Smallholders' Practices of Integrated Agriculture Aquaculture System in Peri-urban and Rural Areas in Sub Saharan Africa

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Résumé :

Pratique des systèmes intégrés agriculture-aquaculture par les petits exploitants agricoles en zones urbaine et péri urbaine d'Afrique subsaharienne

La population de l'Afrique subsaharienne (ASS), qui devrait atteindre 1.998 millions en 2050, connaît une transition démographique avec un taux de croissance annuel moyen de 3,7% et une augmentation de la population agricole de 1,9%. Au cours de la même période, la production agricole globale n'a augmenté que de 2,6%. La satisfaction des besoins alimentaires devrait donc être réalisée en améliorant la productivité du travail des agriculteurs en ASS. En ASS rurale et périurbaine, la plupart des personnes sont de petits exploitants et ont des ressources limitées. Ils vivent de l'agriculture et pour relever les différents défis auxquels ils sont confrontés et accroître leur productivité, plusieurs stratégies ont été développées dans la recherche d'un modèle de développement agricole plus équitable, plus écologique et plus socialement viable. L'adoption du système intégré d'aquaculture agricole (IAA) s'inscrit dans ce cadre. Le système IAA a été adapté à l'Afrique subsaharienne en fonction de ses réalisations. L'adoption de l'IAA est particulièrement positive pour les agriculteurs dans des conditions topographiques permettant une variété d'activités dans l'exploitation agricole, y compris un étang de poissons. Les variantes du système IAA sont diverses formes d'adaptation aux pratiques agricoles de chaque région tropicale. Au cours de son application en Afrique subsaharienne, le système IAA a présenté des avantages ainsi que des inconvénients, mais surtout il ouvre à l'avenir des possibilités d'amélioration significative. Cet article passe en revue l'évolution de ce système intégré depuis son adoption en Afrique subsaharienne et élucide les forces, les contraintes et les opportunités futures de ce système.

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 labor productivity of farmers in SSA. In rural and peri-urban 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 to 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 integrated agriculture aquaculture system (IAA) fits in this framework. The IAA system has been adapted to SSA from Asia based on its achievements. The adoption of IAA is particularly positive for farmers in topographical conditions allowing a variety of activities within the farm including a fish pond. These variants of IAA system are various forms of adaptation to agricultural practices of each tropical region. During its application in SSA, IAA system has presented advantages as well as disadvantages but especially its opens to future opportunity for significant improvement. This paper reviews the evolution of this integrated system since its adoption in SSA and elucidates the strengths, constraints and future opportunity of this system.

Keywords : integrated agriculture aquaculture, livestock, vegetable, fish culture, farm, Sub Saharan African

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 (20). 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 (20). 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 (64). 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 (20). Land degradation caused by deforestation or overgrazing leading to nutrient depletion, soil erosion, salinization, pollution are also major issues in African agriculture (31). 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 fertilizers to replenish the soil (3). 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 (31). 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 form diversification, reduced and more even use of labour across seasons, reduced dependence on external inputs, mobilizable assets to purchase farm inputs, increased added value to agricultural by-products as feed ingredients (24). 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 production receives animal manure inputs (29).

In addition to the benefits provided by the fish itself; highly nutritious and valuable traditional food in most of Asian and Africa 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 of the problems associated with mulches and green manures (6). Pond water can be used for crops watering and livestock wastes as feed and fertilizer for 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 (14). The successful application of IAA systems has been reported in Asian and others 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 paper 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.

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 agroecosystem. In IAA, usually, a fish pond acts as fertility hub connecting with the other subsystems (13, 39).

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 (15).

IAA can be seen as systems in which at least three out of the five key principles of agroecology for animal farming systems are applied, namely

1. the decrease in inputs needed for production,

2. the decrease in pollution by optimizing the metabolic functioning of the farming system and

3. the enhancement of diversity within the animal production systems to strengthen their resilience (12).

IAA has been practiced traditionally for many years in South East Asia and Africa (51). 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 (14). 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 (26). 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 (52). 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 (29). In Africa, research on small-scale aquaculture was widespread in the 1980s and 1990s (4)

Integration of aquaculture with agriculture is more developed in Asia than in any other region of the world (14). 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 (47). Thus some companies intentionally selected species of fish, molluscs and crustaceans to increase the availability and production of protein from rice fields (53). 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 (40). With this progress, integration has taken a commercial mode where farmers excavate ponds near rice field and rear ducks on the ponds (58). Most farmers grow also 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, particularity protein, and increasing the overall incomes from an integrated farming system (58).

Since then, IAA becomes more appreciated by western countries due to a rapid increase in cost of high protein fish feed and inorganic fertilizer as well as the general concern for energy conservation (56). IAA increasingly being developed for more commercial, income generating purposes in both Asia and Western countries (25). 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 integration of aquaculture and irrigated farming systems to optimize the economic and environmentally sustainable use of existing energy, resources and infrastructure (25). 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 (7).

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 lie in factors such as the numbers of subsystems associated to fish ponds, the intensity of fish culture, the area of farm, the animal species reared and types of crop varieties used in association. The fish component 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.

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 (57). Hence, a survey conducted by Kinkela et al. (32) in the Democratic Republic of Congo revealed that, although 21% of the ponds are exploited alone, 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 to fish ponds, different variants of IAA farming can be identified in SSA: IAA with two subsystems with fish associate to crops or livestock (57, 60, 34) and IAA with three of more subsystems (32). 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%)	(38)
Subhumid warm tropics	Tanzania	Fish-crops	*Oreochromis niloticus*, *Clarias gariepinus*	*Brassica rapa chinensis*	-	(33)
Subhumid cool tropics	Rwanda	Fish-Livestock	*Oreochromis niloticus*	-	Rabbit	(59)
Semiaride warm tropics	Malawi	Fish-livestock-crop	Oreochromis niloticus, Oreochromis shiranus	Maize	Chickens, goat, pigs, rabbit, cattle	(4)
Subhumid warm tropics	Tanzania	Fish – crops	*Oreochromis niloticus*	Kale *Brassica* oleracea	-	(56)
Subhumid cool tropics	Zambia	Fish-Livestock	*O. andersonni*, *O. mossambicus*, *O. niloticus*, *Clarias gariepinus* and *Cyprinus carpio*	-	pigs and ducks.	(27)

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 (22). 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 (22). Carpe (Cyprinus carpio) is also cultivated in some areas but with 0.8%, 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 m2 fed with locally available, low-cost agricultural byproducts. Containment or holding facilities such as: concrete tanks, raceways, pens, cages and racks are less common (27).

Aquaculture in SSA is still facing various barriers despite the contribution of various governmental and NGO supported projects that benefited to smallholder farms and all the advances made in fish feed industry (27). 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, fertilizers, 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 (27). 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 (10).

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 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 (32). 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. (41) 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, (7) 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 Nhan et al. (45) 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 us pig manure, vegetable wastes and industrial by-product to produce fly larvae that are part of the natural diet of some farmed fish species (48, 38). 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 such as Black soldier (Hermetia illucens), Yellow mealworm (Tenebrio molitor), Super worm (Zophobas morio) and Housefly (Musca domestica) that may have potential can be reared wholly or partly on vegetable wastes such as carrots, green leaves, and plant stems (17).

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 (20). 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). (21). 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 (20). 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 (57, 4, 34, 32).

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 20 kg N, 10 kg P2O5 and 20 kg K2O, up to a maximum of 40 kg N, 20 kg P2O5 and 40 kg K2O (59). This situation remains until today a problem for SSA that see agricultural development and for smallholders in particular. Mineral fertilizer can be an alternative to solve soil depletion for agricultural development in SSA, who see agricultural use of mineral fertilizer progressing over the last years (2010 to 2015) from 1,556,981 to 1,752,379, from 723924 to 737,252, and from 406,934 to 450,468, in tone of total nitrogen, total nutrient phosphate P2O5 and total nutrient potash K2O, respectively (21). 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 shortages. 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 farm in dry water season since accessing water for productive agricultural use remains a challenge for millions of poor smallholder farmers in SSA (57). 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 (30).

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 (56, 39). In IAA, sediments at accumulating at the bottom of the pond are rich in organic matter, nitrogen and phosphorus (43). This sediment negatively impact 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 (5). High organic matter deposition may also increase biological oxygen demand, asphyxiating the fishes. Pond sediments can be recycled as fertilizers with production levels as high as 5 g C m-2d-1, corresponding to an equivalent production of 100 kg of dry manure ha-1 d-1 (34). (41) have measured after a cultured period of Oreochromis niloticus in pond fertilizer 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.

Pond outlet water quality varies with the type and the level of fertilization of the pond. When used for watering. 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 fertilizers and feeds, or other external nutrients, such as matter derived from soil erosion, run-off and leaching (62). 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 (18). Vegetables irrigated by water pond produce 1.8 times higher net yield than those irrigate with stream water, and pond water analysis show high 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) (34).

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 (49). 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 (49). In SSA, livestock production is dominated in term of animal heads by chicken (1,243,501×103), followed by goats (337,679×103), cattle (283,089×103), pigs (36,597×103), and ducks (11,160×103) (19). In Rwanda, DRC and Malawi, some small herbivores such as rabbits or Guinea pigs are also found (4, 37, 59). 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 (61).

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 (3). 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 consider as a local form of agro ecological production system (49). 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 to the majority of rural households (28). 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 animals manure as an important source of fertilizer in large part of African region (28). 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 (2). 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 crop system and allow 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 environment. Pond in IAA as other pillar among components offers possibility to use more manure as fertilizer and reduce environmental pressure. Water effluent is after effectively managed for multiples use including cleaning pigsties and watering animals (32). In Mekong Delta, it is demonstrated that 40 - 50 kg of organic fertilizer can produce 1kg of fish (45), and despite the large use of crop wasted in aquaculture, the best fish yield is obtained by use of manure in fish pond (>10 t/ha/year). (60) gives value of pond water in Rwanda with pond reared under 1,200 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 (47). 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 fertilizers. 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 culture of intermediate organisms such as fly larvae, duckweed or biogas to process livestock wastes (38). Although little popular, this strategy of processing pig manure into live feeds for fish has been used successfully by Nuov et al. (48) and allowed an 10-fold reduction in required pond area.

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 (53) 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.

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 (50). Research in India and Sri Lanka has shown that productivity on integrated farm can be high and the cost and risk of production low (44). 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. (11) showed that annual farm income of IAA farmers (185$) was on average 1.6 times higher than non IAA farmers (115$). (9) showed that with a Farmer-to-Scientist Research Partnership approach, average fish productivity of integrated Southern Malawian smallholdings (1,650 kg ha-1yr-1) areas was greater than other productive fish farms (1350 kg ha-1 yr-1). When facing severe droughts, (6) 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 (11). In

Tanzania the integration of fish ponds with vegetables produces 14 times higher net annual yields than fish alone (34). Fish cultured under the integrated system exhibited higher growth rates than those in non-integrated systems (64). In addition, in Egypt, Muendo et al. (42) show that using chicken manure in fish pond provide besides a high net fish yields, possibility to have sediment as good fertilizer for corn production.

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 (46). The environmental efficiency of IAA system depends on two groups of elements:

(i) the quantity and quality of fertilizers (nutrients profil) 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 environment pollution. Some of 4 Cameroon's categories IAA had eutrophication potential six times higher (kg P04-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 P04-cq 157 vs 23) (16). The appropriate polyculture increases the nutrients fixation in ponds (and improves the profit margins of aquaculture), hence decreasing the nutrient loading into natural water bodies that causes eutrophication (61). It can be conclude 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. (1) point out the fact that water use efficiency and water productivity in IAA treatments respectively (8.24 kgm-3; 10.3 $m-3) was higher than non-integrating treatment (6.83 kgm-3; 8.53$m-3) in the Bekaa plain in Lebanon conditions. Rukera Tabaro et al. (54) also show best resources, nutrient flow and water quality with integrated system.

In China, the rice--fish-farming system reduces the emission of CH_4 by nearly 30% compared to traditional rice farming (36). The result of Efole et al. (16) on 4 different integrated system in Cameroon are less positive. They show low 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. (41) show that fishponds can improve the nitrogen balance of farming systems in Africa.

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) (52), in Southern Brazil and Colombia (8, 33) but not enough in SSA. This chapter point out constraint and asset of adoption IAA system in SSA.

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 (51).

IAA system has been adapted in Africa to the context of African rural and peri-urban areas (32). 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 (15).

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 (14). Usually applied by smallholders in rural and peri-urban area, with limited resources 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 (11), 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 fertilizers as well as labor availability is also highly dependent on the size and resource endowment of the farming household (23).

Constraints of IAA adoption in SSA

Applications of 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 (35). Financial capital 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 rural and peri-urban areas generally produce for self-consumption or poor community with little access to markets. This partly explains low profitability of farms and unuse of external inputs such as mineral fertilizer 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. (14). High illiteracy among small-scale fish farmers combined to ignorance of the existence of IAA have been revealed as a major hindrance to the growth of integrated fish farming such as fish with Brassica rapa chinensis (34). 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 at the farm.

Adoption of IAA system in African countries and Tanzania in particular has been slow due to little rigorous empirical participatory research aimed at promoting IAA adoption in small-scale farmers' settings (34).

IAA system has disadvantages to use more labor than non IAA farmers and also a quality labor (50, 42, 11). The need of more labor in integrated farm was also emphasized by (55) in Northeast Thailand. The surplus of labor comes from fish production, collection and application of manure or crop residues, and extraction and use of pond sediment (50). Not many works undertaken in SSA have evaluated labor requirements in IAA. Muendo et al. (42) for example did not give any detail about the cost of additional labor in practice of IAA in the farm. It is probably because these labor activities have only short-term demands, e.g. for pond maintenance, mud harvest and spreading and fish harvest that might be made by family labor which are non-paid labor.

Future perspective

Farmers' decisions to adopt production systems such as fish with Brassica rapa chinensis integration are largely influenced by economic factors and dietary preferences (63). 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 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 (20).

Facing the competitive market, 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 (46). Being generally nutrient poor farms, any improvement in nutrient use efficiency is generally beneficial, even if according to Lu and Li (35), this strategy would tend to weaken 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 (35).

In term of activities, SSA small-scale farms can diversify activities in the farm adding various subsystems but as started above labor 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 (15). In this last case efficiency of resource use should to be assessed regionally, as an integrated resource flows occur 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 be done in the study of (34).

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 (45). 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 (9).

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.

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 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 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, whether they can be linked synergistically with other farm and non-farm activities and whether pond construction looks like dyke-pond system adapted to fish-cop integration (65). If 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 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 IAA system in SSA.

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