally, the whole model can also be completed to even include additional modules.

Chapter 5 allowed to estimate the amount of nitrogen available in an integrated system of aquaculture agriculture from pigs that can be used for other subsystems through feces and urine. It also allowed to quantify the large amount of N lost through the urine due to the lack of adequate urine collection equipment and the need to improve the system. Although knowledge of nitrogen quantity provides information on the direction of fecal and urine use for other components, it raises the question of the efficient use of these two forms of nitrogen in other subsystems. Thus, Chapter 6 focuses on a much more efficient use of fecal matter from pigs in fish ponds. It proposes a new system to optimize fish production through pig manure and locally available substrates using houseflies for larval production with a good amino acid profile as a complementary food for fish.

Photo 3. Illustration of the experimental set-up to expose the substrates to the flies on a farm in the urban area of Funa (Kinshasa, Democratic Republic of Congo)

6

Optimization of housefly larvae production on pig wastes and brewers' grains for integrated fish and pig farms in the tropics

Article 4

Optimization of housefly larvae production on pig wastes and brewers' grains for integrated fish and pig farms in the tropics.

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Abstract

Lack of appropriate animal waste management methods in many smallholder farms in the tropics often leads to environmental problems, especially in locations with high population density such as urban and peri-urban areas. On farms integrating pig production to fish farming, manure can be turned into a valuable feed source of high quality protein for fish through housefly larvae and contribute to intensify fish production and reduce cost of fish feed. Three experiments were carried to optimize operating conditions for maggot production on animal wastes and industrial byproducts found in Kinshasa, the capital city of the Democratic Republic of Congo (DRC). The comparisons were: (1) production on pure substrates (manure or brewer's grains) or mixtures with lysine or blood; (2) exposure time to flies for the insemination of the substrates: and (3) dynamics of larvae production. Mixing brewers' grains with Lysine or manure and/or blood more than doubled the amount of larvae that were harvested. Brewers' grains are a good source of energy, but are probably deficient in essential amino acids to support the growth of maggots. It also appears that only the first days of laying eggs are important since no difference was observed between temporary and permanent exposure of the substrates to houseflies. The peak of larvae production was reached 6 days after exposure. The addition of cow blood in increasing doses to a mixture of brewers' grains and manure linearly increased the production of maggots.

Key words: maggot, mixture, nutrient, production, substrates

1. Introduction

In the tropics, stored wet agricultural and agro-industrial by-products as well as on-farm wastes such as manure are prone to spilling due to the quick proliferation of housefly (*Musca domestica*) larvae (maggots) and are also a biohazard for human and animal populations. In pig farms, the problem is exacerbated by the concentration of these facilities in peri-urban areas with a limited acreage, exceeding the assimilation capacity of the environment (Čičková et al., 2012). Several technologies of on-farm wastes recycling have been proposed to reduce their impact on the environment but most of them are too expensive for smallholders (Čičková et al., 2012). Interestingly, in Kinshasa (Democratic Republic of Congo) where crops and pig production are integrated with freshwater aquaculture (IAA), manure is collected and used to fertilize directly the ponds and/or the vegetable crops (Kinkela et al., 2017). For the fish subsystem, this method stimulates the primary production of the pond to produce phytoplankton and zooplankton, which will be an important protein source in the fish trophic chain. This practice is however controversial. According to Nuov et al. (1995) direct use of pig wastes as inputs into fish culture systems may be unacceptable or an inferior use of valuable inputs because non-filter feeding fishes, such as African catfish (*Clarias gariepinus*), may be unable to recover nutrients efficiently through the pond food web and require complete diets. Moreover, organic matter with high nitrogen content typically decomposes quickly with release of appreciable ammonia nitrogen (NH_3+NH_4^+), that can lead to water eutrophication. Microbial oxidation of ammonia nitrogen (NH_3+NH_4^+) usually called nitrification, removes dissolved oxygen from the water and produces acidity. Excessive nitrogen gas in water can cause gas bubble trauma in fish and some other aquatic animals (Boyd, 2015).

Mafwila et al. (2017) observed that despite an optimal mix of subsystems, the majority of IAA farmers faced lack of commercial feeds such as pellets and high protein ingredients such as soya bean, blood meal and fish meal to formulate completed feeds due to their high cost (Charlton et al., 2015). Moreover, in tropical Africa, smallholder farmers strive to trap nutrients, especially N, within their farms while it is a key limitation to sustain higher production levels that are required to reach food security (Rufino et al., 2009). Kinkela et al. (2017) showed that up to 90 % of farmers feed fish with agricultural and agro-industrial by-products such as brewer's grains and wheat bran, that are low in protein quality. Therefore controlled production of housefly larvae by farmers on these substrates could be an opportunity to provide an important additional source of high quality protein and to intensify fish production by concentrating nutrients in a readily available and cheap ingredient. Housefly larvae meal contains good quality protein for poultry and fish (Bondari and Sheppard, 1981; Aniebo and Owen, 2010). Maggot flour has an amino acid profile comparable to that of fish meal. It is also good source of minerals (Fasakin Balogun and Ajayi, 2003; Téguia et al., 2002). Moreover, this strategy could kill two birds with one stone. Insects and earthworms play a significant role in decomposing many types of wastes preventing hazardous release of harmful forms of nutrients in the environment, for example by reducing leaching and the production of volatile organic compounds through microbial fermentation (Hwangbo et al., 2009). For several authors, the use of insects such as dipteran larvae as manure decomposers is a low-input sustainable waste management technique with potential for innovation to increase its efficiency (Pastor Velasquez Gobbi and Rojo, 2015).

This study aimed to improve on-farm production methods of housefly larvae using as substrates local agricultural and agro-industrial by-products available (pig manure, brewer's grains, fresh blood) in integrated agriculture aquaculture farms in Kinshasa. To achieve this goal, we ask three research questions:

- what is the combination of on-farm available agricultural and agro-industrial by-products that lead to optimal production of maggots;
- does spawning time of houseflies affect the production of maggots;
- what is the optimal duration of the housefly rearing cycle to maximize the production of maggots in the main substrates and the cost/benefit ratio?

2. Material and methods

Three experiments investigating complementary aspects of the production and growth of domestic housefly larvae (*Musca domestica*) were carried out on a farm integrating vegetable production to pig and fish farming in ponds in the Funa valley of Kinshasa (D.R.Congo). The first experiment compared the cumulated level of larvae production on different substrates over 6 days: brewers' grains (BG), pig manure (M), an equiproportional mixture of BG and M (BG-M), BG with 1% lysine (BG-LYS), an equiproportional mixture of BG and cow blood (BG-B) and an equiproportional mixture of BG, M and B (BG-M-B). The second experiment compared the production of larvae on BG-M and BG-M-B with two exposure methods to the housefly: 18 days of permanent exposure (PERM) and 2 days of temporary exposure followed by 16 days of growth with no housefly access (TEMP). The third experiment compared increasing doses of cow blood (0%, 10%, 20%, and 30%) in an equiproportional mixture of BG and M during 9 days of larvae production. In the first experiment the presence of lysine among substrates was intended to verify that lysine was a limiting amino acid in BG. However, there is no practical value of its incorporation in the context of IAA farms.

For all experiments, all substrates were run in quadruplicate. The substrates were placed in plastic baskets maintained in the shade, covered in the bottom with a mosquito mesh screen through which the larvae migrated to a 30 × 26.5 × 32 cm^3 plastic bin placed below for collection (Photo 4). The substrates were daily adjusted to 77.5% of water content by addition of water in the morning to allow substrates to maintain humidity levels around 70% during the day. This is appropriate water content to limit fungal populations and to prevent desiccation of eggs (Lomas, 2012). Holmes et al. (2012) proved that with relative humidity around 70% the eggs eclosed faster, the egg eclosion rate was higher, the pupal mortality was lower, and the adult emergence and longevity were higher for the black soldier houseflies.

Photo 4. Growing bed and harvesting bin used in the experiments

The substrates were thoroughly mixed and an amount of 1,500 g for experiment 1, 2,500 g for experiment 2 and 3,000 g for experiment 3 were placed in homogeneous thickness of 3 cm (Lomas, 2012). During the experiments, natural laying of eggs by houseflies on the farm was used.

Several parameters were measured: ambient temperature and substrates temperature were taken three times a day (7:30, 13:00 and 17:30). Weight and number of larvae were measured daily using Kern scale with 0.1 g of precision. After harvest from plastic bin during daily control, larvae were sorted and grouped into two categories (maggots and pupae) before being weighed. The method described by the Association of Official Analytical Chemist (AOAC, 1990), was used to measure dry mater (DM), nitrogen, fat and gross energy content of larvae. Nitrogen content was determined by the Kjeldahl procedure using Kjeltec Auto Sampler System 1035 Analyzer (Tecator), and gross energy by the calorimetric procedure using the Adiabatic Calorimeter 1241 by PARR. Finally, in the third experiment the cost of larvae produced per kg of substrate used was calculated considering market prices of Kinshasa in 2016.

One-factor ANOVA with Average Comparison Test (Tukey Test) were used to compare mean values of larvae production per substrate in the first and second experiment. The GLM procedure of repeated measures Univariate Tests of ANOVA was used to compare mean values of temperature for different substrates in SAS for the first experiment. The three-time measurements were considered as repeated measurements for the experiment. Finally, a general linear model of regression was used to test the effect of blood doses in different mixtures for the third experiment.

3. Results

Result of maggot production over a 6-day period showed that brewers' grains and pig manure used separately provided the lowest production while, highest production was reached by mixing BG-M-B (Table 18). Furthermore, results showed also that mixing brewers' grains with lysine or manure and/or blood more than doubled the amount of larvae that were harvested on the substrates. No differences were found in substrate temperatures during the 6 days of larvae production (p=0.97). Temperature greatly varied according to the time measured (p<0.0001) with highest mean temperature values at 13:30 (33.3°C). During the six days of maggot production temperature varied from 23.1°C up to 47.9 °C (p< 0.0001). The highest value was observed on the fourth day with an average value of 40.7 °C.

Table 18. Maggots and pupae production (g/kg of substrate) during 6 days (g/kg of fresh substrate) reared on different mixtures of brewer's grains (BG), manure (M), Lysine (LYS) and fresh cow blood (B) as substrates (N=4).

Substrates	Maggot production (g/kg substrate)	Pupae production (g/kg substrate)	Temperature (°C)
	Mean values	Mean values	Mean values
BG	53.8^{bc}	0.10	32.7
M	30.6^{d}	0.3	30.9
BG-M	89.3^{b}	0.10	32.8
BG-LYS	94.2^{bc}	0.00	32.6
BG-B	107^{b}	0.00	31.1
BG-M-B	180^{a}	0.00	30.8
SEM	10.3	0.05	0.57
p	0.001	0.52	0.79

[abc] Mean values in the same column without common letter are different at p<0.05

During this first experiment not all the available substrate was consumed by the maggots (Figure 16). Disappearance of substrates started on the 1st day and increased from the third to the fourth day and then decelerated from the fourth to the sixth day. The mixture of BG and M was more consumed by maggots than the other ones (692 g of fresh substrate). BG and mixes of BG-LY were less consumed (455 and 439 g of fresh substrate). The second experiment showed that the peak of larvae migration was reached after 6 days (Figure 17). Consistently with the first experiment, BG-M-B, whether in the TEMP or the PERM treatments presented the best maggot production, with 112 ± 30.3 g/kg and 111 ± 40 g/kg of substrate respectively, compared to BG-M which yielded 47.4 ± 6.73 g/kg and 53.6 ± 8.48 g/kg for the TEMP and PERM treatments respectively. No difference was observed according to the exposure method to the houseflies (PERM vs. TEMP) (p=0.515). Finally, experiment 3 that compared increasing doses of cow blood (0%, 10%, 20%, and 30%) in the mixes of BG-M-B during 9 days of maggot production showed that increasing doses of cow blood improved linearly the production of maggots (Figure 18) (p<0.05). No saturation or plateau effect was observed with the doses of blood that were used.

Table 19 shows that the addition cows blood displays an optimum value between 10 and 20 % of cow blood into BG-M since such levels do not affect the production cost of maggots per kg. However, the addition of blood to 30% increases the cost of production.

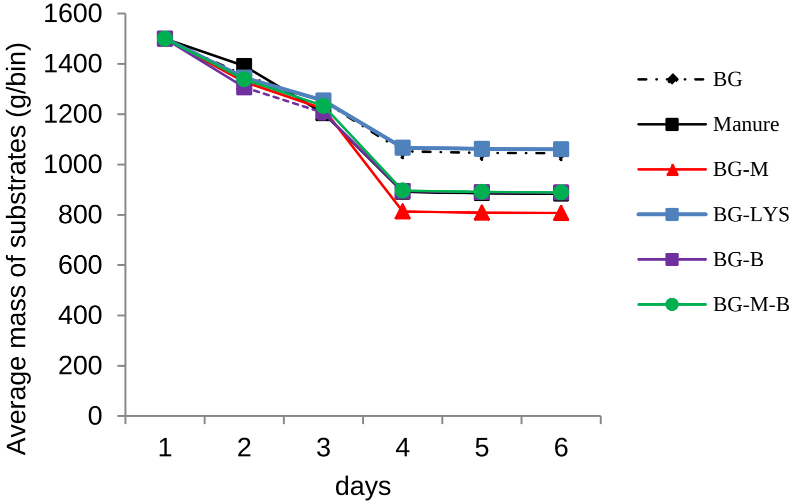

Figure 16. Daily evolution of the mass of the substrates (g/bin)

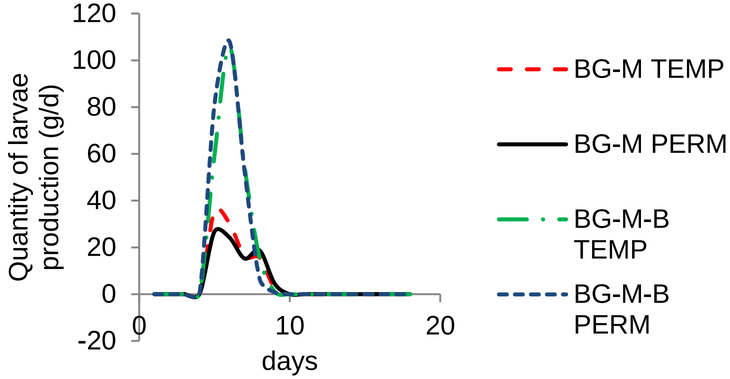

Figure 17. Evolution of the production per kg of substrate as a function of time with two contrasting exposures to the houseflies (N=4).

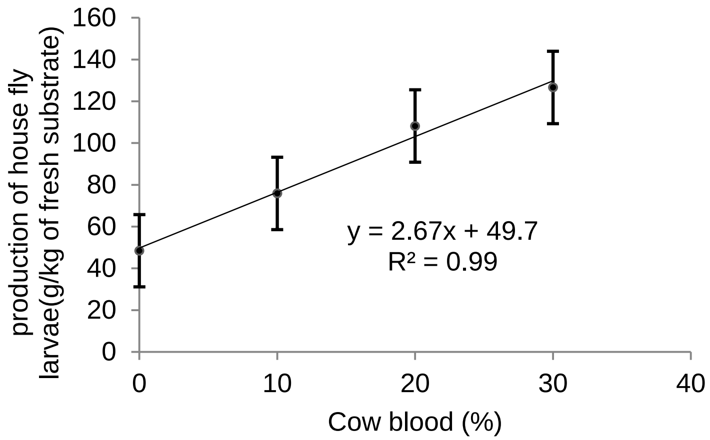

Figure 18. Production of maggot according to the cow's blood content of a BG-M mixture (g / kg of fresh substrate)

Table 19. Cost of house maggot production according substrate use with increasing dose of cow blood

Substrates	Substrates price ($)	Maggot production (g/kg fresh substrate)	CP ($)
BG	0.15	30.6	1.82
BG-M	0.14	48.4	1.19
BG-M-B (10%)	0.21	75.9	1.12
BG-M-B (20%)	0.28	108	1.04
BG-M-B (30%)	0.35	127	1.10

CP: cost price to produce 1 kg of maggot.

4. Discussion

This study has shown that the nutrient content of the substrate is a determining factor to optimize maggot production. An ingredient such as brewer's grains is a good source of energy but is deficient in several amino acids to support the growth of maggots as showed by Mussatto et al. (2006). The addition to the growth substrates of ingredients that appear to be more balanced in amino acids (cow blood or manure) or that provide specific otherwise deficient amino acids (lysine) allowed doubling the production of maggots on BG. As well-known for other more conventional single stomached domestic animal species such as pigs or poultry (Pérez and Sauvant, 2004), BG are deficient in lysine for the growth of maggots (Mussatto et al., 2006). Cow blood is a source of many essential amino acids (NRC, 2000). Nevertheless, it seems that lysine remains the most critical one since no further improvement as compared to pure lysine was observed. Pig manure can improve production on BG probably due to the presence of bacteria from the digestive tract of pigs that are also rich in esential amino acids, among which lysine (Metzler et al., 2005; Dai Zhang Wu and Zhu, 2010). Interestingly, the combination of BG-M-B was able to sustain the highest levels of maggot production, almost doubling that of BG-LYS. The increase in maggot production following the increase in cow blood doses in the BG-M mixture supports this previous argument. Further investigation is needed to identify the optimum dose of cow blood in the mixture combining technical to social, environmental and economical parameters.

Stability in disappearance of substrates observed from the 4th day onwards shows that larvae migration begins on the 4th day of production. Consumption of substrates decrease because larvae are migrating to the plastic bin. The optimal duration of housefly larvae production is 8 to 9 days. This allowed harvesting of maximal housefly larvae without harvesting many pupae that are of lower nutritional value than larvae (Pieterse and Pretorius, 2013). Not all the substrate is consummed by larvae, since only 30 to 40% are used. The remainder can thus be use for other purposes on the farm such as composting. Apparently, only the first days of laying eggs are important to reach the highest housefly larvae production. Indeed, no difference was observed between temporary exposure and permanent exposure modalities. Once the first eggs are laid, substrates are less atractive to houseflies due to the decrease in smell and nutrient content of the substrates. Temperature of the substrates during all experiments allowed a good development of maggots with a mean value of 31.3°C. The temperatures below 20°C tend to slow the development and the transformation of the larvae in adults while temperatures above 35°C tend to accelerate the whole process (Lomas, 2012). Temperatures from 7°C to 43°C are suitable for houseflies, but *M. domestica* are most active at about 33°C that is close to the ambient temperature in the humid tropics.

The increasing price of maggot production per kilogram for 30 % of addition of cow blood suggests that the cost effectiveness depends strongly on the level of blood in the substrate. The most cost-effective substrate seems to be a mixture of BG-M with 20% of cow blood following the increase in production coupled with the lower cost of maggot production per kilogram. Nevertheless, in the case of cow blood shortage, the simple mixture of manure to brewer's grains is already an interesting solution although its cost is higher than the mixture of BG-M with cow blood. Its strength is that it requires very little investment for farmers by using available substrates on the farm, especially those growing pigs in intergrated agriculture-aquaculture system. In general all ingredients used in the mixtures are locally available as agricultural by-products, however cow blood requires the extra investment of the cost of transportation and the time lost for purchasing which was not considered in this economic analysis. Including these economic parameters the optimal amount of cow blood to add in the mixture should be loer than expected.

We conclude that housefly larvae production is a good alternative in integrated agriculture aquaculture production to provide high quality of protein to produce fish. The larvae production using available agricultural and agro-industrial by-products can be further improved by with research to investigate the nutritive and the microbiological value for pond fishes produced as well as the global economic balance of the whole operation for large scale production in the farm.

5. Acknowledgements

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7

General discussion and perspectives

Chapter 7. General discussion and perspectives

The objective of this thesis was to understand which levers can be used to optimize overall production within small IAA farms in the tropics. This objective should be achieved by answering several research questions, namely:

- how do small farms involved in the IAA system work in the outskirts of Kinshasa?
- which components are present and how are they combined?
- do current IAA systems allow farms to be profitable and stable or do they offer opportunities for improvement?
- do types of system and management practices vary according to the location of the farms?
- which subsystems are actually involved in N flows between farm components and how are they managed?
- do N flows management allows to meet the needs of the animals (fish and terrestrial livestock) in terms of quantity and quality?
- Is there some room for improvement or innovative flows that would improve this efficiency?

Practice of the integrated agriculture aquaculture system in Kinshasa

When we examine the functioning of farms in the outskirts of Kinshasa involved in IAA systems, the survey shows that IAA systems exist in complex forms. About 35% combine fish and vegetable farming (FV), 30% combine fish, vegetable and livestock (FLV) and 14 % combine fish and livestock farming on smallholder farm. However, they are still 21% of the farms that, although they have the possibility to host IAA system, operate in fish solely. Size of farms generally varied from 4.7 ± 3.5, 6.3 ± 7.1 and 7 ± 7.4 respectively depending on the location, of acres actually exploited. However, the potentially exploitable area of farms could be around 32 ares of the smallest area and pig density around 6.4 UBT for the largest farm, as in most African countries (FAO, 2016). No striking differences in farm characteristics and farm practices between the locations (urban and rural areas) have been found except for feeding practice. In general, due to the lack of completed feed for fish, fish farming use on-farm resources (6-39%) and purchased ingredients (31-94%) such as *Manihot esculenta* leaves and peelings, leaves of *Ipomoea batatas, Moringa oleifera*, *Chromolaena odorata*, brewer's grains, wheat bran, etc.. harvested on farms, in the immediate vicinity of the farm or from locally available agricultural industries. Such feed ingredients have little values for fishes and are rather acting as fertilisers for the ponds and are not regularly used, but only when these ingredients are available, especially for farms in rural areas that have difficult access to the market due to their distance from the city center of Kinshasa (Figure 2).

Thus, farms in peri-urban and rural area aimed to produce fish such as *Oreochromis niloticus* and *Clarias gariepinus* which have a high amino acid profile using feeds with low amino acid profile (industrial by-product and agricultural wastes). Although they are rich in energy, an additional source of protein should be required to support the growth of fish in ponds. In general, the dietary protein requirement of fish ranges between 35 and 55%, or an equivalent of 45-75% of the gross energy content of the diet should be in the form of protein (Tacon and Cowey, 1985).

To overcome this problem smallholder farm use two main strategies: (1) especially in rural area, around 89% of farms use polyculture (Table 3) as fish production method allowing the *Clarias gariepinus* to feed on tilapia juveniles in order to regulate the population density of *Oreochromis niloticus*, which is very prolific, and thus obtaining an additional source of protein for their growth; (2) farms use pig manure to fertilize directly the ponds and stimulate the primary production of the pond to produce phytoplankton and zooplankton, which will be an important protein source in the fish trophic chain.

Performance of IAA in the outskirts of Kinshasa

Within the farm with up to 11 possible interaction flows when the farm combines 3 subsystems namely fish farming, vegetable farming and livestock farming, e.g. pigs. The highest score for flow use was achieved by pig manure (Table 5) which is used as fertilizer for vegetables farming (80%) and fish farming (64%). Flows such as pond sludge for fertilising vegetables (20%) and manure used for composting (4%) although important to strengthen the farm's autonomy are poorly exploited by farmers. The presence of these flows structure the interaction between subsystems. They should make farms more autonomous and therefore more profitable and possibility increase their stability. However, some IAA farms in the peri-urban and rural areas of Kinshasa, despite the presence of several subsystems, failed to generate a profit even though they have a positive gross margin as shown in Chapter 4 (Figure 5). The improper management and technical skills in integrated farms as pointed out by Limbu et al. (2016), is also noted in our chapter 3 by the low percentage of farms using the available nutrient flows between subsystems (Table 5). It may be at the root of the problem of failed in profit genaration in peri-urban and rural areas of Kinshasa. It seems clear that such system requires a skill and management practices from the main actors in order to maximize production on farm, generate adequate farm income and provide food security. For this purpose the high level of illiteracy among small-scale farmers reported by Ogello et al. (2013) in Kenya is the main barrier to the application of skill management practices for intensification of the small IAA farmer. Chapter 2 pointed out a fairly high education level of farmers in the peri-urban and rural area of Kinshasa. Only 3% of fish farmer have no education versus 47% with high school education (Table 3). That should be an asset, to help farmers in this area to meet the challenges of skill management at the farm. However, another important factor is the farmer's involvement in the farm's activities instead of using a paid workforce to take care of the farms activities on a day-to day basis. Since IAA farms work under limited financial resources and cash flow conditions with total costs ranging from 754 to 5970 USD (see figure 5), involvement of the farmer in farm activities and their level of education are crucial factors that can result in a well-organised farm with good management of nutrient flows, and can lead to profitability. The combination of the above factors increases the resilience of IAA farms and gives them a high degree of resilience to external factors such as diseases, scarcity or rising prices of agricultural inputs and animal feed etc. These lead to more stability in production on the farm.

It should also be noted that in order to properly assess the profitability at the overall level of the farm, an economic study taking into account to financially evaluate the contributions of flows between the different components must be carried out. The compartmentalized economic study of the components did not make it possible, for instance, to financially value the effluents from livestock, which are supposed to be sold to the vegetable and fish components.

Quantitative N flows management in IAA

To increase self-sufficiency of IAA by minimising the need for external inputs and promoting economies of scope as proposed by Bonaudo et al. (2014), IAA farms in peri-urban and rural areas of Kinshasa must focus more on preserving as much nutrients as possible, especially nitrogen. This is because it is one of the main factors limiting terrestrial and aquatic production on the farm. Better use of complementary activities or interaction between subsystems is the safest way to achieve this goal. For instance chapter 4 showed the role that the livestock subsystem can play in the profitability of the farm as well as the subsystem through pig manure availability. This is due to the high transfer of N into the pond through pig manure but also phosphorus from animal feed supplementation with forage as noted by Kambashi et al. (2014). However, the proportion of N transferred to the pond should be assessed for efficient use of the nitrogen flow. Repeated sampling of pond water during farm monitoring show that ponds in smallholder farms with IAA studied in DRC, release very little nitrate. For instance, the PUFVL2 farm with a pig density TLU of 6.4 and 23 are of ponds (see Table 7), even when dropping almost all pig manure in ponds, they release only an average of 0.8 ± 0.6 mg/l of nitrates trough fish pond (see Table 11). These values are much lower than 6.70 ±1.21 mg/l, 6.60 ±1.37 mg/l, 6.42 ±1.22 mg/l of nitrates measured by Zoccarato, Benatti et al. (1995) in pond water after using respectively manure solely, manure associated with completed feed and completed feed solely as fish feed in the pond. This indicates that even for farms with the largest TLUs in farm (6.4 and 4.2), the animal density is not high enough to cause degradation of the water physico-chemical parameters of the corresponding pond water size (23 are and 7 are). Thus, pig density can be increased in the peri-urban and rural areas without fear of water eutrophication or fish intoxication in the fish pond. Thus, the simulation of the model showed that densities of 1 to 10 pigs for a pond area of 1 are, do not easily support the growth of fish on farms (Figure 14c). Modelling approach allow to estimate daily N amount produced around 34 g N/pig, through pig feces and urine under tropical areas. However for farms where pigs are raised on the side of fish ponds as mostly observed in farms monitoring, N flow losses can be observed during harvesting and storage of feces and urine, also the farmers do not have an adequate device for collecting urine. That why this flow is not included in the model and is considered a loss in the system. Only around 14 g N/day are brought per growing pig to the ponds through the feces. Nevertheless this method has the advantage of being able to quantify the nitrogen transferred into the pond. Raising pigs directly on the fish ponds is skilled strategy to limit N flow losses by dropping manure directly into the pond and to reduce use of workforce in the farm. Sophin and Preston (2001) used it in ponds with Tilapia, Silver carp, Bighead carp at a density of 2 fish/m^2 an amount of 0.10 gN/m^2/day. They measured dissolved oxygen and pH values in water respectively of 6.2 mg/l and 8.4. Dhawan and Kaur (2002) have used much higher quantities of 3 gN/m^2/week, which is equivalent to 0.4 gN/m^2/day with dissolved oxygen and pH values of 9.7 mg/l and 8.5. Regarding the quantities previously used by these authors and the results of the simulations run with our own model, pig density can be increased up to a threshold in order to support plankton and fish growth in pond. The amount of 14 g N/day/pig from feces on pond of 1 are represent daily addition of 0.14 gN/m^2 on pond of approximatively 1 meter of depth seems to be insufficient to support significant plankton and fish biomass growth (Figure 14b and 14c) for farms with very little or no food resources such as those we investigated. It is true that the model only took into account the part of nitrogen provided by the feces (14 gN/day/pig) and that by raising the pigs above the ponds, they will benefit in addition to the nitrogen provided by the urine (20 gN/day/pig). In this case, farmers will be able to reduce the density of animals and build stronger structures that support less animals.

The validation of the model proposed in Chapter 5 will indicate the limit amount of N from pig to be discharge into pond for IAA farms in humid tropical areas in order to optimize plankton and fish growth in pond. Nevertheless the model indicates that any change in feed quality and pig density leads to a change in the amount of nitrogen produced by the pig and the evolution of nitrogen in the pond water column, phytoplankton and fish biomass (see table 18, Figure 14a,15a,14b,15b, 14c and 15c). This should serve to guide the strategy to be taken to maximize profit on the farm since animals play a key role in recycling and increasing the efficiency of resource usage (Rufino et al., 2006).

Qualitative N flows management in IAA

The model also shows that the increase in pig density can quickly lead to plankton peaks in the water namely “phytoplankton bloom”, which can lead to high DO consumption in water and low photosynthetic activity due to lack of light in the deepest layers of the pond, which is harmful to fishes. In addition, the release of feces into the water not only provides nitrogen but also phosphorus and organic matter which requires a strong presence of bacteria for their decomposition which is presently not considered in the model. As bacteria are dependent on DO level in water, this can lead to a decrease in bacterial activity and therefore an accumulation of nitrogen as nitrite in the pond. This may explain the low dissolved oxygen levels observed in some ponds during the monitoring (Table 11) while the amounts of nitrogen supplied through the feces were not high enough.

It seems clear that in terms of nitrogen supply to ponds only by feces, IAA farms in peri-urban and rural areas of Kinshasa can increase the density of pigs per available pond area. Until the values of the model on pig densities to be used by are of pond to optimize pond production, farmers will have to monitor physical and chemical parameters such as DO, nitrite and nitrate. However, rearing pigs above the ponds, the urine from the pigs could provide sufficient N to boost the primary production of the ponds without causing a significant decrease in DO. Indeed, in pigs, about 2/3 of the nitrogen is excreted in the urine (Bindelle et al., 2009). Hence, a more limited number of pigs would be used, which would reduce the risk for fecal organic matter to decrease the oxygen dissolved in the water. This might also solve an additional loss of N on the farm by recovering almost all N excreted by pigs, limiting the loss under the form of urine. This would also limited the need for farmers to manipulate excreta, increasing safety for workers. Nonetheless, applied to farms integrating ponds and pigs to vegetable farming, such a strategy poses the risk of diverting the flows from pigs from vegetables to the sole benefit of the ponds. Hence, its consequence on the stability of the farms must be properly addressed before any final recommendation can be proposed.

However, this raises the question of the efficient use of the qualitative nitrogen form available in the pig feces. The alternative must be balanced with the possible addition of insects larvae production subsystem on the farm. The latter does not solve the urinary N loss issue, but clearly improves the form of N available to fish from poorly digestible low quality protein or mineral N. this N must be processed by the planktonic population before being available to fishes, to high quality maggot protein. In term of N quality transferred, Nuov et al. (1995) considered direct use of pig manure in pond as an in inferior use of valuable inputs in pond for non-filter feeding fishes such as *Clarias gariepinus.* These species cannot be able to effectively recover nutrients from the pond food web without the need for a complementary protein source. Pig feces also contains the remains of undigested protein, anaerobic bacteria from the colon (Metzler et al., 2005) that can be a source of essential amino acid that is not fairly exploited by discharging feces into ponds and can be considered as a loss of N flow. To improve N flow used, chapter 6 proposed to use pig feces with others locally available agricultural waste and industrial by-products as substrates to attract houseflies (*Musca domestica*) for larvae production which are of much higher nutritional quality and much more stable (Aniebo and Owen, 2010) in order to improve fish feeding.

The fly larvae production experiments have shown that lysine is a limiting amino acid in the production (Table 18). Since this lysine is not accessible to smallholder farms in peri-urban and rural areas, it can be replaced by cow blood which are locally available with similar results (Table 18). In case of blood shortage, the mixture of brewers' grains as an energy source and pig manure as protein source provides very good larvae production alternative. Ideally, to improve efficiency of N flow in IAA farms, farmers can reared pig on the pond in suitable densities to recover the maximum N flow provided by the urinary N proportion estimated to 13 gN/pig by the model and possibly recover part or all of the feces as necessary to produce fly larvae for use as a complementary feed for fish. Using low cost available substrates price, farmers can obtain quality complementary feed for fish in relatively low production cost per Kg (1.04 to 1.82 USD/kg).

At the farm level, a much more intensive production was tested (Photo 5) and presented several advantages namely: (1) reduced contact between the fly larvae and the farmer. The farmer prepares the substrates and places them above the ponds in the shade; (2) a natural harvest of fly larvae that migrate through a mosquito mesh screen placed underneath the substrate mixture. The natural migration of larvae into the pond allows fish to balance their diet by eating only those they need because the larvae are also rich in fat, which should not exceed 12% in the fish's diet (NRC, 2000).

The fact that farmers are not in direct contact with the larvae limits the ability to carry parasites on the farm and the tentation of using larvae for other on-farm use, especially for feeding the pigs themselves, which would pose a serious health issues for example regarding *Ascaris suum* infestations.

Photo 5. Design of the fly larvae production system on a polyculture pond of *Clarias gariepinus* and *Oreochromis niloticus* in the urban area of Funa (Kinshasa, Democratic Republic of Congo)

In conclusion, the integrated system as practiced in peri-urban and rural areas of Kinshasa still present many challenges to be met in order to match the successes achieved in South East Asia, America and elsewhere. By focusing on both the quantity and quality of nitrogen produced on the farm and by limiting nitrogen losses through the different innovative methods presented in this thesis (photo 2), IAA farms can address most of the challenges facing the system. The system designed (Photo 2) must be studied to determine its capital gains within the farm IAA and the cost of production per kg of fish using this system must be calculated since the costs of the substrates used are well known. Skilled application strategies to maximize profit on the farm are needed for economical farming viability. Among those that have been outlined in this work, the major ones are: a labour management using skilled labour as temporary paid labour only for activities that require an expert intervention and family labour for the remaining activities, since it is inexpensive and a viable alternative due to the low availability of job opportunities for the family members in sectors other than agriculture. Smallholder farms working with IAA in the peri-urban and rural areas of Kinshasa may decide to jointly carry out common expenses such as food transport, a visit by a veterinarian or an expert consultation, rental of special machines, etc. These expenses incurred by a single farmer may strike the farm's benefit while between several farms they would be minimized.

Ecological intensification requires territorial governance to improve it from a sustainable development perspective (Aubin et al., 2017). Competent organizations can popularize the improvement practices of the IAA system to attract the interest of farms with the potential to shelter IAA practices since a lack of enthusiasm in the application of the system was noted.

Finally a more detailed research can validate the mathematical model developed in Chapter 5 to obtain the actual pond dimensions, incorporate them in the model the possibility to have as an N flow input from fish feed and from fly larvae in the fish pond, an appropriate global economic study of the system that can compare the realised gain of different possibilities of N maximisation techniques within the farms.

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APPENDIX

Appendix 1: Survey questionnaire

The survey questionnaire presented below was used to conduct the surveys whose results are presented in Chapter 3 of this thesis as published in the *Journal of Agriculture and Rural Development in the Tropics and Subtropics Vol. 118 No. 1 (2017) 149–160.* It was written in French and, if necessary, translated into Lingala during the interview

CONTENUE DU QUESTIONNAIRE

Pour nous aider à discerner les règles ou principes de votre production, nous vous demandons de partager les détails de votre système de production avec nous. Nous aimerions également savoir comment des facteurs externes affectent vos activités agricoles.

Numéro questionnaire : /……..../
Date de l'interview : /………/ ……/2012
Heure de début de l'interview :………………….
Heure de fin de l'interview :……………….
Nom de l'enquêteur 1: /…………………………. /
Nom de l'enquêteur 2: /…………………………. /

Nom de l'exploitation (le cas échéant) : /……………………………………………. /
Localisation de l'exploitation :
Nom de la vallée :……………………………………………………
Quartier ou Bloc :...
Commune de :……………………………………………………..
Coordonnées GPS :………………………………………………..
Autre localisation :………………………………………………...
Noms et prénoms de l'exploitant :……………………………………………
Qualité du répondant:

1. Propriétaire

1a. de toute l'exploitation☐, 1b. d'une partie de l'exploitation☐, Laquelle ? Précisez...

2. Locataire

2a. de toute l'exploitation☐, 2b. d'une partie de l'exploitation☐, Laquelle ? Précisez…………...

3. Employé ☐ 4. Autre. A préciser…………………………………………

3. Qui décide de la vente des produits de votre exploitation (Animaux et cultures) ? 1. Propriétaire ☐ 2. Employé ☐ Autre à préciser ☐………………...

SECTION I : LA NATURE DE L'EXPLOITATION

4. Tenue de l'exploitation

1. Propriétaire ☐ 2. Métayeur ☐

5. Nature du terrain : 1. Pente ☐ 2. Plaine ☐ 3. Bas-fonds ☐

6. Vocation agricole : 1. Maraîchage ☐ 2. Pisciculture ☐ 3. Elevage ☐

7. Quelle est la superficie de votre exploitation : /………………/ Hectares

8. Approvisionnement en eau du terrain

1. Source ☐ 2. Rivière ☐ 3. Puits ☐ 4. Autres (à spécifier) ☐

9. Coût lié à l'approvisionnement en eau ………………………………FC

SECTION II : IDENTIFICATION DE L'EXPLOITANT

10. Genre : 1. Femme ☐ 2. Homme ☐

11. Statut Marital 1. ☐ Marié(e) 2. ☐Célibataire 3. ☐Divorcé(e) 4.☐ veuf (Ve)

12. Tranche d'âge :

1. moins de 20 ans ☐ 2. 21-30 ans ☐ 3. 31-40 ans☐ 4. 41-50 ans ☐
5. > 50 ans ☐

13. Niveau d'étude

1. pas étudié ☐ 2. Études primaires ☐ 3. Études secondaires ☐ 4. Études supérieures☐

14. Quelle est la taille du ménage /……enfants……….parents/

15. Nombre des personnes de / moins de 12 ans/……/ plus de 12 ans /………/

16. Nombre d'enfants scolarisés /………./ Nombre d'enfants non scolarisés /……/

17. Nombre de personne participant à l'activité ?/……………/

18. Avez – vous une activité complémentaire ? 1. Oui ☐ 2. Non ☐

Si Oui, laquelle ?…………………………………………………………

19. Lieu de résidence de l'exploitant

1. Proche de la ferme ☐
2. Eloigné de la ferme ☐
3. Dans la ferme ☐

SECTION III: PISCICULTURE

20. Exploitez-vous un ou plusieurs étangs piscicoles ? 1. Oui ☐ 2. Non ☐

21. Si oui, combien sont actuellement en exploitation /…../ et combien ne sont pas en exploitation /…./

22. Si non pourquoi ?.. fin de l'interview

23. Remplissons les tableaux ci - dessous avec les caractéristiques des étangs et des productions piscicoles : <u>Remplir le tableau avec le chiffre qui correspond à votre réponse</u>

	Etang 1	Etang 2	Etang 3	Etang 4
Longueur x largeur (m)				
Profondeur Maximale (cm)				
Largeur des digues en son point le plus étroit (m)				
Fonction principale: *1. Alevinage* *2. Reproduction / Frayère* *3. Pré grossissement jusqu'au stade « fingerling »* *4. Grossissement* *5. Etang de stabulation, de stockage, viviers* *6. Autres. A préciser*				
Approvisionnement en eau : *1. Source(s)* *2. Nappe (puits, forage…)* *3. Cours d'eau* *4. Ruissellement d'eau de pluie* *5. Autres. A Préciser*				
Si étang alimenté par un cours d'eau : *1. Etang de barrage (=sans canal de dérivation)* *1.1. Avec déversoir* *1.2. Sans déversoir* *2. Etang en dérivation (=avec une prise d'eau générale)*				
Si étang en dérivation: *1. Etang en série (=connexion entre étangs)* *2. Etang en parallèle (pas de connexion hydraulique entre étangs)*				
Type d'alimentation en eau : *1. Autonome (= une prise d'eau par étang)* *2. Non autonome*				
Système de vidange de l'étang : *1. Moine* *2. Tuyau (coudé,…)* *3. Bouchon de fond* *4. Ouverture de la digue* *5. Autres. A préciser.*				
Système de récolte des poissons : *1. pêcherie hors étang* *2. pêcherie dans l'étang* *3. Filet (épervier…) ou nasses* *4. à la main* *5. Autres. A préciser.*				

	Espèces élevées : 1. Tilapia du Nil 2. Clarias gariepinus 3. Heterotis niloticus 4. Autres. A préciser.	Durée d'un cycle d'élevage (mois)	Mise en charge (nombre ou kg)	Poids moyen à la mise en charge (g)	Quantité récoltée par cycle d'élevage (nombre ou kg)	Poids moyen à la récolte (g)	Récoltes intermédiaires par pêche ? 1. Oui 2 .Non	Quantité vendue (% du total récolté)	Quantité consommée par la famille de l'exploitant (% du total récolté)	Alimentation en eau : 1. Continue 2. Discontinue 3. Autres. A préciser.
Etang 1										
Etang 2										
Etang 3										
Etang 4										

24. Quelle est la provenance de vos alevins et pratiquez-vous le contrôle des sexes ?

Espèce élevées :	Provenance des alevins : Nature Commerce Production interne Autres. A préciser.	Si commerce, nom et coordonnées du fournisseur	Contrôle des sexes ? 1. Oui 2. Non	Si oui, quel sexe ratio utilisez-vous ?	Si oui, technique utilisée ? 1. Tri manuel 2. Hormone et Néomâles 3. Autres. A préciser.
Tilapia du Nil					
Clarias					
Heterotis					

25. Moyens d'intensification des étangs. Remplissons le tableau suivant :

	Fumure des étangs : 1. Oui 2. Non	Chaulage des étangs : 1. Oui 2. Non	Alimentation artificielle des poissons ? 1. Oui 2. Non	Si alimentation artificielle, 1. Aliments composés. Farines Granulé s agglomérés 2. Aliment simple (non composé).	Si aliments composés, Fabrication à la ferme de composition connue Fabrication commerciale de composition inconnue Autre. Précisez.	Présence d'hélophytes ? 1. Oui Azolla sp. Salvinia Autres. Précisez. 2. Non	Pourcentage de la surface couverte par les hélophytes ? < 10 % 10 à 25 % 25 à 50% 50 à 75 % > 75%	Récupération des boues ? 1. Oui 2. Non	Si récupération des boues, Utilisation pour : 1. Maraîchage 2. Vente 3. Consolidation des digues 4. Autres.
Etang 1									
Etang 2									
Etang 3									
Etang 4									

26. Si vous utilisez des aliments composés pour nourrir les poissons de certains étangs, alors, remplissons ce tableau :

Nom de l'aliment composé (= granulés, pellets ou farines mélangées)	Nom des ingrédients	Proportion des ingrédients	Pour l'aliment composé origine des ingrédients : 1. Nature 2. Commerce 3. Interne à l'exploitation 4. Autres. A préciser.	Si commerce, nom et coordonnées du fournisseur	Quantité distribuée par jour (ration) (kg/are)	Fréquence de distribution (/semaine ou par jour)	Coûts (FC)/Kg

27. Si vous utilisez des aliments simples (ingrédients, co-produits, sous-produits, etc.) pour nourrir les poissons de certains étangs, alors, remplissons ce tableau :

Nom des aliments simples	Origine des aliments simples : 1. Nature. 2. Commerce 3. Interne à l'exploitation 4. Autres. (à préciser).	Si commerce, nom et coordonnées du fournisseur	Quantité distribuée par jour (ration)	Fréquence de distribution (/semaine ou par jour)	Coûts (FC) /Kg

28. Si vous utilisez la fumure de certains étangs, tableau à remplir :

Fumures : 1. Minérale 2. Organique	Nom Commercial Principe actif	Origine : 1. Nature 2. Commerce 3. Interne à l'exploitation 4. Autres. A préciser.	Si plusieurs origines, part de contribution de chaque origine à l'application	Composition	Quantité (kg)	Coût (FC/kg)	Fréquence d'utilisation (/an)

29. Si vous utilisez la fumure de certains étangs, précisez la technique d'épandage ?
………………………...
....
30. Si vous utilisez la fumure de certains étangs, précisez la localisation de l'application des fumures ?...
....

Si vous procédez au chaulage de certains étangs, à quel moment ?
Chaulage après mise à sec ☐ Chaulage de l'eau ? ☐

31. Récupérez – vous les plantes hélophytes de tous les étangs ou de certains étangs ?
1. Oui ☐ 2. Non ☐

32. Si oui, remplir tableau :

	Nom de la Plante	Causes de la récupération ? 1. Pour éviter un désagrément (plantes envahissantes…) 2. Pour une valorisation 3. Autres (à préciser)	Type de valorisation 1. Compostage 2. Alimentation des animaux (lesquels) 3. Vente 4. Autres (à préciser)
1			
2			

33. Texture du sol des digues : 1.Sablonneuse ☐ 2. Sablo-argileuse ☐ 3. Argileuse ☐ Autre (à préciser)…………………………………………………..
34. Stabilité des digues : 1.Faible ☐ 2. Intermédiaire ☐ 3. Forte ☐
35. Prix des poissons ?

Espèces	Prix Alevins (FC/pièce) 1 /Kg 2 pièce (poids moyen)	Prix à la vente des poissons produits dans l'exploitation (FC/kg)	Lieu de vente : 1. Etang 2. Marché. Lequel et distance approximative ? 3. Autres.(à préciser).	Qualité des acheteurs 1. Consommateurs 2. Revendeurs
1. *Tilapia du Nil*				
2. *Clarias*				
3. *Heterotis*				

36. A quelle période de l'année avez –vous des prix élevés ……………………. des prix bas…………………..
37. Quelles sont les principales contraintes liées à votre production piscicole?...

SECTION IV: ELEVAGE

38. Possédez – vous des animaux d'élevage ? 1. Oui ☐ 2. Non ☐
39. Taille de l'élevage, origine et ressources génétiques des animaux d'élevage

Espèces :	Porcs	Chèvres	Canards	Autres
Races				
Taille du cheptel				
Nombre de femelles reproductrices				
Nombre de géniteurs mâles				
Origine des animaux Autres exploitations Maisons de vente d'animaux Production interne				
Statut physiologique et nombre d'animaux achetés : Femelle repro Mâle repro Jeunes destinés à l'engraissement				
Si géniteur : maturité sexuelle ? Mature Non mature (âge)				
Coût ($)				
Meilleur moment pour l'achat (mois)				

40. Quelle est la principale espèce animale de votre élevage ?...

41. Considérant vos revenus, l'élevage est –il considérer comme activité : 1. Principal ☐ 2. Secondaire ☐

42. Conduite de l'élevage :

Espèces :	Porcs	Chèvres	Canards	Autres
Conduite « générale » de l'élevage 1. Divagation 2. Stabulation 3. au piquet				
Présence de logement/stabulation spécifique ? En cage à l'abri En cage à l'air libre Non				
Superficie du logement(L x l)				
Sol du logement : 1. terre battue 2. bêton 3. Litière				
Toit Pas de toit Tôle Branchages Autres (précisez)				

43. Pratiques de reproduction et productivité de l'activité d'élevage

Espèces :	Porcs	Chèvres	Canards	Autres
Conduite des animaux 1. En bande (par âge et sexe) 2. En groupe				
Saillie 1. son propre mâle 2. location				
Age à la 1ere mise-bas				
Taille moyenne portées/femelle				
intervalle entre mise bas				
Mortalité avant sevrage				
Age au sevrage (mois)				
Nombre de jeunes sevrés/an				
sur 10 petits combien arrivent en maturité				
Nombre de portée femelle avant reforme				
Critères de choix pour les animaux de renouvellement 1. Au hasard 2. Ceux qui n'ont pas été vendus 3. Les animaux en meilleure santé 4. Les animaux les plus gros 5. Les animaux issus d'une grosse portée/nichée				

44. Finalité des animaux élevés : vente, autoconsommation

Espèces :	Porcs	Chèvres	Canards	Autres
Nbre animaux consommées par la famille (par semaine, par mois ou par an ?)				
Nombre d'animaux vendus sur pieds ou abattu				
Prix /animal				
Age à la vente (semaines)				
Poids à la vente (Kg)				
Clients 1. Consommateurs 2. Revendeurs				
Lieu de vente : 1. Ferme 2. Marché (Lequel)				
Vente 1. Ponctuelle 2. Régulière				

45. A quelle période de l'année avez-vous des prix élevés …………………….des prix bas……………………………
46. Si la vente est ponctuelle à quelles occasions particulières ?..
47. Stratégie alimentaire : Procédez-vous au nourrissage artificiel de vos animaux : 1. Oui 2. Non
48. Si oui, remplissons ce tableau

Espèces :	Porcs	Chèvres	Canards	Autres
Nom de l'aliment composé				
Forme de l'aliment 1. Granulé commerciaux 2. Farine 3. Autre (à préciser)				
Liste des ingrédients qui le composent et leurs proportions				
Proportion				
Origine de l'aliment 1. Commerce 2. Interne 3. Nature 4. Autre (à préciser)				
Si commerce, coordonnées du fournisseur				
Qté distribuée par ration				
Fréquence de distribution (Journalière, Hebdomadaire Autre à préciser)				
Coût (FC/kg)				

49. Procédez-vous au nourrissage artificiel avec des aliments simples (=non composés)

Espèces :	Porcs	Chèvres	Canards	Autres
Nom de l'aliment simple				
Forme de l'aliment 1. Sous-produits de cuisine 2. Fourrage sec 3. Fourrage vert 4. Farine 5. Sous-produit agro-industriels 6. Pellet ou granulé 7. Autre (à préciser)				
Origine 1. Nature 2. Commerce 3. Interne à l'exploitation 4. Autres (à préciser)				
Si commerce, coordonnées du fournisseur				
Qté distribuée par ration				
coût (FC/kg)				

50. Abreuvement

Espèces :	Porcs	Chèvres	Canards	Autres
Apport d'eau aux animaux 1. Oui 2. Non				
Système d'abreuvement (équipement) 1. Abreuvoir 2. Point d'eau naturel 3. Autre (à préciser)				
Origine de l'eau d'abreuvement : 1. Source 2. Rivière 3. Puits 4. Etang 5. REGIDESO 6. Pluie				

51. Hygiène et prophylaxie

Espèces :	Porcs	Chèvres	Canards	Autres
Recours au vétérinaire 1. Jamais 2. Rarement 3. régulièrement (combien de fois par mois/semaine/an ?)				
Appel au vétérinaire 1. Animaux malades 2. Soins prophylaxiques (vaccins, vermifuges) 3. Visite de routine, de suivi 4. Conseil technique 5. Autre				
Prescription et Utilisation de médicaments 1. Oui (lesquels) 2. Non				
Vermifugation (quel produit ?)				
Vaccination (quel produit)				
Fréquence de nettoyage des stabulations (semaine)				
Nettoyage des stabulations : 1. à l'eau (précisez la provenance) 2. à la chaux 3. aux détergents 4. Autres (à préciser)				
Si l'eau quelle est sa provenance 1. Tank 2. Puits 3. Source. 4. Ruisseau				

52. Gestion des effluents : récoltez-vous les déjections animales, à quoi les destinez-vous ?

Espèces :	Porcs	Chèvres	Canards	Autres
Récolte des déjections 1. Nettoyage et stockage de la stabulation 2. Collecte sur parcours 3. Non, je ne conserve pas les déjections de ces animaux				
Nature des déjections récoltées : 1. MF seules 2. MF + urines 3. Urines et MF séparées 4. Autres (à préciser)				
Stockage temporaire 1. Utilisation directe 2. Stockage et Utilisation				
Equipements de stockage: 1. En tas sur l'exploitation 2. Dans une fosse 3. Dans des bacs 4. Autres (à préciser)				
Le lisier est-il dilué ? 1. Par les eaux de nettoyages, 2. Par les eaux de pluie.				
Destination des déjections animales et part (%) de répartition après la récolte : 1. Vente (%) 2. Parcelles de maraichage (%) 3. étangs (%) 4. Compostage (%) 5. Autres (à préciser) (%)				
Disposez-vous d'équipement pour collecter, canaliser et réguler le flux de lisier vers les étangs ou la fosse à lisier ? Préciser. 1. Oui 2. Non Si oui, préciser				

53. Procédez-vous à la vente ou à l'achat de ces déjections ? 1. Oui ☐ 2. Non ☐

Déjetions	Espèce	Fréquence (semaines)	1. Achat 2. Vente	Quantité(Kg)	Prix(FC)
Lisier					
Fumier					
Fiente					

54. Quelles sont les principales contraintes liées à votre activité d'élevage?

SECTION V: PRODUCTION MARAICHERE

55. Espèces cultivées, successions culturales et surfaces agricoles : Quelles sont les différentes cultures dans votre exploitation agricole (Citez par ordre d'importance)?

Espèces cultivées	Nombre de Plate bande	Superficie à mesurer (m x m)	Nombre de fois d'occupation de la plante bande/an	Activités (pour chaque culture) Principale Secondaire	Rendement/plate bande (Kg)	Prix moyen de vente de légume/plate bande
1						
2						
3						
4						

56. Pourquoi pratiquez-vous cette activité ?

Espèces végétales	Motivations Pour gagner ma vie (activité principale) Pour améliorer mes conditions de vie (complément de revenu) 3. Pour l'autoconsommation 4. Pour nourrir mes animaux 5. Autres (à spécifier)	Quelle eau utilisez -vous pour arrosée vos légumes : 1. Eau de l'étang 2. Eau de rivière 3. Eau de source 4. Eau de puits 5. Autre à préciser	Lieu de vente : 1.Marché (lequel) 2.A la ferme : 3.Autre à préciser

57. Considérant vos revenus, le maraichage par rapport à la pisciculture et/ou à l'élevage de porc, est-il considéré comme une activité :

Principale ☐ Secondaire ☐

58. Comment gérez-vous la fertilité de votre exploitation ?

1. Je défriche une nouvelle parcelle si la précédente ne donne plus ☐ 2. Jachère après culture (durée : ……………………..) ☐ 3. Associations de légumineuses ☐ 4. Utilisation de déjections animales ☐ 5. Utilisation d'engrais minéraux ☐ 6. Rien

59. Dans le cas d'application de fertilisants, quelles sont vos pratiques ?

Noms cultures	Fumure 1. Déjections animales, 2. Paillis, 3. Engrais minéral, 4. Autres à préciser	Nombre d'application	quantité appliquée par utilisation	Origine : 1. Interne, 2. Commerce, 3. Milieu naturel 4. autres	Si origine externe (2,3 ou autre) quelle est sa contribution en % par rapport à l'interne	Coût/kg
1						
2						
3						
4						

60. Recourez-vous à d'autres intrants chimiques ? Lesquels ?

Espèces de plante	intrant chimique	Kg/plate bande	Coût/kg

61. A quelle période de l'année avez – vous des prix élevés …………………………des prix bas…………………………………………...
62. Que faites-vous des déchets de maraîchage à la récolte ? ……………………………………………………………………………..

Quelles sont les principales contraintes liées à votre production maraîchère? ……………………………………………………………………………..

SECTION VI: GESTION DE L'EXPLOITATION

63. Quel type de main d'œuvre utilisez-vous dans votre exploitation?
64. Familiale ☐ 2. Salariée ☐ 4. Autres à spécifier:………………………………………….
65. Depuis quand êtes – vous actif dans cette activité ?

	Elevage	*Pisciculture*	*Maraîchage*
Ancienneté (année)			

Spéculation	Contribution en % au revenu généré	Qui fixe le prix au terme d'échange pour vos produits ?	Possibilité d'influencer les prix 1. Oui 2. Non	Si oui comment*
Pisciculture				
Maraîchage				
Elevage				

* :………………………………………………………………………………

66. Remplissons le tableau suivant :

Opérations	Quantité de main d'œuvre	Coût unitaire/ homme-jour	Coût total/homme-jour
Si agriculture			
défrichement			
-labour			
-semis			
-sarclage			
-fertilisation			
-récolte			
-vente			
-autres (à spécifier)			
-			
Si élevage			
-aménagement des locaux			
-entretien			
-alimentation			
-autre (à spécifier)			
-			
Si pisciculture			
-la construction des étangs			
- l'alimentation des poissons			
-la récolte des poissons			
- la récolte des boues			
- la récolte des hélophytes			
-autre (à spécifier)			

67. Lesquels de ces intrants avez-vous dans votre exploitation, prière de remplir ce tableau ?

Matériels	Nombre	Coût unitaire	Coût total
-bèche			
-pèle			
-houe			
-râteau			
-arrosoir			
-seau			
-machette			
-brouette			
-filet			
-épuisette			
-coupe coupe			
-hache			

68. Quels sont les facteurs qui influencent les plus votre décision de production ?
…………………………………………………………………………...

Appendix 2: DRAFT SUIVI DES EXPLOITATIONS AGRICOLES

1. Objectif

Quantification de l'influence de l'intégration des composantes du système de production (étang, porcherie, maraichage) sur les performances technico-économiques des exploitations.

2. But de l'étude

- Décrire les différentes composantes des systèmes observés lors des enquêtes.
- Mesurer (quantifier) les paramètres importants pour chaque composante,
- Faire une analyse du cycle de vie des exploitations agricoles des composantes différentes.

3. Résultat

- Bilan économique des exploitations agricoles intégrées,
- Bilan zootechniques et agricoles des exploitations,
- Quantification des flux de matière et des nutriments (N) dans les exploitations agricoles intégrées.

4. Traitements à observer

Après la réalisation de l'enquête sur les trois sites sélectionnés, nous avons opté pour un suivi des exploitations agricoles, basées sur les systèmes d'intégration ci-dessous en raison de leurs fréquences élevées sur terrain (Etang + maraichage ; Etang + porcherie + maraichage ;) mais aussi pour ceux qui ont une faible fréquence sur terrain comme Etang + porcherie, dans le but de susciter un intérêt, dans le chef de ceux qui le font sans pour autant obtenir des résultats encourageant pour l'une ou l'autre raison. Ainsi les trois systèmes d'intégrations à suivre seront:

- Etang + porcherie
- Etang + maraichage
- Etang + porcherie + maraichage

Pour chacun de ces systèmes d'intégration (traitements), un nombre de 2 exploitations seront suivie pendant une durée de 2 ans. La sélection des exploitations sera faite de manière aléatoire, mais orienté principalement sur les exploitations détenues par les propriétaires. Cela permettra de tirer les plus d'informations possible, sur différents aspects de la vie des exploitations (données économiques, zootechniques et agricoles). Un cahier sera remis à chaque exploitant pour tenir quotidiennement sa comptabilité. Les données seront prélevées chaque 15 jour. Et les échantillons seront également prélevés chaque 15 jour au passage des enquêteurs. Le suivi se déroulera sur le site de FUNA, N'djili et Mbankana, le premier jour dans une exploitation les données seront prélevées par tous les enquêteurs disponibles.

Caractéristiques initiales de la ferme

Nom de l'exploitation:
Localisation de l'exploitation:
- Nom de la vallée :
- Quartier ou Bloc :
- Comme :
- Coordonnées GPS :

Qualité du répondant:
N° téléphone:
Nom de l'enquêteur:

1. Composantes et superficie consacrée :

Superficie totale :	Nombre
- Prairie/Parcours : - Etang : - Maraîchage :	

2. Modification des superficies en plein exercice :

Superficie modifiée	Spéculation	Cause (Pourquoi ?)
- Superficie achetées : - Superficie louées auprès d'un tiers : - Superficie perdue : - Superficie construite :		

3. Inventaires des outils

Type de matériel et outillage	Nombre	Date d'achat	Prix d'achat	Composante	Durée de vie espérée	Date de « fin de vie »
1. Outillage						
2. Matériel industriel						

ELEVAGE PORC

Caractéristiques initiales de la porcherie

1. Inventaire porcin (à remplir au début de l'enquête)

N° de l'animal	Date de naissance	Race	Sexe	Poids	Catégories (P, E, FR, MR)	Père		Mère	
						Numéro père	Race	Numéro père	Race

P : porcelet, E : jeune à l'engraissement, FR : femelle reproductrice, MR : mâle reproducteur

2. Inventaire bâtiments (à remplir au début de l'enquête et à la fin)

Bâtiment	Superficie totale	Matériaux	Nombre loges	Superficie loges	Nbre d'animaux/loge	Catégorie animales	Année de construction	Système de nettoyage	Origine d'eau de nettoyage	Fréquence de nettoyage

3. Entrée dans l'élevage (tous les 15 jours)

N° de l'animal	Race du porc	Sexe	Date	Mode d'entrée (A, N, P, D)	Origine	prix d'achat	Catégories (P, E, FR, MR)

A : achat, N : naissance, P : Prêt, D: don

3. Sortie dans l'élevage (tous les 15 jours)

N° de l'animal	Date	Mode de sortie (V, D, P, F)	Cause	prix de vente	Catégories (P, E, FR, MR)

(V : vente, D : don, P : prêt, F : propre ferme (soit étang, soit maraîchage)

4. Suivi de poids des femelles reproductrices (à l'entrée, à la saillie, au sevrage)

N° de l'animal	Race du porc	Poids	Date de la pesée

5. Suivi de la croissance porc jeune et mâle reproducteurs (tous les 15 jours)

Date de la pesée:

N° de l'animal	Poids

Coûts liés aux interventions vétérinaires, main d'œuvre et autres frais

6. Frais vétérinaire et produits (tous les 15 jours)

7. Frais de main d'œuvre (tous les 15 jours)

Opération	Date	Type de main d'œuvre (F, S, T)	Coût (FC)	Temps de travail	N° de l'animal	Nom de loge

F : familiale, S : salariée, T : temporaire

Autres frais (tous les 15 jours)

Dépenses (opération)	Date	Quantité	Coût (FC)	Destination	Temps de travail	N° de l'animal

8. Suivi des caractéristiques lisiers (tous les 15 jours)

Code Echantillon	Date	Mode de récolte	Traitement	Qualité du lisier L/S

L : liquide, S : solide

11. Récolte lisier

Date	Mode de récolte	Traitement	Qualité du lisier L/S	Mode de sortie (V, P, D, F)	Quantité (Kg)			Coût (FC)	Destination (étang, maraîchage etc..)
					Qté vendu	Qté Prêté	Qté utilisée		

L : liquide, S : solide, V : vente, P : prêt, D : don, F : propre ferme

12. Reproduction et naissances (tous les 15 jours)

Nom de l'activité	Date	N° de l'animal	Nom de la maladie	Nom des produits	Coût de l'intervention (FC)

Animal	N° du mâle (identité)	Date saillie	Avortement		Naissance		Nombre jeunes morts-né	Nombre jeunes morts-né avant sevrage	Nombre jeunes sevrés
			Date	Nbr avortés	Date	Nbr aissance			

12. Suivi de l'alimentation des porcs (tous les 15 jours)

Echantillon	Nom de l'aliment	Composition (ingrédients)	Date de prélèvement	Quantité distribuée par loge	Fréquence de distribution	Nbr d'individus/loge	Catégories nourris			
							Jeunes avant sevrage	Jeunes après sevrage	Adultes (Mâles reproducteurs	Adultes(femelle reproductrice)

PISCICULTURE

1. Caractéristiques initiales de la pisciculture (à remplir au début et fin)

	Superficie	Débit		Espèces	Poids moyen Mise en charge	Date mise en charge	Durée cycle de production	Quantité récoltée	Poids moyen à la récolte	Origine des alevins
		Saison sèche	Saison de pluie							
Etang 1										
Etang2										

3. Suivi des étangs (tous les 15 jours)

N° étang	Espèce(s)	Entrée			Sortie			Passage 1							
		Type d'entré	Quantité	date	Type de sortie	Quantité	date	Débit	pH	O_2	NH3-NH4	NO2	NO3	PO4	date

MARAICHAGE

1. Caractéristique initiale maraichage

N° plate-bande	Nombre de la culture	Durée de la culture	Fonction (pépinière, repiquage)	Superficie

2. Suivi des opérations techniques du maraîchage et récolte

Nom de l'opération	N° Plate-bande	Nom Culture	Date	Main d'œuvre (F, S, T)	Destination (V, C, P)	Quantité			Revenus (FC)	Temps de travail
					Type de d'engrais	Qté vendu	Qté consommée	Qté prêtée ou don		

F : familiale, Salarié, T : temporaire, V : vente, C : consommation, P : prêt ou don

3. Suivi des intrants

Nom de l'intrant	Quantité	Date d'achat	Origine	coût (FC)

4. Autres frais liés au maraîchage

Libellé de la dépense (opération)	Date	Destination	Quantité	Coût (FC)

Appendix 3: Additional analyses of pond water

Systems Farms	FVL		FV			FL	
	UFVL1	PUFVL2	UFV1	PUFV2	PUFV3	UFL1	PUFL2
Number of ponds	4	4	4	1	2	2	2
Number of observations	72	72	41	40	24	71	42
NO2 (mg/l)	0.16a ± 0.20	0.16a ± 0.20	0.10ab ± 0.05	0.10ab ± 0.04	0.10ab ± 0.10	0.13ba ± 0.09	0.08b ± 0.05
NH4 (mg/l)	0.16ab ± 0.20	0.18ab ± 0.15	0.11b ± 0.09	0.18ab ± 0.15	0.13b ± 0.08	0.16ab ± 0.10	0.21a ± 0.14
TAN (mg/l)	0.66ab ± 0.29	0.67ab ± 0.29	0.76ab ± 0.37	0.79 ± 0.31	0.69 ± 0.27	0.65±0.26	0.63±0.20

Appendix 4: Pictures of the thesis process

Photo 6. Overview of urban 1 area

Photo 7. Surveyors interviewing a small farmer in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 8. Surveyor observing a pond with a farmer after interview in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 9. Surveyors assisting to pig manure spilling in the pond in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 10. Family members involved in farm activities located in the same enclosure with the family home in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 11. Surveyor assisting with the pond cleaning activity

Photo 12. Flowerbed after harvest of the crops in the municipality of N’djili in the urban area of Kinshasa (DRC)

Photo 13. Fish pond with crops on the dikes in the municipality of N’djili in the urban area of Kinshasa (DRC)

Photo 14. Fish and vegetable farming in the municipality of N’djili in the urban area of Kinshasa (DRC)

Photo 15. Overview of the CADIM valley in the municipality of MBANKANA in rural area of Kinshasa

Photo 16. Pig farming above fish pond in the municipality of MBANKANA in rural area of Kinshasa

Photo 17. Manure pit for collection and storage of pig manure near the pond in the municipality of MBANKANA in rural area of Kinshasa

Photo 18. Fish, livestock and vegetable farming in PUFVL2 farm in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 19. Crops flowerbed in PUFVL2 farm in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 20. Physical and chemical parameters of ponds collection during farm monitoring in PUFVL2 in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 21. Pig and fish farming in PUFL2 farm in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 22. Pond after draining in PUFV2 in the municipality of N'djili in the urban area of Kinshasa (DRC)

Photo 23. Data collection of maggots production during the experiment in PUFVL2 farm in the municipality of Funa in the urban area of Kinshasa (DRC)

Photo 24. Migration of maggots during the growth experience

Photo 25. Harvesting of maggots after migration in plastic containers

Photo 26. Experimental design for maggots production in the farm

Photo 27. Seminar on fish feeding at the University of Kinshasa

Photo 28. Question-and-answer session during the training seminar on fish feeding at the University of Kinshasa

Photo 29. Workshop on integrated systems with finalist agronomist students at the University of Kinshasa