Integrated Aquaculture: A Tool for Sustainable Development/Food Security and Poverty Alleviation in Achieving MDG's Goals

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Abstract: Aquaculture is a multiculture of plants and animals in an aquatic environment. Thereby aquaculture is enriched through integration of formerly existing cultivation of crops cum horticultural, and /or agronomical or domesticated animals such as piggery, poultry, rabbitery or even wild domesticated animals such as guinea fowls, and cane rats. Hence, this study investigated integrated aquaculture cum horticulture as a possible tool for sustainable food production in order to ensure food security in Nigeria and alleviate poverty. The study utilized four homestead concrete tanks located at the back of my house in University of Ibadan senior staff quarters. Catfish bloodstock's males and females were used to raise fry through fingerlings to juveniles to adult fish. Data were taken at each stage of the fish life cycle i.e. the products harvested and sales. Data on numbers of horticultural trees planted were taken and numbers of produce at harvest were recorded. These data were collated and analyzed yearly and at the end of the 10- year period. The result showed that diversification in integrated aquaculture ensures better environmental and on farm resource management which is much needed globally but much more in the developing countries for food security and poverty alleviation. At each point in time, there is one product or the other available for consumption or for sale which ensured better cash flow. During the dry season the drought was ameliorated by the availability of water for wetting the crops and incorporation of vegetables growing into the system. Horticulture cum fish farming integrated system has been adjudged recently to be a solution to drought, poor soil condition management; climate change along with unsustainable water management and farming practices. This study showed that this system is more natural and sustains better food production practice. It is capable of bringing food production closer to urban consumers who do not have access for extensive farm land and reduces the transport cost in retail food marketing.
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1. Introduction

Aquaculture which is the farming of aquatic plants and animals is known and practiced for around 4000 years in some regions of the world (Iwama, 1991). However, in the mid-1980s, production of fish, crustaceans and shellfish by aquaculture has grown massively. Globally, aquaculture has become the fastest growing food production sector involving animal species. About 97% of the aquatic species presently cultured have been domesticated since the start of the 20th century (Duarte *et al*., 2007) and the number of aquatic species domesticated is still rising rapidly. It was recently estimated that aquaculture provides 43% of all the fish consumed by humans today (FAO, 2007). Production from aquaculture has increased from about 3.5 million tonnes in 1970 to more than 50 million tonnes in 2003, with most of this growth taking place in the developing world, which now accounts for more than 80 percent of global aquaculture production. This tremendous growth has provided a number of opportunities for greater food security, improved livelihoods and reduced poverty.

Aquaculture can be defined as the human cultivation of organisms in water (fresh, brackish or marine). It is distinguished from other aquatic production by the degree of human intervention and control that is possible. As such, it is in principle more similar to forestry and animal husbandry than to traditional capture fisheries. In other words, aquaculture is stock raising rather than hunting. The production process in aquaculture is determined by biological, technological, economic and environmental factors. Many aspects of the production process can be brought under human control. Environmental conditions can be controlled to a large extent, breeding programs undertaken, and harvesting timed to ensure continuous supplies of fresh product. This is in contrast to capture fisheries, which are controlled only through harvesting regulations, if at all. And while search for the resource is a very important part of the production process in capture fisheries, no such effort is required in aquaculture. A number of criteria can be used to classify an aquaculture system. From the economic point of view, the most significant criterion is its intensity, that is, its division into intensive, semi-intensive or extensive forms of culture. Measures of intensity include stocking density, production-by-area, feeding regimes and input costs, while the most interesting feature is the degree of control within the production process.

Integrated aquaculture is described in the Aquaculture glossary of the Food and Agriculture Organization of the United Nations (FAO, 2008) as: aquaculture system sharing resources, water, feeds, management, etc., with other activities; commonly agricultural, agro-industrial, infrastructural (wastewaters, power stations and so on.). According to FAO (2008), integrated farming systems as: the use of output from one subsystem in an integrated farming system, which otherwise may have been wasted, as an input to another subsystem resulting in a greater efficiency of output of desired products from the land/water area under a farmer's control. Using inexpensive and simple techniques, aquaculture can supply more protein than normally produced through conventional agriculture such as diary, poultry, cattle rearing and even traditional fishing. This is more so, judging from high cost of inputs necessary for running of any of the arm of conventional agriculture.

Integrated aquaculture is a combination of aquatic organisms, such as fish, culture with other forms of agriculture such as piggery, duck rearing, cattle, poultry, crops plantation (e.g. rice, plantain), in such a way that either some of the by-products of this forms of agriculture that are considered as wastes can still be reused as direct/ indirect consumption by fish or the revenue from such agriculture can be used to run fish production successfully and as well increase the total profit of the farmer/owner. The goal of integrated aquaculture is embedded in its benefits such as: low operating and maintenance cost; multiple uses of land that would otherwise have been useless; increased revenue; saves feeding cost; efficient cash flow i. e. revenue from other agricultural practices can be readily available for use in enhancing fish production; continuous harvests of both plants and animal in the same piece of land which also ensures continuous cash flow and more profits; labour efficiency and effective monitoring since both fish and other plants/animals are within the same range. Bioremediation is one of the most relevant and yet unvalued form of integrated aquaculture which has numerous benefits. Risk management is another advantage and profitable aspect of farming multiple species: a diversified product portfolio will increase the resilience of the operation, for instance when facing changing prices for one of the farmed species or the accidental catastrophic destruction of another crop.

1.1 Integrated Aquaculture as a Farming System

In developing countries, populations, incomes and urbanization are all increasing. As a consequence consumption of animal foods is growing fast. By 2020 developing countries will be producing 60% of the world's meat and 52% of the world's milk (Delgado et al., 2001). Aquatic food is an alternative animal protein source. It offers an excellent source of high quality, easily digestible protein. Aquaculture provides over 50% of total aquatic food production. Developing countries provide more than 90% of the global aquaculture production. In these countries, aquaculture plays an important role in the diets and livelihoods of many of the poor people (Van der Mheen, 2002; Roos et al., 2007).

Aquaculture can be integrated into many different farming systems via the use of multipurpose farm ponds and other water sources. Mathias (1998) defined integrated fish farming as integrated agriculture-aquaculture (IAA). It is based on fish culture in ponds which are closely integrated into the energy and nutrient pathways of conventional farming. Integrated farming systems with fish are often less risky than stand-alone fish farms because, if managed efficiently, they benefit from synergisms among enterprises (Pullin, 1998; Prein et al., 1998). The majority of rural households are smallholder farmers. Potential benefits from integrating aquaculture in smallholder farming systems include: enhanced rural employment and income through additional or off-season production; improved food security; increased availability of high-value protein food; decreased economic risk through diversification; improved water availability and nutrient recycling; environmental benefits through better on-farm natural resource management (Williams, 1997; Dalsgaard and Prein, 1999; FAO, 2000; Prein, 2002). The ponds can accept many forms of agricultural waste, including livestock manure and human excreta, and convert these wastes into high-grade fish protein. The pond sediment acts as a trap for excess nutrients, and prevents those nutrients from flowing into drainage waters. The sediment can be used to fertilize vegetable crops (Muendo, 2006) or grasses which are fed to livestock (Mathias, 1998), and restore soil fertility (Alibes, 2001). IAA systems represent one potential avenue towards sustainable forms of smallholder farming (Dalsgaard and Christensen, 1997; Dalsgaard and Oficial, 1998; Dalsgaard and Prein, 1999; Christensen et al., 2000).

Sustainable smallholder farming is indicative of the concern that in future current farming practices might endanger the continuity of farming systems. This concern expresses environmental, economic and societal demands on farming systems. The increase in food demands, changing consumer preferences and degrading resources in farming will continue to pose new challenges (Dixon et al., 2001). Intensification is a major strategy in meeting the increasing demands of animal products. The effects of intensification of farming activities on the environment are potentially worrisome (Delgado et al., 2001). The use of compound feeds is the major tool in intensification of aquaculture. It also involves different species of fish and higher stocking densities. IAA systems in general are labeled semi-intensive as opposed to extensive systems relying exclusively on natural feed without intentional inputs, and intensive systems depending on nutritionally complete feeds (and fertilizers) (Edwards, 1993).

Small-scale farming in rural areas worldwide is almost always done in a way which combines several production components. Different from large-scale monocultures, such as palm oil plantations or the production of sugarcane or wheat on hundreds of hectares, a typical smallholding produces different crops and vegetables, and rears livestock. Such farming systems are beneficial to the farmer for two main reasons:

i. Combining several production components decreases the risk element which agriculture entails. If one component fails, the other can provide the critical means for survival;

ii. The different components interact in a symbiotic and synergetic manner, enhancing overall production, optimizing resource use and thus providing for the subsistence needs of the household. Trees provide shade for crops and livestock while producing fruit; livestock manure is used as a fertilizer and crop by-products are fed to animals.

Smallholder farming systems have evolved over centuries. Their technological and socio-economic features are part of the indigenous knowledge of the social group for whose basic needs they provide. Over the years, farmers in foreign countries such as Asia and Europe have integrated pond culture into diverse farming systems using techniques which rely almost exclusively on the recycling of by-products from animal and crop production. Commonly used feeds include oilcakes and cereal bran while manure is used as pond fertilizer. Pond culture has a number of advantages, in terms of inherent production efficiency, over crop production and livestock rearing. The three dimensional aspect of a pond habitat offers a variety of ecological niches which can support numerous and diverse organisms. In China, a well-managed pond is stocked with more than eight different fish species all of which can grow well because they occupy different strata of the pond water and exploit these different nutritional niches. In addition, aquatic animals are cold-blooded and therefore expend more energy on growth rather than on the maintenance of body temperature. Also, they make use of both natural and added feeds.

There are several potential advantages that can be derived from integrating aquaculture with other smallholder farming system components. The diversification of farming systems to include aquaculture diminishes the risks associated with small-scale farming. This is because pond water not only yield fish, an edible and tradable commodity, but can also contribute to crop irrigation and livestock watering in the dry season, thereby increasing the viability of year-round production. The extra production from aquaculture can imply an increased availability of protein for household consumption. Alternatively, aquaculture products can be treated as a commodity which can be traded for cash or essential household items. Both strategies increase household economic security by increasing overall net benefits.

Certain plants which grow in ponds without additional inputs, such as azolla, duckweed or water hyacinth, can be used as green manure or compost to enhance soil fertility, or as fodder for fish and livestock. Also, seasonal or rain-fed ponds may be used for crop production when they fall dry during the dry season, using no additional water or nutrient sources. Rotations between aquaculture and agriculture have been shown to improve soils over time. The water in aquaculture ponds need not only serve to culture fish. In parts of South Asia, fishponds are used for bathing and irrigating homestead fruit and vegetables, others for disposing of domestic wastewater. As a source of irrigation water, pond water is usually richer in nutrients than well water and also contains nitrogen-fixing blue-green algae which can improve soil fertility. After the fish harvest, nutrient-rich pond mud can be used as fertilizer or the pond can be used to grow forage and other crops. In areas where seasonal water shortages occur, a pond can be vital for ensuring year-round crop production, livestock watering, domestic water supplies and fire protection. More so, where farm wastes are produced in significant quantities, their application into aquaculture ponds not only leads to a more efficient system, but prevents them from being disposed into the environment. Some forms of integrated aquaculture, such as rice-fish farming, can decrease if not eliminate the need for harmful pesticides. Some fish species not only eat rice pests but also disease carrying organisms of human health importance, such as mosquito larvae or snails. When appropriate fish species are stocked in rice fields, the feeding of the fish on weeds and algae, and their subsequent excretion, not only reduces the need for herbicides but also increases phosphorus and nitrogen levels in the water. This therefore reduces the requirement for chemical fertilizers. The integrated fish farming system holds great promise and potential for augmenting production, betterment or rural economy and generation of employment.

1.2 Integrated Aquaculture Systems

There are varieties of integrated aquaculture practices, these include:

a. Rice-Fish System: Scientific rice-fish systems can ensure higher productivity, farm income and employment in these areas. The rice fields which retain water for a fairly long duration and free from flooding are generally suitable for rice-fish integration. Some modification of rice-fish plot is required to make the system more profitable. Clay soil is suitable. A peripheral, trench is excavated around the rice growing area (width 3.5 - 4.0 m, depth 1.5 m) which is blocked at one place and connected to the main land for easy access for farmers and agricultural appliances to the rice plot. The rice plot may range from one acre to one hectare or more and preferably be rectangular or even square. A dyke is constructed all around. For a 1 ha plot area required for dykes, trenches, pond refuge and field will be:

Dykes 2000 sq. m. (20%)
Trenches and pond refuge 1300 sq. m. (13%)
Field 6700 sq. m. (67%)

b. Mushroom Cultivation in Conjunction with Aquaculture: Mushrooms are fleshy fungi and are the most preferred food item. References to their consumption as food and even medicine are recorded in the classical religious writings (Vedas, Bible, etc). The first record of mushroom cultivation was during 1638-1715. Most early advances on the extensive mushroom cultivation were made particularly in different parts of Europe. Being a source of most nutritious food, its alternative use in pickle preparation, medicines etc., also provides a good scope for possible job opportunities to many unemployed persons in the country.

c. Horticulture-Fish System: Ponds are well situated for this purpose. The top, inner and outer dykes of ponds as well as adjoining areas can be best utilized for horticulture crops. These crops are fertilized by the pond silt and fertile pond water is used for watering. The success of the system depends on the selection of plants. They should be of : Dwarf variety; Less shady; Evergreen; Seasonal; Highly remunerative

Dwarf variety of fruit bearing plants like mango, banana, papaya, coconut, lime can be grown around the pond. This will not obstruct the sunlight to the water bodies and also the pond will be free of dry leaves. Pineapple, ginger, turmeric, chilly can be grown as intercrops. Ponds dykes are used for growing vegetables solo as well as intercrops. During dry season, tomato, chilli, gourds, cucumber, melons, ladies finger is cultivated while during wet season peas, beans, cabbage, cauliflower, carrot, beet, radish, turnip, spinach, ethic etc. can be raised. Pond silt and pond water can be used for providing nutrient for these crops. Flower bearing plants like tuberose, rose, jasmine, gladiolus, marigold, cassandea, chrysanthemum are grown on the pond dykes. These flowers have tremendous market potential in the cities which provides additional employment to the farmers. Farming practices are carried out on broad dykes which can stand ploughing and irrigation. Ideal management involves utilization of the middle portion of the dyke covering about 2/3 of the total area for intensive vegetable cultivation and the rest on the areas along the length of the periphery through papaya cultivation keeping sufficient space on either side for netting operations. Semi intensive farming is done where the dykes are not good. Crops of longer duration like beans, ridge gourd okra, papaya, tomato, brinjal, mustard and chilli are suitable for such dykes. Narrow dykes are suitable for cultivating sponge gourd, sweet gourd, bottle gourd citrus and papaya. Where the dykes are shaded ginger ad turmeric can be cultivated.

Other aquaculture systems include:

d. Duck-Fish integrated system
e. Semi-Fish System
f. Livestock-Fish System
g. Rabbit-Fish system
h. Goats-Fish system
i. Poultry-Fish System

It should be noted that each system has its own management requirements. Most of the current integrated farms in South East Asia are operated in the traditional way without proper planning, modern technology or modern farm management techniques and rely on personal experience. Marketing is therefore a recurrent problem except in years where demand is sufficient. Fish disease constitute a further major problem with the farmers cannot solve by themselves since they have inadequate experience and knowledge, and such knowledge is not as readily accessible as with other farm animals where feed manufacturers or veterinary supply companies offer services to assist farmers in many cases. A further problem for farmers is the shortage of credit and working capital, which forces them to contact their produce sales to middlemen, usually at unfavorable prices.

1.3 Horticulture-Fish Integrated System

This form of agriculture is the integration of crop production (horticulture) with aquaculture. Toxic ammonia in fish tank effluent is converted by bacteria in a bio-filter to nitrites then nitrates, which, together with phosphates and trace elements, are taken up as nutrients by the plants grown either hydroponically directly in the water or in a soil matrix which is immersed in the water, allowing cleansed water to be recirculated back into the fish tanks. The combination of aquaculture with hydroponic systems is commonly known as aquaponics.

In effect, aquaculture-horticulture systems provide a balanced relationship between plants, fish and bacteria that mimics nature, while minimizing water consumption. These systems efficiently eliminate the need for inorganic fertilizers and prevent environmental pollution by the effluent from fish production.

Aquaculture-horticulture systems have been practiced in their modern forms for the last 30-40 years, but its origins can be traced to ancient Egyptian and Aztec cultures. The Aztecs developed man-made floating islands on lakes and canals called chinampas to cultivate maize and other plants together with fish in the water surrounding them. The fish waste that settled on the bottom of the lakes and canals were collected and used as fertilizer. Other ancient cultures such as those in Thailand and China have long used similar techniques by growing fish in rice paddies.

In Australia, this technology emerged in the 1990's and is growing rapidly off a small base due to on-going food production problems associated with drought, poor soil conditions and climate change along with unsustainable water management and farming practices. Aquaculture-horticulture system are increasingly recognized as more natural and sustainable food production systems capable of bringing food production closer to urban consumers and reducing the "food miles" component in retail food prices.

1.4 Objective

The overall objective of this 10-year study on integrated horticulture-fish system was to evaluate its profitability and as well assess the economic viability of the production system.

2. Methodology

Figure 1 below showed schematic layout of the farm where the study was carried out from 2001 to 2010. The fish production facility is a reinforced concrete tanks partitioned into four with dimension 3.5m x 2m x 1.5m each. Major fish cultured was *Clarias gariepinus* commonly known as mud catfish. Reservoir and rain water were the two main sources of water to the system. Fish production was throughout the year with better water supply during the rainy season. Varieties of horticultural plants such as Banana/Plantains, African apple, Coconut, Mango, Orange, Lemon, Pawpaw, Guava, Pineapple, bamboo, and cashew were cultured together on the same land area. The entire production system was subsistence. As previously discussed in the introduction, there is a symbiotic relationship between the fish which is of utmost priority and other plants. Waste water and slug from fish pond were used to irrigate and fertilize plants thereby providing additional nutrients for the plants. Banana trees and other shady plants not only provided shade for the fish cultured and more revenue. It was observed that there was a continuous cash-flow throughout the years. Money generated from horticulture was used to purchase input such as feeds for fish production – this made fish production easier without running out of funds.

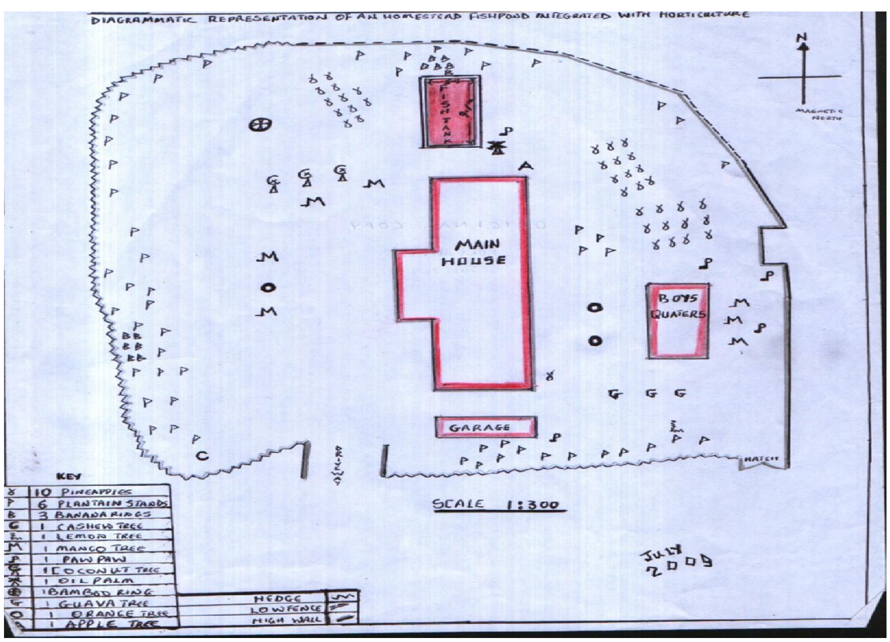

Figure 1: Schematic Layout of Horticulture Fish Integrated System.

Table 1: Summary of the Revenue Generated from the System for 10 years

	Year									
Income	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Egg/chicken	12600	29546	12500							
Horticulture	1275	15825	38568	53059	12640	6450	4945	8900	18810	34950
Honey	8080	59600	42550	30550	27300					
Fish sales	25340	38790	50150	245420	7800		158700	233490	227297	393990
Books					58425	7000	24000	23550	900	
Hand net								7000	2000	
Others	2600	16000	16390	11700						
Total income	**49895**	**159761**	**147658**	**340729**	**106165**	**13450**	**187645**	**272940**	**249007**	**428960**

Table 2: Summary of the Total Expenditure for 10 years

Expenditure	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Poultry/feeds	9509	21831	4351	13126						
Labour	1700	14410	7640	12220	14900	12000	10400	36000	43000	59000
Honey	2700	44400	13500	23550	16000					
Fish feed					7894		9570	128756	126010	192140
Equipment repairs					700		500		2000	
Hatchery							100700		4500	49480
Medicals							450		490	
Brooder stock/fing	8000			135000			53350	56500	47260	
Hand nets								10000		
Poultry cages	15000	59930								
Miscellaneous	13225			11600						12160
Total expenditu	**50134**	**140571**	**25491**	**195496**	**39494**	**12000**	**174970**	**231256**	**223260**	**312700**

Table 3: Cost-profit analysis of the production system

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Revenue	**49895**	**159761**	**147658**	**340729**	**106165**	**13450**	**187645**	**272940**	**249007**	**428940**
Expenditure	**50134**	**140571**	**25491**	**195496**	**39494**	**12000**	**174970**	**231256**	**223260**	**312780**
Gross margin	-239	19190	122167	145233	66671	1450	12675	41684	25747	116160

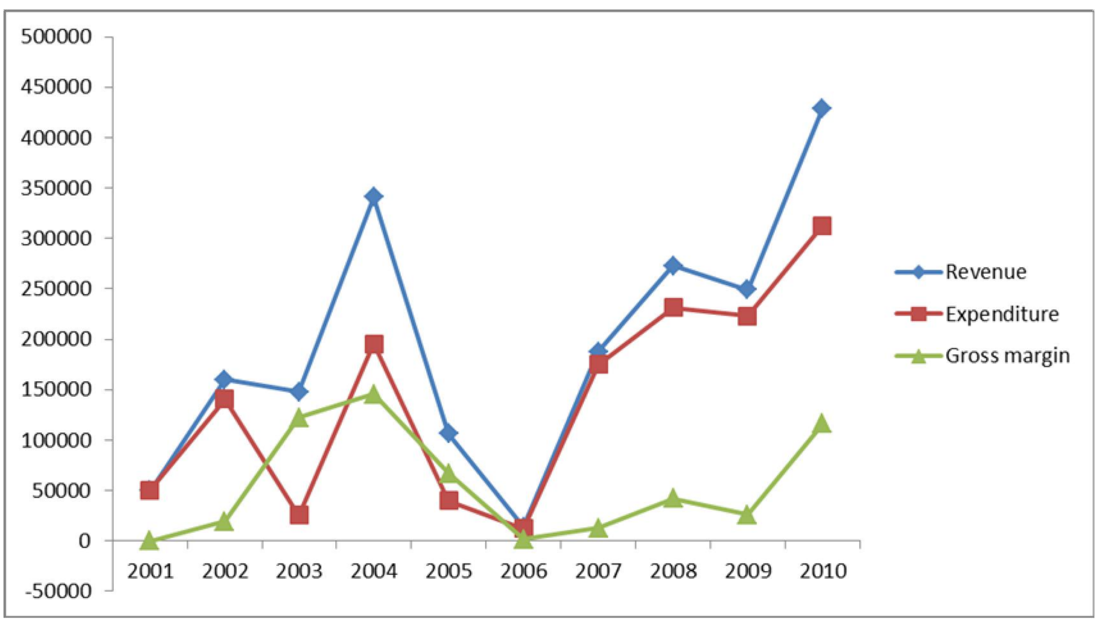

Figure 2: Graphical representation of cost benefit analysis of horticulture-fish integrated system

3. Results and Discussion

3.1 Economic viability of the system

The system though practiced extensively, Returns Over Investments(ROI) generated annually were 12.01%-2002, 82.74%-2003, 22.67%-2004, 62.80%-2005, 10.78%-2006, 6.75%-2007, 15.27%-2008, 10.34%-2009, 27.08%-2010 as presented in Tables 1, 2 and 3. In 2003, the ROI was 82.74% (very high) as a result of multiple integration of horticulture, poultry, honey and fish together. Integration of horticulture and fish together gave a ROI of 6.75% - 27.08% which was quite high, while with honey inclusive gave 62.80% in 2005. Integrated (horticulture)-aquaculture practice fetched about 6-27% higher returns compared to aquaculture alone besides generating employment opportunity round the year. In addition to extra crops and extra income, there was biologically control of weeds as the land areas were fully utilized. In Table 2, and in the year 2002, the introduction of poultry accentuated production of protein for sale, home consumption and profit margin but there was increased un-reported and un-paid family labour utilization. .It had to be discontinued because of the strain on other family needs. However it should be reported that it was a profitable addition to the project

3.2 Challenges of Integrated system

Most of the current integrated farms in South East Asia are operated in the traditional way without proper planning, modern technology or modern farm management techniques and rely on personal experience. Marketing is therefore a recurrent problem except in years where demand is sufficient. Fish disease constitute a further major problem which the farmers cannot solve by themselves since they have inadequate experience and knowledge, and such knowledge is not as readily accessible as with other farm animals where feed manufacturers or veterinary supply companies offer services to assist farmers in many cases. A further problem for farmers is the shortage of credit and working capital, which forces them to sell their produce to middlemen, usually at unfavorable prices.

4. Conclusion and Policy Implications

The result of this project as indicated by Fig 2 shows that the Gross margin kept rising except for the years that the researcher went on sabbatical leave (2005- 2006). In Table 1 -the margin between income and expenditure was accentuated when activities on fish production was increased in (2009 -2010). As the horticultural trees are ageing, and the aquaculture aspects was intensified, the profit margin increased. If increased fish production is encouraged, the farmer's income will increase and his poverty level will be reduced while concomitantly there will be more protein available for the farmer's family, his associates and the community at large especially in the urban areas. And if the farmer's production is replicated by hundreds of farmers we are getting nearer the million goal. Fish is higher in protein content than other animal protein sources. Increase of food supply to cope with the high rate of population especially in urban areas requires much more than an increase in agricultural land. Land is a limited resource and if more land is used in agriculture, the forest will be depleted to a degree that will be harmful to the environment. Correspondingly, the cost of production of food will rise. Therefore, a method is needed to produce more food from existing agricultural land, and integrated farming offers a possible solution.

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References

1. Alibes, M. B. (2001. Livestock in integrated fish farming systems. MSc thesis. Animal Sciences Department, Wageningen University, Wageningen.
2. Christensen, V., Walters, C.J., Pauly, D. (2000). Ecopath with Ecosim: A user's Guide. Fisheries Centre, University of British Columbia, Vancouver, Canada and ICLARM, Penang.
3. Dalsgaard, J.P.T., Oficial, R.T. (1998). Modeling and analyzing the agro-ecological performance of farms with ECOPATH. ICLARM Technical Reports 53. International Center for Living Aquatic Resources Management, Manila.
4. Dalsgaard, J.P.T., Prein, M. (1999). Integrated Smallholder Agriculture-Aquaculture in Asia: Optimizing Trophic Flows. In: Smaling, E.M.A.; O. Oenema; L.O.Fresco (Eds.) Nutrient Disequilibria in Agro-ecosystems. Concept and

Case Studies. CABI Publishing. CAB International, Wallingford, Oxon, pp. 141-155.
5. Dalsgaard, J.P.T., Christensen, V. (1997). Flow modeling with ECOPATH: providing insights on the ecological state of agro-ecosystems. *In* P.S. Teng, M.J. Kropff, H.F.M. ten Berge, J.B. Dent, F.B. Lansigan and H.H. van Laar (Eds.) Applications of Systems Approaches at the Farm and Regional Levels, 203-212. Kluwer Academic Publishers, Dordecht.
6. Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., Courbois, C. (2001). Livestock to 2020: the next food revolution. Outlook Agric. 30: 27-29.
7. Dixon, J., Gulliver, A., Gibbon, D. (2001). Farming Systems and Poverty. Improving Farmers' Livelihoods in a Changing World. FAO and World Bank, Rome and Washington.
8. Duarte, C.M., Marbá, N. And Holmer, M. (2007). Rapid domestication of marine species. Science 316. (5823): 382-383.
9. Edwards, P. (1993). Environmental issues in integrated agriculture -aquaculture and wastewater-fed culture systems. In: Pullin, R.S.V., Rosenthal, H., and Maclean, J.L. (Eds.) Environment and Aquaculture in Developing Countries. ICLARM Conference Proceeding 31, pp. 139-170.
10. Edwards, P. (1998). A systems approach for the promotion of integrated aquaculture. *Aquaculture Economics & Management* **2** (1): 1-12.
11. FAO, Food and Agriculture Organization of the United Nations (2008). *The State of the World Fisheries and Aquaculture FAO, Rome Italy.*
12. FAO (2007). The state of world fisheries and aquaculture 2006. FAO Fisheries and Aquaculture Department. Food and Agricultural Organization of the United Nations, Rome, Italy. 162 pp.
13. FAO (2000). Small ponds make a big difference. Integrating fish with crop and livestock farming. Farm Management and Production Economics Service Inland Water Resources and Aquaculture Service. FAO, Rome.
14. Iwama, G. K. (1991). Interactions between aquaculture and the environment. *CRC Critical Reviews in Environmental Control.* 21(2):177–216.
15. Mathias, J. (1998). Integrated fish farming in the context of world food security. In: Mathias, J.A.; Anthony T. Charles; Hu Baotong (Eds.) Proceedings of a Workshop on Integrated Fish Farming held in Wuxi, Jiangsu Province, People's Republic of China. October 11-15, 1994. CRC Press. Boca Raton, New York, pp. 3-18.Pullin, R.S.V. (1993). An overview of environmental issues in developing country aquaculture. *In:* Pullin, R.S.V, Rosenthal, H. and Maclean, J.L. (eds) pp. 1-19. *Environment and aquaculture in developing countries*. ICLARM Conf. Proc. 31, 359 p.
16. Muendo, P.N., (2006). The role of fish ponds in the nutrient dynamics of mixed farming systems. PhD thesis. Wageningen University, Wageningen.
17. Prein, M., Lightfoot, C., Pullin, R.S.V., (1998). ICLARM's approach to the integration of aquaculture into sustainable farming system. In: ADB/NACA Report on a Regional Study and Workshop on Aquaculture Sustainability and Environment. Network of Aquaculture Centres in Asia, Bangkok, Thailand and the Asian Development Bank, Manila, pp. 257-265.
18. Prein, M, (2002). Integration of aquaculture into crop-animal systems in Asia. Agric. Syst. 71: 127-146.
19. Pullin, R.S.V., (1998). Aquaculture, integrated resources management and the environment. In: Mathias, J.A.; Anthony T. Charles; Hu Baotong (Eds.) Proceedings of a Workshop on Integrated Fish Farming held in Wuxi, Jiangsu Province, People's Republic of China. October 11-15, 1994. CRC Press. Boca Raton, New York, pp. 19-42.
20. Roos, N., Wahab, Md. A., Chamnan, C., Thilsted, S.H., (2007). The Role of Fish in Food-Based Strategies to Combat Vitamin A and Mineral Deficiencies in Developing Countries. American Society for Nutrition, J. Nutr. 137: 1106-1109.
21. Van der Mheen, H., (2002). Integrated Aquaculture and Irrigation for Improved Food Security. ALCOM/FAO. Available at: www.fao.org/fi/alcom/alc25ar1.htm
22. Williams, M. J., (1997). Aquaculture and Sustainable Food Security in the Developing World. In: John E. Bardach (Ed.). Sustainable Aquaculture. John Wiley & Sons, Inc., New York, pp. 15-51.

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