The role of fish ponds in the nutrient dynamics of mixed farming systems

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The role of fish ponds in the nutrient dynamics of mixed farming systems

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To my husband, Robert Muendo, and our daughter, Victoria Mueni

&

To mum, Annah Mbaika, and dad, William Mwau

Contents

Chapter 1

General introduction

Background

Food security remains a major global challenge as the world population continues to increase. Recent projections indicate a 32% increase in the world population between 1995 and 2020 (Badiane and Delgado, 1995; Rosegrant et al., 1995). Over 97% of the increase will be in the developing world and the relative increase will be greatest in Africa, where the population will increase by 70% (Rosegrant et al., 1995).

Because of an increasing demand for higher food production to feed the growing population, Africa is under high land pressure. Most of the arable land has already been sub-divided to the smallest land holdings (Thomas, 1988) and further intensification of agricultural production has been through conversion of marginal lands, such as forest reserves and river banks, into arable land (Okoba, 2005). This has resulted in increased soil degradation and further threatens food production, and impedes attainment of food security (Thomas, 1988; Stoorvogel et al., 1993). Inorganic fertilizers, that are essential for replenishing soil nutrients and improving productivity, are unaffordable (Thornton et al., 1995) and recycling of agricultural by-products (such as returning crop residues and animal manures) to cropped lands is constrained by a temporal mismatch between availability and application.

Phased with high population pressure and nutrient limitation for higher food production, farming communities in rural Asia integrated aquaculture into their agricultural farming systems (Little and Muir, 1987). The integrated aquaculture - agriculture (IAA) systems have led to improved agricultural waste resource utilization efficiency, enhanced soil fertility, and increased food production in resource-poor smallholdings (Ruddle and Zhong, 1984; Jensen, 1993). As such, they are potentially a sustainable method of increasing food production for resource constrained farmers in Africa, in an environmentally friendly manner. IAA systems have only been applied in a few countries in Africa (Central African Republic, Cote d'Ivoire, Cameroon, Zambia, Congo and Malawi) for which also improved farm productivity and soil fertility have been reported (Jamu and Piedrahita, 1995; Brummett and Noble, 1997;Dalsgaard and Oficial, 1997). Their promotion for wider adoption in both Africa and Asia is hampered by lack of insight in the nutrient dynamics of the IAA systems, and hence insufficient knowledge how system components interact and mutually benefit each other (Hopkins and Bowman, 1993; Lin and Yi, 2003).

Fish ponds have a pivotal role in the nutrient dynamics of the IAA systems since organic amendments are converted into fishes, shrimps or aquatic plants, and nutrient-rich pond sediments can be recycled as fertilizer for agricultural crops (Jamu and Piedrahita, 2002; Chikafumbwa, 1996). However, in many integrated farming systems, the aquaculture component does not recycle nutrients to the agriculture component while it receives nutrients from the crop and animal components (Brankeret, 1979; Hopkins and Bowman, 1993; Pillay, 1994). Yet, a large proportion of nutrients (30 – 95%) contained in fertilizers and feeds applied to fish ponds is trapped and accumulates in the pond sediments (Wahab and Stirling, 1991; Boyd, 1992; Funge-Smith and Briggs, 1994; Smith, 1996). When pond sediments are removed and disposed during pond servicing, the nutrients pose a threat to the environment (Avinmelech and Ritvo, 2003). Reutilization of the trapped nutrients as fertilizer in the crop production component, would improve the overall resource efficiency (Lightfoot et al., 1993; Pullin, 1998).

Objectives of this thesis

The major objective of the study, is to explore the use of ponds as nutrient traps (besides fish production) to increase nutrient use efficiency in integrated farming systems. It focuses on (i) nutrient utilization efficiency of agricultural by-products such as crop residues and animal manure for fish production, and (ii) quantitative aspects of sediment and nutrient accumulation in aquaculture ponds, and pond sediments potential as a fertilizer in land-based agriculture.

Thesis outline

Based on available literature data, **Chapter 2** conceptualizes the integration of fish ponds in African farming systems, explores the use of the ponds to trap and retain nutrients from erosion, leaching and from farm residues, and evaluates and quantifies the effect of fish pond integration on farm output and soil fertility.

IAA systems rely heavily on the use of agricultural by-products for fish production. Although agricultural by-products have been used for aquaculture production, they are said to result in low fish yields, and often the use of supplemental feeds is recommended, to boost productivity (Diana et al., 1991; 1994). However, supplemental feeds are costly and are often a reason for many farmers not to engage in aquaculture (Omondi et al., 2001). In **Chapter 3,** the nutrient utilization efficiency of agricultural by-products in the pond system was investigated and compared to that of supplemental feeds. Ecological processes that result in food availability for fish in organically fertilized ponds and in feed-driven ponds were explored and compared. Attention was given to water and sediment quality and important processes affecting fish growth and pond yields were identified.

The feed back of nutrients from the pond to land-based agriculture is the key process in IAA systems. Although sediment accumulation and nutrient retention in pond sediments have been reported (Wahab and Stirling, 1991; Boyd, 1992; Funge-Smith and Briggs, 1994; Smith, 1996)**,** quantitative data on sediment and nutrient accumulation in aquaculture ponds and its potential as an agricultural nutrient input is still minimal (Lin and Yi, 2003). **Chapters 4** and **5**, are dealing with sediment and nutrient accumulation in aquaculture ponds. In chapter 4, the quantity of sediment accumulation within one culture period was estimated, accumulation rates and sediment sources were described, and nutrients, in the accumulated sediment, potentially available to fertilize crops, were quantified

Nutrient losses through water seepage reduce the quantity of nutrient accumulation in aquaculture ponds and hence those available for recycling in agriculture (Jamu, 1998; Teichert-Coddingtion, 1989). Due to lack of methods for sampling seepage water in ponds, pond nutrient losses due to seepage are commonly under-estimated (Muendo et. al, 2005), which may result in over-estimation of nutrient accumulation in pond sediments. In **chapter 5**, a standard method for sampling seepage water in ponds was described.

In **Chapter 6**, an overall discussion concerning the feasibility, the potentials and practical implications of IAA systems is presented.

Chapter 2

Ideotyping integrated aquaculture systems to balance soil nutrients

Abstract

Due to growing land scarcity and lack of nutrient inputs, African farmers switched from shifting cultivation to continuous cropping and extended crop area by bringing fragile lands such as river banks and hill slopes into production. This accelerated the decline of soil fertility caused by erosion, harvesting and insufficient nutrient replenishment. The feasibility to reduce nutrient depletion by increasing nutrient utilization efficiencies, while diversifying and increasing food production through the development of integrated aquaculture – agriculture (IAA), was explored. Considering the climatic conditions prevailing in Kenyan highlands, aquaculture production scenarios were ideotyped by agro-ecological zone. These aquaculture production scenarios were integrated into existing NUTrient MONitoring (NUTMON) farm survey data sets for Kenyan highlands and the nutrient balances and flows of the resulting IAA-systems were compared to the present land use situation. The effects of IAA development on nutrient depletion and total food production were evaluated. With the development of IAA systems, nutrient depletion rates dropped 23 – 35%, agricultural production increased 2 – 26% and overall farm food production 22 – 70%. The study demonstrated that from a bio-physical point of view, the development of IAA-systems in Africa is technically possible and could raise soil fertility and total farm production. Further studies that address the economic feasibility and impacts on the livelihood of farming households are recommended.

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1.0 Introduction

Loss of soil fertility is a major setback in agricultural production in Africa (Stoorvogel et al., 1993; Gruhn et al., 2000). While on average nitrogen losses of 22 kg ha^{-1} $year^{-1}$ have been estimated for sub-Saharan Africa (Stoorvogel et al., 1993), up to 76 kg ha^{-1} $year^{-1}$ of nitrogen losses have been reported for arable lands in various African countries (Shepherd et al, 1995, 1996; Nandwa and Bekunda, 1998; Wortmann and Kazizi, 1998; Shepherd and Soule, 1998; Baijukya and De Steenhuijsen Piters, 1998; Defoer et. al., 1998; Mohamed-Saleem, 1998).

Nutrient losses to erosion, in combination with nutrient removal through cropping and insufficient nutrient inputs, have contributed to the observed decline of soil fertility (Kumwenda et al., 1996; Mango, 1996; Gruhn et al., 2000). Growing land scarcity has led to increased utilization of land for cultivation resulting in a decline in fallowing, previously used for soil nutrient replenishment (Mango, 2002). Grazing areas have also been cleared for cultivation leading to a decline in cattle population and less manure availability for soil nutrient replenishment (Mango, 2002). Nutrient replenishment through application of inorganic fertilizers is constrained by high costs that make them unaffordable to most farmers (FAO, 1995, Nandwa and Bekunda, 1998; Gruhn et al., 2000). With the land shortage, and lack of nutrient inputs, farmers intensify crop production through reliance on continuous cropping and other inappropriate land use practices, such as cultivation on river banks and hill slopes, which increase susceptibility of the land to erosion (Thomas, 1988).

To reduce the ongoing nutrient depletion, research attention is shifting towards technologies that allow for more efficient recycling of available organic nutrient resources, and that result in conservation of existing soil nutrient resources, e.g interception of erosion and leaching (Reijntjes et al., 1992; Smaling, 1993, Buresh et al., 1997; Nandwa and Bekunda, 1998). Unfortunately, re-utilization of farm organic residues is constrained by temporal mismatch between availability and application (Prein, 2002). When available, residues are stored through composting for later use at the appropriate time. However, in the process of composting, high nutrient losses occur through gaseous emission (Karlsson and Jeppson, 1995; Eghball et al., 1997) and nutrient leaching (Petersen et al., 1998; Sommer, 2001). Nitrogen losses of 5 - 77% during composting have been reported (Martins and Dewes, 1992; Eghball et al., 1997; Petersen et al., 1998; Thomsen, 2000). Higher efficiencies in nutrient recycling can potentially be achieved through diversification of African farming systems and incorporation of additional farm activities (Stoorvogel and Smaling, 1990, Buresh et al., 1997).

In Asia, such diversification of farming systems has been practiced in integrated fish – livestock – crop systems. Crop, vegetable wastes and livestock droppings are used as fish pond inputs and when silt gradually makes the pond shallow it is removed and thrown on the dykes. Vegetables, crops, and fruits are successfully planted on these dikes. Nutrient dynamics and sustainability of such integrated systems are yet to be studied in more depth, but increased profits from fish, animal and crop production, due to reduced costs of feeds and chemical fertilizers, have been reported (Little and Muir, 1987; Prein, 2002).

In Africa, ponds are still a rare component of local farming systems. Development of integrated aquaculture-agriculture (IAA) systems in African farming could contribute to reduction of the ongoing nutrient depletion. If ponds are located in low lying areas of the farm, they can trap run-off water and sediments rich in nutrients and utilize crop and animal residues year-round. Pond sediments can subsequently be used at any time as an on-farm crop fertilizer and improve on-farm nutrient retention and utilization efficiencies. They would not only serve to combat nutrient depletion, but would also improve household nutrition and income by adding a new protein source to the diet which in addition is a potential cash crop.

This paper explores the feasibility of integrating fish ponds in African farming systems. Based on existing farm survey data sets available from extensive NUTrient MONitoring (NUTMON) studies in Africa (De Jager et al., 1998; Bosch et al., 1998a; 1998b), and using Kenyan highlands as a case study, an aquaculture component (fish pond) was ideotyped within existing farming systems. Nutrient balances of the resultant ideotype IAA systems were calculated and in comparison with those of the existing farming systems, the effects of fish ponds integration on nutrient depletion and food production were evaluated and quantified. The study focused on nitrogen because it is the major critical element limiting productivity in both aquatic and terrestrial environments in Africa (Vitousek et al., 1997; Shepherd and Soule, 1998), and is closely linked with the overall soil condition, including organic matter content (Sekhon and Meelu, 1994).

2.0 Materials and methods

2.1 Study area

In 1997, a NUTMON study was carried out in Embu district in the Eastern Province of Kenya (00^0 8’ and 00^0 50’ South and longitude 37^0 3' and 37^0 9' East) (Bosch et al., 1998b). The district rises from about 515 m above sea level at the River Tana Basin in the east to 4,570 m on the top of Mt. Kenya in the North-West. It is characterised by hills and valleys to the northern and eastern parts and steep slopes at the foot of Mt. Kenya. Variations in altitude, rainfall and temperature between highlands and lowlands, coupled with differences in geology, result in different agricultural potentials. Average rainfall increases with altitude from 640 mm to 2000 mm year^{-1}. The upper highland areas are cool, wet and steep and forestry is the main land use while in the lower highlands, coffee and tea are grown. In the low lying areas, cash crops such as cotton and tobacco and food crops such as maize and millet are grown and livestock is kept. The district shows the typical agro-ecological profile of the windward side of Mt. Kenya. Five agro-ecological zones were identified in previous studies (FURP, 1987) and the present study covers those 5 zones (Table 1).

Table 1: Characteristics of the 5 agro-ecological zones (AEZ)

Characteristic	AEZ				
	1	2	3	4	5
Altitude	1770	1590	1320	980	830
Annual mean temp (^{0}C)	16,8	18,2	20,2	21,4	22,6
Annual average rainfall (mm)	1750	1400	1200	900	800
Main soil types	Andosol/Nitosol	Nitosol	Nitosol	Nitosol/Combisol	Arenosol

2.2 NUTMON

The NUTMON toolbox was developed as a monitoring tool for soil nutrient balances. The toolbox allows for monitoring actual nutrient flows on the farm and to calculate soil nutrient balances. The balances are based on an accounting exercise in which the net balance equals the sum of the nutrient inputs minus the sum of the outputs. Table 2 provides an overview of the various inputs and outputs considered. The farming system is subdivided into a number of compartments including

a. the primary production units (PPU’s) which include fields with crops or grassland,
b. the secondary production units (SPU’s) which include the animals on the farm,

c. the household (HH) defined as the actual household with all the people that spend a significant amount of time on the farm,
d. the redistribution units (RU) which are locations within the farm where nutrients are collected or accumulated and from where nutrients are redistributed over the farm (including *e.g.* garbage heaps and stables),
e. the stock which allows for temporary storage of e.g. crop products and fertilizer on the farm.

During monitoring the various nutrient flows that are management-related are recorded. This includes IN 1, IN 2, OUT 1, and OUT 2. Other flows are not recorded and will have to be estimated in a later stage using simple transfer functions or models. The NUTMON-toolbox makes calculations for the various compartments and the sum of the various compartments yields the farm balance.

Table 2: Nutrient inputs and outputs

Nutrient inputs		***Nutrient outputs***	
IN 1	Mineral fertilizer	**OUT 1**	Crop product
IN 2	Organic fertilizer[1]	**OUT 2**	Crop residues[2]
IN 3	Atmospheric deposition	**OUT 3**	Leaching
IN 4	Nitrogen fixation	**OUT 4**	Denitrification
IN 5	Sedimentation	**OUT 5**	Erosion

[1] including feeds, organic fertilizer, external grazing, and imported food

[2] including crop residues but also manure from the SPU and grass through grazing.

2.3 NUTMON data, Embu district, Kenya

For the main agro-ecological zones in Embu province, out of 3 farms per AEZ presented in the NUTMON study, one representative farm was selected. This resulted in 5 farms, one per agro-ecological zone, that were evaluated. Each representative farm had a cropping pattern and management representing general farming practices in its AEZ (as observed in the NUTMON surveys).

On a typical farm, up to 14 different PPU's and 5 different SPU's would be observed, each one with its own intrinsic properties. For this explorative exercise the various PPU's were aggregated into a single overarching PPU. Similarly, the SPU's and RU's were aggregated. For the long term evaluation in this manuscript we assumed the stock and the HH to be constant. They were therefore excluded from the analysis. As a result, the farming system was described by three compartments, the PPU, SPU and RU.

2.4 Data analysis

NUTMON analyses yield inputs and outputs to the PPU in terms of *e.g.* crop products, fodder, and grass. However, the relationship between the various inputs and outputs is not dynamic. Although the NUTMON-toolbox is a valuable tool in evaluating farming systems under all kind of agro-ecological conditions, that allows people to determine where major losses of nutrients take place and to get a better understanding of the farming system, it does not include the required feedbacks that would allow for evaluation of alternative interventions. As such, the existing NUTMON methodology does not serve the purposes of this manuscript to ideotype a farming system comprising a fish pond. To do so, feedbacks necessary to dynamically model the farming system were incorporated in NUTMON. Here, we report on the various adaptations that were made to the standard NUTMON methodology (De Jager et al., 1998; Bosch et al., 1998a; 1998b).

- For the aggregated PPU we derived a number of basic properties: the current productivity, the harvest index, average nitrogen concentration of inputs and outputs, and the level of inputs. Crop growth simulation is often described as the exponential relationship between nutrient availability (N_{avail}) and nutrient uptake (N_{uptake}). Nitrogen availability was calculated on the basis of soil nitrogen contents, bulk density, and estimated mineralization rates plus nitrogen supplied through the various inputs. Subsequently, we defined the following exponential model:

$$N_{uptake} = c_0 + c_1 \cdot e^{-c_2 \cdot N_{avail}}$$

  The three constants were estimated using the observed nitrogen uptake in the system and an assumed 50% nitrogen use efficiency for the current systems which corresponds to the results of the large fertilizer use recommendation program (Smaling et al, 1992).

- The current efficiency of the various redistribution units is set at 30% corresponding to the observed rates (ratio of nitrogen input and output) in various Kenyan studies (Rufion et al., 2006).
- While making changes in the farming system, the secondary production unit is maintained (in other words the number of animals is kept constant). Lack of food is compensated for by external feeding. A surplus of food enters the redistribution units and will leave as part of the farm yard manure. This is often observed in the extensively managed 'bomas' (animal stables) where crop residues are left on the ground and mix with manure. Note that feeding requirements have been defined in NUTMON and were kept the same.

Management decisions in terms of use of e.g. crop residues are derived from the initial datasets and flows are redefined in percent terms. For example, part of the crop residues may be incorporated in the soil, another part may be fed to the animals, and finally a fraction may be sold. The fractions are calculated as observed in the system and kept constant even if the total production of residues increases or decreases.

2.5 Ideotyping fishponds

In idiotyping fish ponds for potential integration in the farming systems, the following further adaptations were made.

- Immediate re-utilization (in fish ponds) of nutrients that accumulate in the RU is expected to result in reduced nutrient losses from the RU due to reduced storage period and improve the RU efficiency. As such, the efficiency of the RU was re-set at 60% (Lekasi et al., 2001, Woomer et al., 1998; Kirchman, 1985).
- To increase nutrient use efficiency, 70% of nutrients from RUs, currently applied to PPUs, were re-allocated to fish production assuming their compensation on re-utilization of enriched pond sediment on crop fields.
- The sum of the nutrients that became available due to increased RU efficiencies and the 70% re-allocated from PPUs was set as the quantity of nutrients available in the farm for aquacultural use. Based on a reported nitrogen application requirement rate of 4 kg ha^{-1} day^{-1} in tropical fish ponds (Knud-Hansen et al., 1993), and assuming a 12 month culture period, the size of fish pond that can be supported with the available nutrients was determined.

- Interception of nutrients contained in eroded sediments by the fishpond was set at 50%, an average drawn from reported rates of 21 – 100% sediment trap efficiency by small retention ponds constructed on drainage ways of cropped fields (Fiener et al., 2005; Verstraeten and Poesen, 2001; Renwick et al., 2005)
- Annual atmospheric nitrogen deposition in ponds was calculated following the NUTMON calculation as $0.014 * \sqrt{\text{rainfall}}$(in mm/yr).

Based on averages of pond nutrient flows for semi-intensive tropical ponds available in literature, pond nutrient balances were calculated as follows:

(i) Nitrogen fixation of 24 mg N m^{-2} day^{-1} (Acosta-Nasser et al, 1994),

(ii) Nitrogen retention in fish as 20% of total pond nitrogen input (Green and Boyd, 1995; Acosta-Nasser et al, 1994)

(iii) Nitrogen accumulation in pond sediments as 65% of total pond nitrogen inputs (Acosta-Nasser et al, 1994),

(iv) Denitrification, volatilization and leaching as 10% of nitrogen inputs (Briggs and Funge-Smith, 1994; Lorenzen et al., 1997; Gross et al., 2000),

(vi) Nitrogen content of drainage water as 5 % of input nitrogen (Green and Boyd, 1995).

2.6 Effects of fish pond integration

After fish pond integration, the IAA farming system would be described by 4 components, the PPU, SPU, RU, and Fish Pond (FP). Nutrient balances of the ideotyped IAA-systems were calculated considering the various inputs and out puts listed in Table 2 (section 2.2), assuming:

- Incorporation of pond sediment nutrients in PPUs (IN 5) is 100%
- Incorporation of nutrients contained in drainage water from ponds (for irrigation purposes) is 50% and is included in the PPU balance (combined with pond sediment) as IN 5 (sedimentation)

Nutrient depletion rates and overall food production in the ideotyped IAA-systems were compared with those in the existing farming systems and the differences were evaluated and quantified.

3.0 Results

3.1 Nutrient balances of existing farming systems

In the nutrient balances of existing farming systems (Table 3), the major nutrient inputs to the PPUs are mineral and organic fertilizers, while crop products, crop residues, leaching and erosion are all major nutrient outputs, the magnitude of each varying between farms. The sources of the organic fertilizer input to the PPUs include the RUs and household wastes (organic fertilizer input – RU crop residue output). The majority of the crop residues from the PPU are recycled as organic feeds to the SPUs and the remainder is incorporated into the fields or sold (as observed in the NUTMON flows). Organic feeds (crop residues from PPUs + external supplemental feeding) are the main input to the SPU. Of the total SPU inputs, 10% is contained in harvested animal products and 85% is excreted as manure. All excreted manure is stored in the RUs (main RU input) where 70% of the nutrients are lost to leaching and denitrification and the remaining 30% is recycled in the PPUs. In all the zones, total nutrient outputs from the PPUs are higher than total inputs resulting in nutrient depletion rates ranging from 40 to 116 kg N/ha/year. Overall food production in the farms (crop products in PPU + in SPU) range from 40 – 83 kg N /farm/year.

3.2 Nutrient balances of the ideotyped IAA-systems

With the estimated reduction in N losses in RUs and the decrease of organic inputs in PPUs (section 2.5), 56 to 94 kg nitrogen per farm per year became available for pond use. These quantities were sufficient to support ponds ranging between 400 and 700 m^2 in size (Table 4). IAA-systems were not idiotyped for the farming system in AEZ 1 due to unavailability of information on nutrient utilization efficiencies in ponds at low temperatures (Table 1). The major pond nutrient inputs are organic fertilizer (manure from RU) and sediments (intercepted erosion). Compared to the existing farming systems (Table 3), nutrient depletion rates were lower, ranging between 30 and 89 kg N/ha/year in AEZ 2 – 5, and overall food production (crop products in PPU + in SPU + in FP) was higher, ranging between 81 and 129 kg N/farm/year (Table 5).

3.3 Effects of fish ponds integration

Because part of the land is converted into fish ponds, the PPU area in the ideotyped IAA-systems is 1 – 4% smaller than in the original farms. On the other hand, the nutrient inflow to

Table 3: Nutrient balance in existing African farming systems

	AEZ 1				***AEZ 2***				***AEZ 3***				***AEZ 4***				***AEZ 5***			
	PPU	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***
Area (ha)	*1.21*	*-*	*-*	*0*	*1.41*	*-*	*-*	*0*	*3.51*	*-*	*-*	*0*	*2.12*	*-*	*-*	*0*	*2.28*	*-*	*-*	*0*
Inputs																				
Mineral fertilizer	139	0	0	0	111	0	0	0	25	0	0	0	131	0	0	0	0	0	0	0
Orgnic .fertilizer/feed	46	133	113	0	56	211	179	0	42	129	109	0	65	162	138	0	66	168	184	0
Atmospheric deposition	8	0	0	0	9	0	0	0	22	0	0	0	12	0	0	0	11	0	0	0
Nitrogen fixation	6	0	0	0	7	0	0	0	18	0	0	0	11	0	0	0	12	0	0	0
Sedimentation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total IN	**199**	**133**	**113**	**0**	**183**	**211**	**179**	**0**	**107**	**129**	**109**	**0**	**219**	**162**	**138**	**0**	**89**	**168**	**184**	**0**
Outputs																				
Crop/animal products	58	13	0	0	19	21	0	0	57	13	0	0	56	16	0	0	66	17	0	0
Crop residues	145	113	34	0	44	179	54	0	73	109	33	0	127	138	41	0	10	142	55	0
Leaching	85	0		0	67	0		0	112	0		0	74	0		0	41	0		0
Denitrification	32	0	79	0	35	0	126	0	62	0	77	0	31	0	96	0	4	0	129	0
Erosion	13	0	0	0	182	0	0	0	154	0	0	0	18	0	0	0	134	0	0	0
Total OUT	**333**	**126**	**113**	**0**	**346**	**200**	**179**	**0**	**458**	**122**	**109**	**0**	**306**	**154**	**138**	**0**	**255**	**159**	**184**	**0**
Net balnce	**-134**	**7**	**0**	**0**	**-163**	**11**	**0**	**0**	**-351**	**6**	**0**	**0**	**-87**	**8**	**0**	**0**	**-166**	**8**	**0**	**0**
Depletion rate (kg/ha/yr)	**111**				**116**				**100**				**41**				**73**			

AEZ = agro-ecological zone, PPU = primary production unit, SPU = secondary production unit, RU = Redistribution unit and FP = fish pon

Table 4: Ideotyped aquaculture units for integration in existing farming systems and their nutrient balances

	AEZ 1	AEZ 2	AEZ 3	AEZ 4	AEZ 5
N available for use in pond (kg)					
From increased RU efficiency	34	54	33	41	55
Re-allocated from PPU inputs	24	38	23	29	39
Total	**58**	**92**	**56**	**70**	**94**
Possible pond size (m^2)	-	600	400	500	700

N = nitrogen and AEZ = agro-ecological zone.

the PPU is 11 – 69% higher in ideotyped IAA-systems due to additional input from pond sediments. Based on increased nutrient inputs, crop production in the PPU is 2 – 26% higher in ideotyped IAA-systems than in the existing farming systems despite the reduction in PPU land area. Increased crop production plus new fish yields raise the overall food production in ideotyped IAA-systems by 22 to 70% (Table 6). Mainly due to an increase in total PPU inputs, ideotyped IAA-systems nutrient depletion rates were 23 -35% lower than in existing farming systems (Table 6).

4.0 Discussion and conclusion

The results have demonstrated that development of IAA-systems in African farming would improve nutrient use efficiencies and enable increased food production while reducing soil fertility losses (Table 5 & 6). To achieve these positive impacts, important characteristics of the aquaculture component are ability (i) to utilize available farm residues (e.g, a variety of animal manures, crop residues, household residues (garbage) etc) as fish pond nutrient inputs, (ii) to trap and retain nutrients in pond sediments and (iii) to operate year round.

(i) Utilization of available farm residues as fish pond nutrient input

As a fish feed, terrestrial vegetation results in negligible fish growth due to its low palatability and digestibility (Castanares et al., 1991). However, application of composted green manures resulted in net fish yields of up to 3 tons ha^{-1} year^{-1} (Veverica et al., 1990; Rurangwa et al., 1991; Chikafumbwa et al., 1993). A variety of animal manures such as chicken litter, cow dung, buffalo and pig manures have also been used successfully to provide nutrients to tropical and sub-tropical ponds (Hopkins and Cruz, 1982; Green et al, 1989) and 6 – 10 tons of fish ha^{-1} year-^{1} were produced (Wohlfarth and Schroeder, 1979; Schroeder, 1980, 1990;

Table 5: Nutrient balance in ideotyped IAA systems

	AEZ 2				**AEZ 3**				**AEZ 4**				**AEZ 5**			
	PPU	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***	***PPU***	***SPU***	***RU***	***FP***
Area (ha)	*1.35*	-	-	*0.06*	*3.47*	-	-	*0.04*	*2.07*	-	-	*0.05*	*2.21*	-	-	*0.07*
Inputs																
Mineral fertilizer	111	0	0	0	25	0	0	0	131	0	0	0	0	0	0	0
Organic .fertilizer/feed	18	211	179	91	20	129	109	56	37	162	138	70	27	168	185	94
Atmospheric deposition	8	0	0	0.4	22	0	0	0.2	12	0	0	0.3	11	0	0	0.3
Nitrogen fixation	7	0	0	0.2	18	0	0	0.1	11	0	0	0.2	12	0	0	0.2
Sedimentation+irrigation	121	0	0	87	89	0	0	76	54	0	0	9	108	0	0	65
Total IN	**265**	**211**	**179**	**179**	**173**	**129**	**109**	**132**	**244**	**162**	**138**	**79**	**158**	**168**	**185**	**160**
Outputs																
Crop/animal products	24	21	0	36	64	13	0	26	57	16	0	16	80	17	0	32
Crop residues	56	179	108	0	82	109	66	0	128	138	83	0	12	143	111	0
Leaching/pond drainage	73	0	72	9	118	0	44	7	75	0	55	4	51	0	74	8
Denitrification	38	0	0	18	65	0	0	13	31	0	0	8	5	0	0	16
Erosion/pond sediment	174	0	0	116	152	0	0	86	18	0	0	52	131	0	0	104
Total OUT	**366**	**200**	**179**	**179**	**481**	**122**	**109**	**132**	**309**	**154**	**138**	**79**	**278**	**160**	**185**	**160**
Net balnce	**-101**	**11**	**0**	**0**	**-308**	**6**	**0**	**0**	**-65**	**8**	**0**	**0**	**-120**	**8**	**0**	**0**
Depletion rate (kg/ha/yr	**75**				**89**				**31**				**54**			

AEZ = agro-ecological zone, PPU = primary production unit, SPU = secondary production unit, RU = Redistribution unit and FP = fish pond

Table 6: A summary of the main differences between nutrient balances of existing farming systems (Table3) and those of the ideoyped IAA systems (Table 5)

	AEZ 2			**AEZ 3**			**AEZ 4**			**AEZ 5**		
	Existing	**IAA**	**% change**	**Existing**	**IAA**	**% change**	**Existing**	**IAA**	**% change**	**Existing**	**IAA**	**% change**
PPU area (ha)	1.41	1.35	**-4**	3.51	3.47	**-1**	2.12	2.07	**-2**	2.28	2.21	**-3**
Total PPU input (kg)	183	265	**45**	107	173	**62**	219	244	**11**	89	158	**69**
PPU crop products	19	24	**26**	57	64	**12**	56	57	**2**	66	80	**21**
Depletion rate (PPU)	116	75	**-35**	100	89	**-23**	41	31	**-23**	73	54	**-25**
Overall food production	40	81	**22**	70	103	**58**	72	89	**30**	83	129	**70**

AEZ = agro-ecological zone, IAA = integrated Agriculture - agriculture

Knud-Hansen, 1993). Fish production in manure driven ponds is primarily phytoplankton based (Colman and Edwards, 1987; Knud-Hansen et al., 1993). The manures decompose slowly releasing inorganic nutrients which stimulate algal production. Since on-land composting results in a net loss of carbon and nitrogen through leaching (Lin et al., 1997), farmers (e.g Rwanda) have developed in-pond composting methods. Grasses, kitchen wastes and some animal manures are added to enclosures built within the ponds where the decomposing wastes are regularly stirred to release nutrients (Veverica et al., 1990).

Although on-farm residues are high in carbon and consume large amounts of dissolved oxygen during decomposition (Lin et al., 1997), careful management of application rates will alleviate this constraint (Veverica et al., 1990). Besides tropical fish species such as tilapia tolerate large dial dissolved oxygen fluctuations (Popma and Lovshin, 1995).

(ii) Nutrient trapping and retention in pond sediments

The ability of aquaculture ponds to trap and retain nutrients in sediments has been demonstrated in numerous studies. On average, 20 – 30% of the total nitrogen input to aquaculture ponds is retained in fish (Avnimelech and Lacher, 1979, Boyd, 1985, Krom et al, 1985, Porter et al., 1987, Green and Boyd, 1995) and up to 80% is retained in the pond sediment (Avnimelech and Lacher, 1979, Schroeder, 1987, Myint et al., 1990; Acosta-Nasser et al., 1994; Briggs and Funge-Smith, 1994; Olah et al., 1994). Besides the retention of a large proportion of nitrogen inputs in aquaculture ponds, small retention ponds constructed on spillways in hilly areas could trap 21 – 100% of soil eroded from fields in the upper slopes (Fiener et al., 2005; Verstraeten and Poesen, 2001; Renwick et al., 2005).

(iii) Year round operation

To allow instant utilization of farm residues and to minimise nutrient losses during storage in the RUs, fish ponds need to be operational year-round. The tropical conditions in sub-Saharan Africa favor year-round pond aquaculture. However, in high altitude areas, temperature becomes sub optimal. Nile tilapia, the commonly cultured species in Africa, grows best at 25 – 28 ^{o}C and stop growing below 20^{o}C (Popma and Lovshin, 1995). In areas where temperatures drop below 20^{o}C, more cold tolerant species should be stocked. Various carp species thrive well at 17 – 37 ^{o}C (Coutant, 1977; Jhingran, 1982). When temperatures drop below 17^{o}C for extended periods of the year, trout which grows best in 12 – 18 ^{o}C waters could be farmed (Shelton, 1994). Thus, considering the temperature regimes in the various agro-ecological zones (Table 1 - Section 2.1) suitable culture species are: tilapia in AEZ 3 – 5, carp in AEZ 2 (but also possible in AEZ 3 – 5) and trout in AEZ 1.

Nutrient pond budget studies from low temperature areas comparable to AEZ 1 are not available. Available data on nutrient dynamics in tropical ponds (section 2.5) is mainly based on fish culture within a temperature range of 20 – 40^{o}C. However, reported pond nutrient balances for carps under semi-intensive conditions in a temperate climate (Olah and Pekar, 1992) are within the same range. Therefore, the same balances were used to ideotype IAA systems in AEZ 2 – AEZ 5. Because of the lack of data, IAA-systems were not ideotyped for AEZ 1.

High water quality is essential to produce trout in ponds. The water should be below 18 ^{o}C and clear, dissolved oxygen levels should be 5 – 12 mg l^{-1} and pH levels 6.5 – 8.5 (Shelton, 1994). Grown purely on natural foods, trout yield are 100 – 150 kg ha^{-1} year $^{-1}$ and yields of 1000 – 2000 kg ha^{-1} year^{-1} are achievable with feeding (Marriage, et al., 1971), which increases production costs by 60% (Sloene, 1994). Such characteristics make trout farming unsuitable for small-scale IAA-systems since organic wastes, not formulated feeds, are the available nutrient inputs. Due to high respiratory demand of bacterial degradation of organic wastes, night and dawn oxygen levels below 5 mg l^{-1} are common in organically fertilized ponds (Popma and Lovshin, 1995), and pond waters are turbid, mainly due to high plankton concentrations. In addition, trout farming in small-scale ponds may not be economically feasible.

Carps and tilapia are omnivores (Jhingran, 1982; Popma and Lovshin, 1995), growing well in organic wastes driven ponds (Nandeesha, 1982). They are tolerant to high fluctuations in water quality, capable of tolerating low oxygen levels (Huet, 1972; Popma and Lovshin, 1995) and production of 3000 – 8000 kg ha^{-1} year^{-1} were achieved in organically fertilized ponds (Popma and Lovshin, 1995; Pekar and Olah; 1991). These characteristics make them suitable culture species for small-scale IAA-systems where on-farm residues are the available pond nutrient sources.

Therefore, based on available literature, as demonstrated in the foregoing discussion, the required characteristics of the aquaculture component are possible in most of the agro-ecological zones. An important factor for successful integration of the various components of the IAA-systems is the utility of pond sediment to fertilize crops. Studies in Thailand, The Philippines and Japan showed that incorporating pond sediments in degraded rice fields increased productivity for several years (Mochizuki et al., 2006). The pond sediments are commonly used to sustain rice productivity (Conklin, 1980; Furukwa, 1997) or to improve the chemical and physical properties of soils (Iwata et al., 1973; Matsushima, 1980).

In conclusion, this explorative study shows that from a bio-physical point of view, the development of IAA-systems in Africa is technically possible and would result in improved soil fertility management and increased total farm production. In a further step, economic feasibility and on-farm conditions (e.g availability of water, soil characteristics, etc) should be considered. A pilot study, monitoring IAA-system nutrient budgets, while recording economic feasibility and impacts on the livelihood of farming household, is recommended as the next step towards the development of IAA-systems in Africa.

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Chapter 3

Exploring the trophic structure in organically fertilized and feed driven tilapia culture environments using multivariate analyses

Abstract

Reports of similar yields in manure and feed driven tilapia culture environments raise questions on food utilization in these environments. The possibility that similar production rates are due to utilization of different foods was investigated using exploratory techniques of multivariate analyses. Using factor analysis, trophic pathways through which food becomes available to the fish were explored and by ANOVA models, water quality, sediment quality and tilapia growth and yields in the two environments were compared. Conceptual graphic models of the main ecological processes occurring in feed driven and organically fertilized environments are presented and discussed. In both environments, autotrophic and heterotrophic pathways are important processes which result in the availability of natural foods that are utilized by the fish. Extrapolated fish yield data indicate that with equal nutrient input and stocking density, organically fertilized environments could achieve production rates similar to those in feed driven environments. The general assumption that supplemental or complete foods are well utilized by tilapia in outdoor stagnant ponds remains challanged and further research on tilapia feeding behavior and food selection in feed and organic fertilizer driven environments is needed.

Muendo P.N., A. Milstein, A. A. van Dam, E. N. Gamal, J. J. Stoorvogel and M. C. J. Verdegem, 2006. Exploring the trophic structure in organically fertilized and feed driven tilapia culture environments using multivariate analyses. Aquaculture Research 37: 151 - 163

Introduction

Tilapia is farmed in varying environments that based on density and corresponding required addition of inputs have been classified into extensive, semi-intensive and intensive systems (Edwards, 1988; Egna et al., 1997). In extensive systems fish are reared at low densities in stagnant outdoor ponds generally with no inputs at all (Edwards, 1988), relying on natural foods for their nutrition. In intensive systems fish are reared at high densities and depend on nutritionally complete feeds with little or no nutrition from natural foods (Egna et al., 1997). In semi-intensive systems, fish are reared in outdoor stagnant ponds, but rely on fertilization to enhance natural food production and/or on supplemental or complete feed to complement the natural foods.

Besides being regarded as better quality inputs than organic fertilizers, supplemental and complete foods are said to increase food availability in ponds above levels available in organically fertilized ponds. Further, the increased food availability increases fish growth and allows culture of fish at higher stocking densities resulting in fish yields higher than those possible with organic fertilization (Diana et al., 1991; 1994). Several researchers reported yields of male tilapia monoculture ranging between 8.6 – 19.2, 23.7 – 33 and 30.8 – 49.4 kg ha^{-1} day^{-1} in manure-only, manure plus supplemental feed and feed-only treatments, respectively (Collis and Smitherman,1978; Nerrie, 1979; Stone, 1980; Hopkins and Cruz, 1982; Green et al., 1989; Peralta and Teichert-Coddington, 1989; Diana et al., 1994). However, tilapia yields comparable to those obtained in feed-only ponds (29.5 – 30.5 kg ha^{-1} day^{-1}) have been reported in manure-only systems (Schroeder et al., 1990; Delince, 1992 and Knud-Hansen et al. (1993).

What fishes eat in stagnant outdoor ponds and hence what drives fish growth and production is still not well understood. If fishes in feed driven environments utilize both natural foods and supplemental feeds, why is it possible to achieve comparable production with organic fertilization only? It can be hypothesised that fishes in feed driven environments reduce their dependency on natural foods. If different foods are used, most likely differences in the food webs in organically fertilized and feed driven environments can be observed. The flow of matter and energy through the food web will influence the water quality and sediment properties differently and therefore differences may be observed in the water and sediment properties of organically fertilized and feed driven ponds.

The goal of this preliminary study was to investigate whether different foods are utilized by tilapia in fertilized and feed driven environments through multivariate analyses. Using factor analysis, the trophic structure through which food becomes available to the fish were explored and compared. Using ANOVA models, water and sediment qualities in the two environments were compared to establish whether differences due to utilization of different food can be detected on water and pond sediments' qualities. Fish growth rates and yields in the two environments were also compared to establish whether fish performance is better in feed-driven than in organically fertilized environments.

Materials and methods

Experimental design

The study was conducted between June and October 2002 at the World Fish Centre, Egypt. Nine newly constructed earthen ponds with concrete banks, 200m^2 and 1.2m deep were used for the study. Ponds were filled with water to the 1m level a week before they were stocked with 18-20g tilapia (*Oreochromis niloticus*) fingerlings, and water losses due to seepage and evaporation were replaced weekly during the culture period. In a completely randomised design, the ponds were allocated to 3 treatments in triplicate. In the first treatment fishes were fed 25% protein floating pellets (P) at 3% body weight day^{-1}. Ponds in the second treatment were fertilized with chicken manure (C) while in the third, they were fertilized with field grass (G) that was partially composted aerobically for one month prior to pond application.

Since the common practice is to have higher stocking density in feed driven environments than in organically fertilized environments, ponds in P were stocked at a rate of 2 fish m^{-2} while those in C and G were stocked at a rate of 1 fish m^{-2}. To enable a comparison of the systems with different stocking densities, the quantity of chicken manure and composted grass inputs were determined so that nitrogen (N) input rates were half of those in the P treatment. To estimate the N input in the P treatment, it was assumed that the fish would grow to 250 g in 5 months. Assuming a feed conversion ratio of 2 and 16% N in the 25% protein of the pellets, about 7.5 kg of N would be added in each of the P treatment ponds. All the chicken manure required for the whole culture period was bought in one batch at the beginning of the experiment, from which a composite sample was collected and analysed for its nitrogen content that was found to be 2.5%. Thus, for the same period, chicken manure fertilization rates of about 50 kg ha^{-1} day^{-1} would result in addition of about 4 kg N. After composting, nitrogen content of the grass was analysed (averaged 2.3%) and applied to the ponds in quantities to be iso-nitrogenous with treatment C. In total the quantity of composted grass added translated to an average application rate of 60 kg dry matter ha^{-1} day^{-1}.

A delay in starting the experiments resulted in a 139 day culture period rather than the originally planned 150 day culture period. In addition, during the culture period, feeding and fertilization were occasionally suspended due to low dawn oxygen levels. The combined effects resulted in a deviation of the originally planned N-loading per treatment. By the end of the culture period, total N input per pond was 5.8, 2.6 and 2.4 in P, C and G, respectively. Hence, the N load in organic fertilizer ponds was still about half that in feed driven ponds.

Fish feeding/pond fertilization and fish growth measurement

Pellets were supplied twice a day at 10 a.m and 3 p.m while chicken manure was applied daily at 10 a.m. and the grass compost weekly (every Sunday at 10 a.m). Fish were sampled monthly using a seine net. At each sampling time, a minimum of 10% of the stocked fish population was seined, counted, and weighed (total weight) to calculate the average weight. Feed amounts were adjusted monthly based on the observed average weights and on the assumption of 100% survival. Fertilization or feeding was suspended when dawn oxygen levels dropped below 2 mg/l and resumed when the dawn oxygen levels were restored above this level. During the last months of culture, it was observed that the fish did not finish their daily feed ratio and henceforth they were fed *ad libitum* at the same times of the day as when fed at 3% body weight. At harvesting, fish were seined and the remaining ones collected by hand from the mud after complete drainage. All fish from a pond were counted, their total weight recorded, and the average weight determined. Based on these measurements, further calculations of daily fish growth rates and yields were made.

Water quality sampling and analytical procedures

Temperature, dissolved oxygen (DO) and pH were measured twice daily (6 a.m and 3 p.m), water transparency once daily (12 p.m) and primary productivity biweekly. Temperature and DO were measured using an oxygen meter with a combined oxygen and temperature probe (OXYGARD HANDY III), pH using a pH electrode (ACCMET pH meter 25) and water transparency using Secchi disk (Boyd and Tucker, 1992). Primary productivity (PP) was measured using the free water method (Hall and Moll, 1975), in which changes of pond water DO at different depths (5, 25, 50 and 75cm) are monitored over a 24-h period (4 hourly beginning at 6 a.m.). Community respiration is taken as twice the decrease in mean DO between 1800 h and 0600 h the following day. Gross primary productivity is calculated as the sum of gains in mean DO during the day plus half of community respiration (assumes no difference between diurnal and nocturnal community respiration). Dissolved oxygen values can be corrected for diffusion across the air-water interface by relating the oxygen transfer coefficient to wind speed (Boyd and Teichert-Coddington, 1992). However, in this study a correction for diffusion was not made due to unavailability of weather data. The aim of the study was to compare treatments and since diffusion would be the same in all ponds, the lack of a diffusion correction does not affect the conclusions of the study.

All other water quality parameters mentioned below were determined biweekly. The first sampling was done after pond filling and before fish stocking to determine the initial pond water characteristics. Samples were collected at 8 a.m from three points in a pond using a column sampler (Boyd and Tucker, 1992). The samples from the three points were mixed together, a one-litre sample collected from the homogenously mixed composite sample and taken to the laboratory for the various analyses. Soluble reactive phosphorus (SRP) was determined by ascorbic acid method (APHA, 1995) and total phosphorus (TP) by persulphate digestion (Gross and Boyd, 1998) followed by ascorbic acid method. Determination of total ammonia nitrogen (TAN) was by the phenate method (APHA, 1995), nitrite nitrogen (NO_2-N) by diazotization method (Boyd and Tucker, 1992), nitrate nitrogen (NO_3-N) by phenoldisulfinic acid method (Boyd, 1979) and total nitrogen (TN) by persulphate digestion (Gross and Boyd, 1998) followed by phenoldisulfinic acid method. Potassium (K) was determined by atomic absorption (Page et al., 1982) and chlorophyll *a* by filtration through GF/C Whatman glass fibre filters followed by acetone extraction and calorimetric determination of the pigment concentration (APHA, 1995).

Sediment samples

Sediment samples were taken from the upper 10-cm stratum using a core sampler (Boyd and Tucker 1992). Initial samples were collected before stocking and preceding samples biweekly. In each pond 9 cores were taken and mixed to form a composite sample from which a sub-sample was taken for analysis. They were analysed for total nitrogen by the Kjeldahl method (Page et al. 1982), phosphorus by Olsen's method (Buurman et al., 1996), organic carbon by Walkley-Black dichromate method (Buurman et al., 1996) and potassium by determining the exchangeable potassium in a cation exchange-replacing solution ($BaCl_2$) followed by atomic absorption determination of potassium (Buurman et al., 1996).

Statistical analyses

Data were analysed through factor analysis (e.g. Kim and Mueller 1978; Milstein 1993) to identify the main ecological processes acting in the environments. Factor analysis, a multivariate statistical technique, is used to study patterns of interrelationships within one set of variables. The method is based on the analysis of linear relationships, which express the simplest relationships between variables, with a common objective of reducing the number of variables into a smaller number of new hypothetical variables (factors). The factors have no units and are normally distributed standardized variables. The value of each factor for each observation of the original variables can be calculated and used as a new variable in plots, histograms and statistical analyses such as ANOVA. To run the analysis, a data matrix is constructed with each column containing a variable and each line an observation. From the correlation matrix among the variables of that matrix factors are then extracted by calculating eigenvalues and eigenvectors. The proportion of variance accounted for by each factor is calculated from the corresponding eigenvalue. Each eigenvector contains the coefficients of the linear combination corresponding to each original variable. Factors with eigenvalues larger than one are used for interpretation. The interpretation of the factor (hypothetical variable) is then performed based on the relative size and sign of the coefficients (eigenvector). Only the coefficients with the highest values are considered for interpretation, usually those larger than 0.5. Of the available techniques for extracting factors, principal component analysis (PCA) (e.g.: Seal, 1964; Jeffers, 1978) was used. The first calculated factor is the linear combination that accounts for as much of the variation contained in the sample as possible. The second factor is the second linear function that accounts for most of the remaining variability, and so on. Factor analysis assumes that the observed variables are linear combinations of some underlying factors, independent of one another, which generally reflect an ecological or operational process. Factor analysis is used as an exploratory technique, thus the results are interpreted as general trends.

After identification, the factors, their differences between treatments and sampling dates as well as the water quality, fish and soil data were compared in a repeated measures split-plot ANOVA as shown in the model below:

$$Y_{ijk} = \mu + \alpha_i + e_{ij} + T_k + (\alpha T)_{ik} + e_{ijk}$$

Where Y_{ijk} = observed value; μ = overall mean; α_i = treatment effects ($i = 3$); e_{ij} = experimental error due to treatment ($j = 3$); T_k = time effects ($k = 10$); $(\alpha T)_{ik}$ = time*treatment cross effects; e_{ijk} = experimental error due to treatment*time interactions. Treatment means were compared using Fisher's Least Significance Difference (LSD) procedure for multicomparison tests (Zar, 1984). The analyses were run using the procedures FACTOR and

GLM of the SAS statistical package (version 8.2, SAS institute Inc., Cary, NC 27513, USA). Differences were declared significant at alpha level of 0.05.

Results

Fish growth and yields

Fish growth rates and yields are shown in Table 1. Due to bird predation, survival rates were low and ranged between 41 - 54% with no significant treatment effects. The daily fish growth rate was somewhat higher in C but differences were not significant among treatments. Average tilapia weights at harvest were significantly higher in C than in P and G but the net fish yield (NFY) was significantly higher in P.

Table 1. Tilapia growth and survival rates

	Treatment		
Parameter	**C**	**G**	**P**
Stocking weight (g)	18.5^{a}	18.3^{a}	19^{a}
Number stocked	200	200	400
Average weight at harvest (g)	252^{a}	172^{b}	174^{b}
Survival (%)	41^{a}	48^{a}	54^{a}
Daily growth rate (g day^{-1})	1.7^{a}	1.1^{a}	1.1^{a}
Total biomass at harvest (kg pond^{-1})			
Stocked tilapia	20.7^{b}	16.5^{b}	37.6^{a}
Recruits	10.0^{a}	9.5^{a}	15.5^{a}
Total (stocked tilapia + recruits)	30.7^{b}	26.0^{b}	53.1^{a}
Net fish yields (NFY) (recruits inclusive)			
Kg pond^{-1}	27.0^{b}	22.3^{b}	45.5^{a}
Kg ha^{-1}	1350^{b}	1117^{b}	2275^{a}
Kg ha^{-1} year^{-1} (assuming 2 seasons)	2700^{b}	2234^{b}	4550^{a}

Values are means of 3 replicates for each treatment. Same letters (superscripts) indicate no significant difference at the 0.05 level. a>b……

Water and sediment quality

Results of ANOVA and multi-comparison tests of treatment means of water and sediment quality variables are shown in Tables 2 and 3. The model accounted for over 70% of the variability in all the variables (r^2 of the ANOVA) and the main source of variability in water and sediment variables was week, which represents time effect.

Table 2 ANOVA and multi-comparison of treatment means (by Fishers' Least Significance Difference test (LSD)) of variables measured daily.

Variables:	Dissolved oxygen (mg l^{-1}) (6 a.m)		Dissolved oxygen (mg l^{-1}) (3 p.m)		Temperature (°C) (6 a.m)		Temperature (°C) (3.p.m)		Secchi depths (cm) (12 p.m)		pH (6 a.m)		pH (3 p.m)	
ANOVA models														
Significance	***		***		***		***		***		***		***	
Coeff. determination (r^2)	0.92		0.85		0.99		0.99		0.72		0.91		0.87	
Variance Source	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS
Trt	ns	0	***	36	*	0	ns	0	*	27	***	62	***	56
Week	***	86	***	53	***	99	***	99	***	40	***	10	***	23
Week *Trt	***	14	***	11	***	1	ns	1	***	33	***	28	***	21
Multi-comparison of means by TRT														
C	1.5 a		12.3 a		26.3 ba		29.4 a		14.4 ba		9.1 a		9.3 a	
G	1.4 a		10.3 b		26.2 b		29.3 a		16.9 a		8.8 b		9.1 b	
P	1.4 a		7.6 c		26.5 a		29.2 a		12.3 b		8.3 c		8.6 c	

Coeff. = coefficient, Sign.= significance level: ns= not significant, *= significant at 0.05 level, **= significant at 0.01 level, ***= significant at 0.001 level. %SS= percent of total sum of squares, Trt = treatment. Same letters in the multi-comparison of means columns indicate no significant difference at the 0.05 level. a>b>…

Factor analysis

Results of the factor analysis are presented in Table 4. Five factors were important in describing the variability of the data and together accounted for 74% of the overall data variability. The five factors (F1 – F5) are identified and described in the paragraphs below and results of ANOVA and multi-comparison tests of the factors' means by treatment and time are shown in Table 5.

Table 3 ANOVA and multi-comparison of means (LSD) of variables measured weekly.

Variables:	TAN in pond water (mg l^{-1})		NO_2–N (in pond water) (mg l^{-1})		NO_3–N (in pond water) (mg l^{-1})		TN (in pond water) (mg l^{-1})		SRP (in pond water) (mg l^{-1})		TP (in pond water) (mg l^{-1})	
ANOVA models												
Significance	***		***		***		***		***		***	
Coeff. determination (r^2)	0.77		0.96		0.91		0.82		0.95		0.84	
Variance Source	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS
TRT	ns	3	**	7	***	14	*	13	**	16	**	21
WEEK	***	83	***	64	***	76	***	70	***	66	***	60
WEEK*TRT	ns	15	***	29	**	9	*	17	***	18	**	19
Multi-comparison of means by TRT												
C	0.54 a		0.04 b		0.13 b		11.9 a		0.11 a		1.05 a	
G	0.47 a		0.07 a		0.21 a		9.5 ba		0.05 b		0.79 b	
P	0.45 a		0.009 c		0.10 c		7.9 b		0.03 b		0.71 b	
Multi-comparison of means by WEEK												
1	0.4 cb		0.006 b		0.06 g		4.2 e		0.06 cb		0.38 c	
2	0.8 a		0.001 b		0.09 gfe		4.4 e		0.06 b		0.40 c	
3	0.4 cb		0.010 b		0.08 gf		7.1 d		0.01e		0.72 b	
4	0.3 c		0.009 b		0.12 edcb		7.5 d		0.07 b		0.90 a	
5	0.7 a		0.001 b		0.12 fedc		12.3 b		0.03 e		1.01 a	
6	0.4 cb		0.001 b		0.11 fed		11.9 b		0.03 e		0.99 a	
7	0.1d		0.000 b		0.15 cb		12.6 b		0.03 ed		0.99 a	
8	0.7 a		0.000 b		0.15 dcb		10.8 cb		0.04 ed		1.00 a	
9	0.7 a		0.180 a		0.40 a		17.5 a		0.05 dcb		1.06 a	
10	0.5 b		0.180 a		0.18 b		9.1 dc		0.27 a		1.02 a	

Coeff. = coefficient, Sign.= significance level: ns= not significant, *= significant at 0.05 level, **= significant at 0.01 level, ***= significant at 0.001 level. %SS= percent of total sum of squares, TRT = treatment, TAN = Total ammonia nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus. Same letters in the multi-comparison of means columns indicate no significant difference at the 0.05 level. a>b>…

Factor 1 (F1): phytoplankton biomass synthesis in the water column

This first factor accounted for 30% of the data variability (Table 4). It comprises two groups of variables, those with high positive coefficients and those with high negative coefficients. High factor values indicate high primary productivity (PP), chlorophyll-*a* levels, organic phosphorus and nitrogen, monthly average fish weights, NO_2-N and NO_3-N, and K in both sediment and water column (variables with positive coefficients), together with low morning DO, afternoon temperature and Secchi depth transparency (variables with negative coefficients) (Table 4-F1). The factor reflects phytoplankton biomass synthesis in the water column. High PP levels reflect high rates of phytoplankton synthesis while high values in chlorophyll-*a*, organic nitrogen and phosphorus reflect

Table 3 (continuation)

Variables:	Potassium (in pond water) (mg l^{-1})		Chlorophyll *a* (mg l^{-1})		Primary production (mg O_2 l^{-1})		Available P (in sediment) (%)		TN (in sediment) (%)		Potassium (in sediment) (%)		Organic carbon (in sediment) (%)	
ANOVA models														
Significance	***		***		***		***		***		***		***	
Coeff. determination (r^2)	0.93		0.86		0.93		0.64		0.69		0.98		0.82	
Variance Source	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS
Trt	ns	2	***	22	***	24	ns	12	ns	16	ns	1	ns	39
Week	***	92	***	66	***	65	***	91	*	34	***	98	***	36
Week*Trt	**	6	**	22	***	11	ns	8	ns	50	ns	1	ns	25
Mean multicomparison by TRT														
C	13.8 a		381 a		20.1 a		0.18 a		0.15 a		0.07 a		1.7 a	
G	14.8 a		264 b		16.1 b		0.17 a		0.12 a		0.07 a		1.3 a	
P	14.3 a		211c		11.9 c		0.17 a		0.14 a		0.07 a		1.7 a	
Mean multicomparison by WEEK														
1	8.90 g		17 f		5.01 e		0.28 a		0.12 cb		0.059 ed		1.9 a	
2	11.8 f		123 e		7.20 ed		0.16 cb		0.12 cb		0.057 e		1.5 dc	
3	9.3g		241 d		15.4 c		0.14 dcb		0.11 c		0.060 d		1.4 dc	
4	16.7 cb		300 dc		18.3 b		0.12 dc		0.13 cba		0.065 c		1.2 d	
5	14.8 e		348 cb		22.1 a		0.11 dc		0.13 cba		0.084 b		1.4 dc	
6	18.3 a		316 c		21.0 a		0.14 dcb		0.13 cba		0.055f		1.4 dc	
7	16.1 dc		347 cb		18.8 b		0.27 a		0.15 a		0.060 d		1.5 c	
8	17.4 ba		400 ba		21.0 a		0.15 dcb		0.14 ba		0.088 a		1.6 cb	
9	15.2 ed		462 a		15.0 c		0.08 d		0.15 a		0.088 a		1.8 ba	
10	14.2 e		298 dc		16.6 cb		0.21 ba		0.14 ba		0.082 b		1.7 cba	

Coeff. = coefficient, Sign.= significance level: ns= not significant, *= significant at 0.05 level, **= significant at 0.01 level, ***= significant at 0.001 level. %SS= percent of total sum of squares, TRT = treatment. Same letters in the multi-comparison of means columns indicate no significant difference at the 0.05 level. a>b>…

the presence of high plankton biomass in the water column. The high synthesis of phytoplankton biomass is a result of availability of inorganic nutrients (Hargreaves, 1998) in the water (high positive values in NO_2-N and NO_3-N). Phytoplankton biomass supports fish growth (Diana et al., 1991) but also increases the water turbidity resulting in low Secchi depth transparency. Night respiration of the high phytoplankton biomass, coupled with other biotic respiration consumes oxygen resulting in low values of DO in the morning. In the ANOVA and mean multi-comparison test of the factor (Table 5), the applied model accounted for 97% of the factors variability of which 86% was due to time

Table 4 Factor analysis results. Coefficients in bold were used for interpretation.

Factors	**F1**	**F2**	**F3**	**F4**	**F5**
Morning dissolved oxygen	**-0.68**	-0.28	0.42	0.15	0.13
Afternoon dissolved oxygen	0.42	**0.64**	0.15	-0.05	-0.13
Morning Temperature	-0.45	**0.74**	-0.26	0.14	0.18
Afternoon Temperature	**-0.55**	**0.74**	-0.16	0.15	0.15
Morning pH	0.24	**0.52**	**0.73**	0.01	0.21
Afternoon pH	0.32	**0.71**	**0.53**	0.08	0.21
Secchi depth	**-0.50**	-0.23	0.29	-0.21	0.00
Total ammonia nitrogen	0.02	-0.28	-0.21	0.35	**0.54**
Nitrite nitrogen	**0.50**	**-0.57**	0.25	-0.28	0.11
Nitrate nitrogen	**0.58**	-0.35	-0.01	-0.30	0.30
Organic nitrogen	**0.77**	0.20	0.07	-0.02	0.04
Soluble reactive phosphorus	0.27	-0.39	**0.56**	0.08	-0.20
Organic phosphorus	**0.77**	0.42	-0.06	0.05	0.01
potassium	**0.56**	0.22	-0.41	-0.14	-0.28
Chlorophyl a	**0.87**	0.32	0.05	0.09	0.12
Primary productivity	**0.71**	**0.59**	0.03	0.02	-0.01
Monthly average fish weight	**0.89**	-0.11	0.04	-0.02	-0.18
Sediment phosphorus	-0.04	0.17	0.41	-0.10	**-0.68**
Sediment nitrogen	0.4	-0.15	0.10	**0.70**	-0.21
Sediment potassium	**0.68**	-0.36	-0.16	0.22	0.29
Sediment organic carbon	0.04	-0.37	0.06	**0.72**	-0.20
Variance Explained (%)	**30**	**20**	**11**	**7**	**6**
Interpretation	**phytoplankton biomass synthesis in the water column**	**Photosynthetic activity**	**Role of pH in orthophosphate liberation**	**Organic matter accumulation in the sediment**	**Organic matter decomposition**

Tabl 5. ANOVA of factors and multi-comparison tests (LSD) of their treatment means

Factors	F1		F2		F3		F4		F5	
ANOVA models										
Significance	***		***		***		***		***	
Coeff. determination	0.97		0.97		0.94		0.83		0.85	
Variance source	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS	Sign.	%SS
TRT	***	9	**	11	***	49	ns	52	*	10
WEEK	***	86	***	84	***	32	***	25	***	82
WEEK*TRT	***	5	***	6	***	19	*	23	ns	8
Multi comparison of means by TRT										
C	0.40 a		0.40 a		0.8 a		0.4 a		-0.06 ba	
G	-0.05 b		0.01 b		0.1 b		-0.7 a		0.40 a	
P	-0.30 c		-0.40 c		-0.9 c		0.3 a		-0.30 b	
Multi-comparison of means by Week										
1	-1.55f		-0.8 g		1.1 a		0.20 cba		-0.3 d	
2	-1.40f		-0.4 f		0.1 dc		0.30 ba		-0.5 cb	
3	-0.60 e		0.7 cb		0.4 cb		-0.03dcb		0.7 ba	
4	-0.30 d		0.9 ba		-0.3 f		-0.20dc		0.2 dc	
5	0.20 c		0.6 dc		-0.8g		0.60 a		0.9 ba	
6	0.30 c		0.4 a		-0.5 f		-0.40dc		-1.3e	
7	0.30 c		0.4 ed		0.02 ed		-0.30dc		-1.2e	
8	0.70 b		0.3 e		0.5gf		0.50 ba		0.1 dc	
9	1.40 a		-1.3 h		0.2 fe		-0.30dc		1.1 a	
10	0.90 b		-1.5i		0.6 b		-0.40d		-0.8e	

Sign.= significance level: ns= not significant, *= significant at 0.05 level, **= significant at 0.01 level, ***= significant at 0.001 level. %SS= percentage of total sum of squares. Same letters in the mean multi-comparison columns indicate no significant difference at the 0.05 level. a>b>…

(weeks), 9% to treatment and 5% to the interaction of treatment and time. The multi-comparison of the means by week shows that biomass increased with time and the multi-comparison of means by treatment shows that the highest plankton biomass occurred in treatment C followed by G and the lowest in P (Table 5-F1). Figure 1-F1 illustrates the factor's trend over time in the three treatments (week*treatment interaction effect). It shows similar biomass in the first two weeks in all treatments, and from then on the biomass increase was larger in C than in G, the latter being larger than in P.

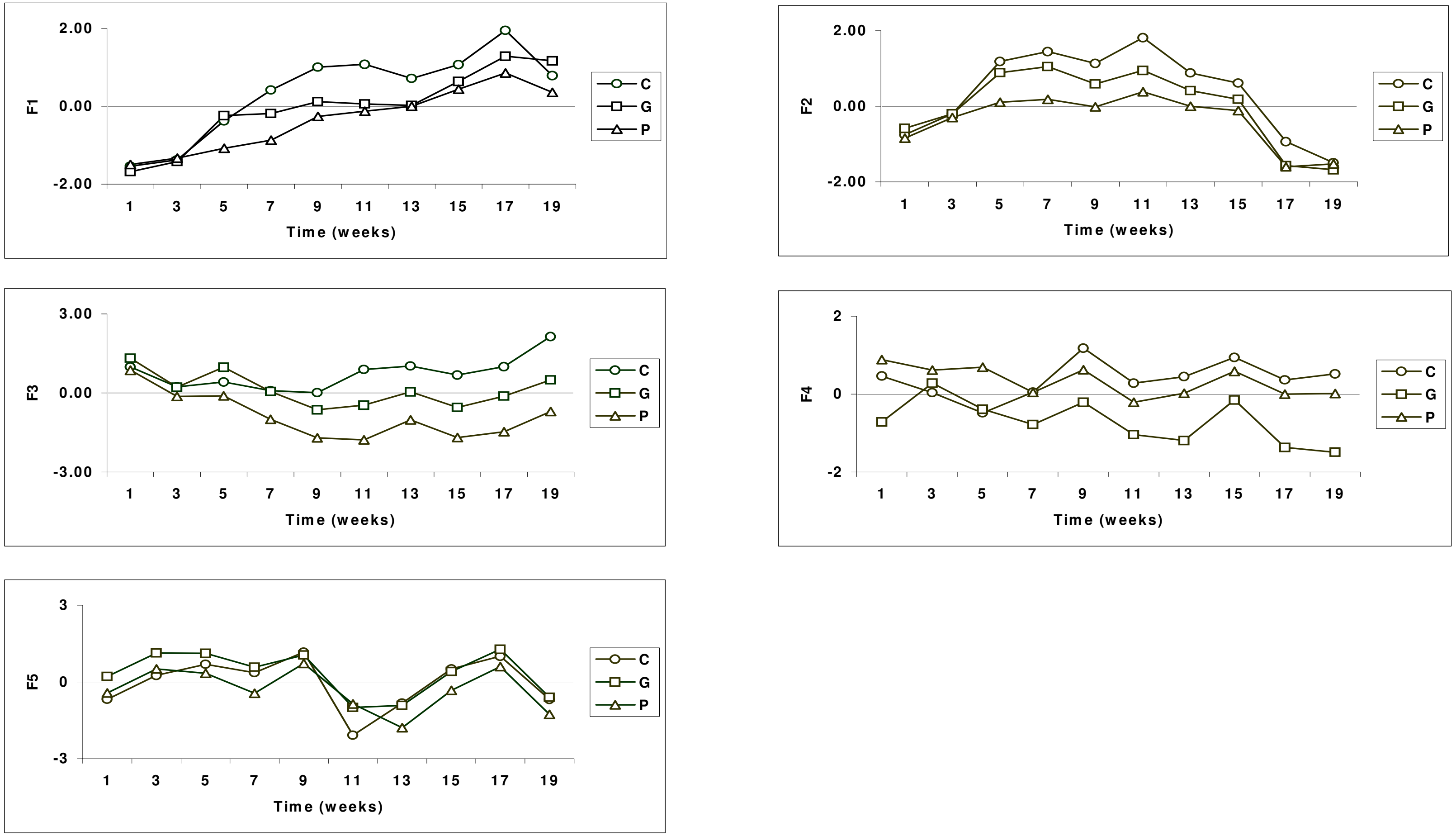

Figure 1: Treatment and week interaction for factors 1 to 5

Factor 2 (F2): photosynthetic activity in the water column

This factor accounted for a further 20% of the data variability (Table 4). It has high positive coefficients in temperature, pH, DO in the afternoon hours and PP, and high negative coefficient in NO_2-N (Table 4-F2). It reflects photosynthetic activity in the water column. High temperatures favour high photosynthetic activity in which primary producers utilise carbon dioxide and release oxygen. Reduction of carbon dioxide in the water leads to an increase in water pH (Boyd 1998). Released oxygen is utilised in the nitrification processes hence reduction of NO_2-N (Boyd, 1998). The ANOVA model accounted for 97% of the factors variability of which 84% was due to time, 11% due to treatment and 6% due to the interaction between time and treatment. Multi-comparison tests of means by week show that photosynthetic activity increased with time in the first months but decreased in the last 2 months, while multi-comparison of treatment means show that photosynthetic activity was significantly higher in C than in G than P (Table 5-F2). The cross-effect of treatment and time (figure 1-F2) shows that photosynthetic activity in the first 2 and last 2 weeks was similar in all treatments while in between was higher in C than in G than in P.

Factor 3 (F3): role of pH in orthophosphate liberation

A further 11% of the overall data variability is accounted by this factor. It shows high positive coefficients in water pH and SRP in the water column (Table 4-F3). It reflects the role of pH in orthophosphate liberation. An increase in pH causes the dissolution of phosphate resulting in an increase in orhophosphate concentration in the water column (Kamp-Nielson 1974; Boyd, 1990). Besides this dissolution, an increase in pH will make the surface charge of particles (hydroxides and clays) more negative causing a lesser ability to adsorb the negative phosphate ions (Hillerod, 1974) that then remain in the water column. The ANOVA model accounted for 94% of this factor variability, of which 49% was due to treatment, 32% to time and 19% to the interaction between time and treatment. The multi-comparison of means by treatment show significant treatment effects with higher means in C than G than P. The multi-comparison of means by week shows that the factor was high the first weeks, decreased and remained low the following weeks, increasing again the last weeks (Table 5-F3). Figure 1-F3 shows that at the beginning of the culture period all treatments had similar F3 values, but from the third week on there were strong differences between treatments.

Factor 4 (F4): accumulation of organic matter in the sediment

This factor accounted for a further 7% of the data variability. It shows high positive coefficients for organic carbon and nitrogen in the sediment (Table 4-F4), reflecting accumulation of organic matter. Organic carbon and nitrogen occur in soil as a constituent of organic substances (Boyd 1995) and most of the nitrogen in aquaculture pond sediments is associated with organic matter (Boyd, 1990; Hargreaves, 1998). The ANOVA model accounted for 83% of this factor variability, of which 25% was due to time, 23% to the interaction between time and treatment, and no significant treatment effect. The multi-comparison of means by week shows a trend of increased organic matter accumulation in the sediment the first month with some variations afterwards (Table 5-F4). In the treatment and week cross effect (Figure 1-F4), variations in time were different in the three treatments.

Factor 5 (F5): decomposition of organic matter

It accounted for a further 6% of the data variability. It shows a high positive coefficient in TAN in the water column and a high negative coefficient in sediment phosphorus (Table 4-F5). This reflects decomposition of organic matter. During the decomposition of organic matter in sediments phosphates are liberated leading to a decline in sediment phosphorus (Hillerod, 1974; De Pinto et al., 1986; Boyd, 1990) and organic nitrogen is mineralised to ammonia increasing the total ammonia nitrogen in the water column (Boyd, 1995). The ANOVA model accounted for 85% of the factors variability of which 82% was due to time and 10% to treatment. Multi-comparison of means by week show that organic matter decomposition increased over time during the first half of the culture period and was lower in the second half. Multi-comparison of means by treatment shows that decomposition in G was significantly higher than in P (Table 5-F5).

Discussion

Fish growth and yields

Similar fish growth rates in all the environments imply that organically fertilized environments can perform equally well as feed driven environments, or perhaps even better considering the significantly higher tilapia average weight at harvest in C (Table 1). Though the stocking density in the feed driven environment was twice than that in the organically fertilized environments, the nutrient inputs were also twice as much. The higher NFY in P is a result of the double stocking density. Assuming equal nutrient input in the environments (double the organic fertilizer quantity), equal stocking density and assuming the observed growth rates in the organic manure environments, NFY in C and G would be double the values in Table 1 and would be comparable to those in P. Similar observations were made by Knud-Hansen et al. (1993) who concluded that with increased primary production in organically fertilized environments, food constraints at higher stocking densities are overcome**.**

Ecological processes defining the food webs

Conceptual graphic models of the main ecological processes in the organic manure and the feed driven environments are shown in figures 2 and 3. The figures were constructed following the results of the factor and ANOVA analyses (Tables 2 – 4), and the widths of the arrows represent the importance of the flows.

The factors describe autotrophic and heterotrophic pathways in which photosynthetic activities (F2) result in the development of phytoplankton biomass (F1) in the water column. Phytoplankton cells are said to have a lifespan of 1-2 weeks (Boyd, 1995) after which the dead cells settle at the pond bottom at a daily rate of about 50% of the algal standing crop (Schroeder et al., 1991). This algal matter, in addition to the organic matter from the pond inputs, accumulates in the sediment (F4) and supports the heterotrophic pathway by providing substrate for decomposition (F5). In turn, decomposition favours the liberation of orthophosphate (F3) and a flux of inorganic nitrogen from the sediment (Boyd, 1995; Shrestha et al., 1996). Nutrients released to the water column from decomposition

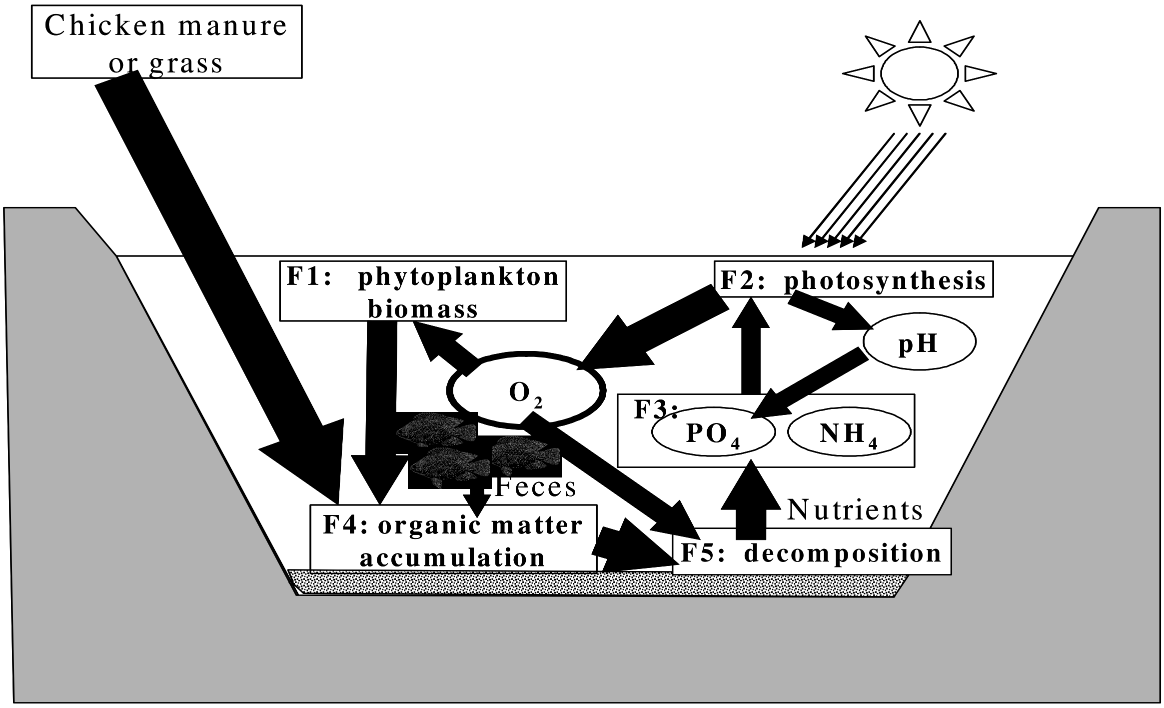

Figure 2: Main ecological processes occurring in organically fertilized environments

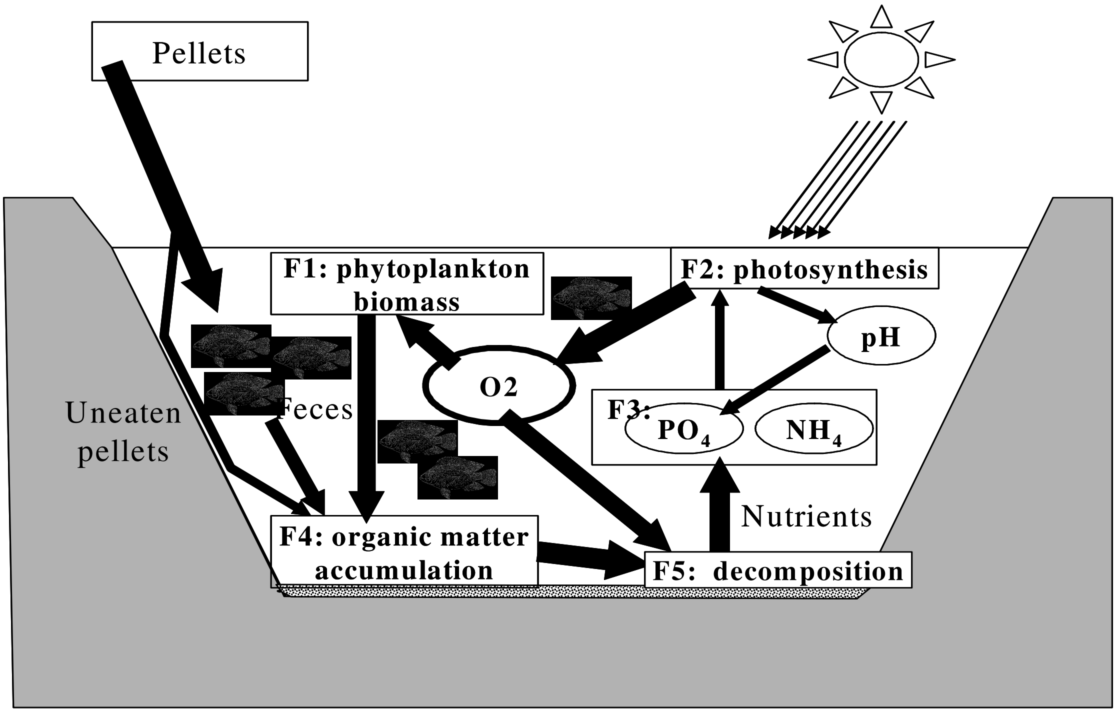

Figure 3: Main ecological processes occurring in feed driven environments

augment the availability of inorganic nutrients (SRP and TAN) for higher rates of phytoplankton synthesis and results in increased algal biomass and more organic matter settling in the sediment. High photosynthetic rates supply the oxygen needed for decomposition and the cycle continues with increasing rates over time, hence the reason why time accounts for a high proportion of variability in most of the factors (Table 4).

The autotrophic and heterotrophic pathways developed in all three treatments, and hence natural foods availability. However, except for F4, the magnitudes of the factors were higher in the organically fertilized environments (Table 4) and also proceeded at a higher rate in the fertilized than in the feed driven environments (Figure 1). In P, the quantity of organic matter input was lower and much so at the beginning when the fish were small. Moreover, only a fraction of the feed remains unconsumed. For example, in the first week, P received 240g of feed pond^{-1} day^{-1}. Since only 15% sediments as uneaten feed (Boyd and Tucker, 1995) and 30% of the ingested feed is excreted (Porter et al., 1987), only about 97 g pond^{-1} day^{-1} would form organic matter at the bottom. On the other hand, C and G received at least 1 kg of organic input (from the organic fertilizer) pond $^{-1}$ day^{-1}. The higher organic matter input in C and G than in P, especially in the first weeks of culture when feed quantities were low resulted in higher decomposition rates (F5) during which larger amounts of nutrients were released (F3). For example, assuming 16% N in the 25% protein feed, only 4 g N pond^{-1} day^{-1} would be released upon decomposition of the 97 g organic matter where as assuming complete decomposition of 1 kg chicken manure (2.5% N content), 25 g N pond^{-1} day^{-1} would be released in C. Consequently, larger amounts of nutrients would become available for photosynthesis (F2) resulting in higher phytoplankton biomass (F1). Higher organic inputs in C and G did not result in more organic matter accumulation on the bottom (F4), due to efficient microbial processes (Maclean et al., 1994), that result in rapid organic decomposition (Smith, 1996). The microbes responsible for organic matter decomposition are present in all ponds, their numbers increase with increase in organic matter (Boyd, 1998; Gasol and Duarte, 2000) and can process organic matter at the same rate as it is precipitated (Schroeder, 1987).

As the culture period progressed, fish weights increased and feed amounts in treatment P were regularly adjusted upwards with the increase in fish weights. With increase in feed amounts with time, the quantity of organic matter (F4) input from uneaten feed and feacal matter also increases. Expectedly, decomposition rates (F5) and nutrient release (F3) should increase too, approaching levels of those released in C and G and result to increased rates of photosynthesis (F2) and plankton biomass (F1). However, the rate of the processes, still remained lower in P (Figure 1) which could be explained by the double fish biomass in P. Consumption of natural foods by the higher fish biomass can keep the phytoplankton biomass lower in P. With a lower phytoplankton biomass, organic matter input from phytoplankton sedimentation would also be lower, keeping heterotrophic and autotrophic activities lower too. This on the other hand, implies similar rates of natural food consumption in both feed driven and organically fertilized environments, and disputes the study hypothesis that natural foods are less utilized in feed driven environments. Similar observations have been reported in previous studies where natural foods accounted for a great percentage (50 – 80%) of tilapia growth, both in fertilizer and in feed driven environments (Schroeder, 1983; Schroeder et al., 1990; Knud-Hansen et al., 1993; Lochmann and Phillips, 1996). The question therefore is whether the pellet feeds are efficiently utilized or are an expensive pond fertilizer (Green et al., 2002). The results further contribute in the on-going debate on the merits of supplementary or complete feeds in semi-intensive tilapia culture in the tropics (Shang, 1992; Green, 1992) where feed costs are a major factor limiting fish production (Omondi et al., 2001). Further investigations on food selection in feed and organically fertilized environments could offer useful information on this debate.

Conclusion

The trophic structure in organically fertilized and fed ponds is similar (Figures 2 and 3), as autotrophic and heterotrophic pathways are important processes in both environments providing natural foods that are a main part of the diet in both environments. The results support previous indications that with equal nutrient inputs and stocking densities, manure driven environments could perform equally well as feed driven environments. Further, they support emerging evidence that supplemental feeds may not be well utilized by fishes in outdoor stagnant ponds.

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Chapter 4

Sediment accumulation in fish ponds; its potential for agricultural use

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Abstract

An experiment was conducted to describe and quantify sediment and nutrient accumulation in semi-intensive tilapia ponds, and estimate its potential for use in land-based agriculture. Sixteen 200 m^2 earthen ponds were allocated 4 treatments with 4 replicates in a completely randomized 2x2 factorial design. The factors were input type (chicken manure vs pelleted feed) and stocking density (1 or 2 fishes m^{-2}). All ponds were stocked with 20 – 25g tilapia (*Oreochromis niloticus*) fingerlings and harvested after 4.5 months of culture. Ceramic tiles of 0.5 by 1 m^2 were installed horizontally in the sediment, at 5 cm depth, before pond filling. Core sediment samples were taken above the tiles at monthly intervals, for determination of sediment and nutrient accumulation. Based on the quantified sediment and nutrient accumulation, the fertilizer potential of pond sediment was estimated. Up to173 tons of sediment ha^{-1} $cycle^{-1}$ accumulated in the semi-intensive tilapia production ponds. Based on recommended Egyptian fertilization rates, the nutrient content of the accumulated sediment could potentially meet the nitrogen fertilizer requirement for 0.35 – 1.2 hectare, and the potassium fertilizer requirement for 0.7 – 1.5 hectare. In addition, the accumulated sediment contained 1.8 – 5 tons of organic matter, hence, has a high potential as a soil conditioner. Sediment and nutrient accumulation were not affected by input type or stocking density.

Muendo, P. N., M. C. J. Verdegem, J. J. Stoorvogel, A. Milstein, E.N. Gamal, P. M. Duc and J.A.J. Verreth. Sediment accumulation in fish ponds; its potential for agricultural use (Submitted)

Introduction

Sediment rich in organic matter, nitrogen and phosphorus, accumulates in fish ponds during culture (Briggs and Funge-Smith, 1994; Hopkins et al., 1994; Krom et al., 1985; Smith, 1996; Jamu and Piedrahita, 2001; Boyd et al., 2002). From a management perspective, accumulation of sediment is a menace, as it fills ponds reducing their volume (Boyd et al., 2002). Accumulation of organic matter is undesirable too, as it may accumulate to levels that can negatively impact fish yields, due to release of toxic elements such as hydrogen sulfides and nitrites. High organic matter deposition may also impact a high oxygen demand and lead to oxygen depletion (Boyd, 1995; Banerjea, 1967) which in turn affects fish yields. To maintain desired pond volumes and an environment conducive for fish growth, accumulated sediment needs to be removed periodically (Briggs & Fudge-Smith 1994; Jamu and Piedrahita, 2001; Boyd et al., 2002). On the other hand, management of the sediment removed from ponds becomes a scientific concern.

Disposal of pond sediments to natural systems poses an environmental threat (Briggs & Smith 1994; Smith, 1996) and is a waste of valuable nutrients (Lin and Yi, 2003). In China, Thailand and Vietnam, pond sediment has been used to fertilise crops and higher yields have been realised (Little and Muir, 1987; Prein 2002). Although pond sediment use in agriculture and its resultant positive impacts on crop yields in China are widely reported (Pullin and Shehadeh, 1980; Little and Muir, 1987; Prein 2002), the information is not supported scientifically (Hopkins and Bowman, 1993; Lin and Yi, 2003). Lack of scientific documentation on quantitative and qualitative aspects of pond sediment hampers wider adoption and promotion of pond sediment use in agriculture (Lin and Yi, 2003).

The objectives of this paper are (i) to quantitatively describe sediment accumulation in semi-intensive tilapia production ponds; its sources and accumulation rates (ii) quantify nutrients (N, P and K) in the accumulated sediment that are potentially available for land-based agriculture and (iii) evaluate whether pond input type (chicken manure vs. pellets) and stocking density (1 or 2 fishes m^{-2}) affect the quantity and nutrient content of the accumulated sediment.

Materials and methods

Study site and experimental design

The experiment was carried out in June - October 2003 at the World Fish Centre in Egypt. Sixteen 200 m^2 and 1-m deep earthen ponds, with concrete banks, were allocated 4 treatments with 4 replicates, in a completely randomized 2x2 factorial design. The factors were input type (chicken manure (CM) or pellets (P)) and stocking density (1 or 2 fish m^{-2}). In treatments CM_1 and CM_2, ponds were fertilized with chicken manure at a rate of 50 kg dm ha^{-1} $day^{-1}$and stocked at a density of 1 and 2 fish m^{-2}, respectively. In treatments P_1 and P_2, fishes were fed floating 25% protein pellets at 3% body weight day^{-1} and stocked at a density of 1 and 2 fish m^{-2}, respectively. Ponds were filled with water from canals that received water from the Nile river. They were stocked with 20 – 25g tilapias (*Oreochromis niloticus*) and harvested after 4.5 months of culture.

Water replacement and fertilization, feeding, oxygen and temperature monitoring

Chicken manure was applied daily at 10 a.m while pellets were supplied twice a day at 10 a.m. and 3 p.m. Dissolved oxygen (DO) and temperature were monitored twice daily at 6 a.m. and 3 p.m. using an oxygen meter (OXYGARD HANDY III) with a combined oxygen (mg l^{-1}) and temperature (^oC) probe. Fertilization or feeding was suspended when dawn oxygen levels dropped below 2 mg/l and resumed when the dawn oxygen levels were restored above 2 mg/l. Feed amounts were adjusted monthly based on average weights of 10% fish samples and assuming 100% survival. In the last month of culture, fish were fed *ad libitum,* at the same hours as when fed 3% body weight, because of a decrease in their feeding rate. Water losses due to seepage and evaporation were replaced weekly.

Sediment accumulation and its available nutrient content

Ceramic tiles were installed in the pond floor at 5 cm depth to have a reference point to measure the depth of the sediment layer. In each pond, 5 ceramic tiles measuring 0.5m by 1m were installed. Sticks protruding above the water surface were put at each corner of each ceramic tile to mark tile locations. Sediment samples were collected monthly using a soil core sampler with a 5 cm diameter (Boyd, 1995). On each sampling date, two core samples per tile were collected, by pushing the core sampler through the sediment until the tile was reached. The top 5-cm of the first sediment cores were placed each in one tarred crucible for dry bulk density analysis, by drying them to constant weight at 105°C in the oven. From the 5 samples per pond, the average dry bulk density (g cm^{-3}) of the top 5-cm sediment layer was calculated. The second sediment core per tile, was immediately taken to the pond embankment, where the sediment depth was measured, while the sample was still in the core liner tube. Once the sediment depth was measured, the top 5-cm segment of the sediment core was transferred to a container. All five segments per pond, per sampling date, were homogenously mixed to form a composite sample, from which a sub-sample was collected for nutrient analysis. The sub-samples were air dried and analysed for total nitrogen, available phosphorus, organic carbon and potassium. Total nitrogen was analysed by the Kjeldahl method (Page et al. 1982) and organic carbon by the Walkley-Black dichromate method (Buurman et al., 1996). Available phosphorus was analysed by Olsen's method of sodium bicarbonate extraction followed by a colorimetric determination of phosphorus with ammonium molybdate as a colouring agent (Buurman et al., 1996). Exchangeable potassium was analysed by determining the exchangeable potassium in a cation exchange-replacing solution ($BaCl_2$) (Buurman et al., 1996) followed by atomic absorption determination of potassium (Page et al., 1982).

Sediment and nutrient quantification

Sediment

The quantity of pond sediment in the layer above the ceramic was determined monthly as a product of the sediment depth on the ceramic, the pond area and the sediment dry bulk density. The difference between pond sediment quantity at the end of culture and in the beginning of culture was taken as the quantity of accumulated pond sediment over the culture period. Over the experimental period, bulk densities were determined for the upper 5 cm. However, to quantify the pond sediment in the sediment layer above the ceramic, the bulk density for the total sediment depth above the ceramic was required. Two assumptions were made to give an estimate of the maximum and minimum sediment accumulation (i) that the monthly bulk density of the total sediment layer above the ceramic was the same as that observed in the upper 5 cm layer (minimum) (ii), that in the preceding months, the bulk density of the sediment layer above the ceramic and below the upper 5cm remained the same as that of the first month (maximum).

Nutrients

The quantity of nutrients in the upper 5-cm pond sediment layer was quantified monthly as a product of the sediment nutrient concentrations (% on dry weight basis), the pond area and the sediment dry bulk density. The difference between the nutrient quantity in the upper 5-cm layer at the end of the last month of culture and that by the beginning of culture represents the quantity by which nutrients accumulated during the culture period.

Sediment Sources

Inflow water

Water samples were collected from pond inlet pipes for analysis of total solids during pond filling and weekly water replacements to seepage and evaporation losses. The volume of water added to ponds was estimated by monitoring water levels in the pond. PVC pipes, about 1.3m high and marked in cm were installed in the deeper side of ponds, and used to monitor changes in pond water depth and volume. To determine the sediment load of inflow water, 100ml samples were put in previously cleaned, dried and weighed crucibles and dried in the oven at 105^{o}C. The dry crucibles were cooled in a desiccator and weighed. The increase in crucible weight represents the total solids in 100ml and was used to estimate the total solids per liter. Based on the estimated volume of water added to ponds (in litres), the quantity of solids added to the ponds through inflow water, was estimated.

Organic sources

The quantity of organic inputs into the ponds (feed and manure) was recorded daily. Total organic inputs were quantified at the end of the culture period and their contribution to sediment accumulation was estimated based on the following assumptions: (i) direct consumption of manure by fish is minimal and most of the input settles to the sediment (Hargreaves, 1998), (ii) in feed driven ponds, 15% of the feed offered is not eaten (Boyd and Tucker, 1995) and 30% of ingested feed is excreted as faeces (Porter et al., 1987) and (iii) 50% of the phytoplankton standing crop sediments daily (Schroeder et al., 1991). To estimate the portion of plankton settling from the water column, primary productivity was estimated monthly using the free water method (Hall and Moll, 1975).

Nutrient budgets

Nitrogen, phosphorus and potassium budgets were prepared for each treatment to compare with the observed nutrient accumulation in the pond sediments. Nutrient gains considered were feed/manure, stocked fish and inflow water while considered nutrient losses were fish harvest, drainage, seepage and pond sediment. To estimate nutrient gains from inflow water, water samples were collected from inlet canals during pond filling and pond water replacements and their nitrogen, phosphorus and potassium contents determined. To estimate nutrient gains from stocked fish and pond inputs, proximate analyses were made on fish, feed and manure samples.

To estimate nutrient losses through drainage, water column samples were taken before drainage. The water column samples were collected from three points in a pond using a column sampler (Boyd and Tucker, 1992). Samples from the three points were mixed homogenously to form a composite sample, from which a one-litre sample was collected for total nitrogen and total phosphorus analyses. Sub-samples drawn from the one-litre sample were digested through simultaneous persulphate digestion (Gross and Boyd, 1998), and subsequently, analysed for total nitrogen by phenoldisulfinic acid method (Boyd, 1979), and for total phosphorus by the ascorbic acid method (Boyd and Tucker, 1992). Another sub- sample was analysed for potassium by atomic absorption (Page et al., 1982).

To estimate nutrient losses through seepage, the amount of water lost through seepage was measured by periodic observations of water levels in closed PVC pipes. The PVC pipes, which were also used for monitoring pond water levels, were pushed 30cm into the pond bottom and protruded to the water surface. A meter rule marked in centimetres was fixed on the inside of the pipes with the zero cm mark at the surface end. The pipes were filled with water to the zero mark and changes in water levels inside the pipes reflected loss of water through seepage. Seepage water was collected using rhizons (Muendo et al., 2005). Two rhizons pond^{-1} were installed in pond bottoms at a 10 cm depth before pond filling. The rhizons were connected to plastic extension tubes extending above the water surface to allow for easy sampling. Water samples were collected monthly by connecting the extension tubes to a vacuum tube. Seepage water samples from a pond were pooled and analysed for nitrogen, phosphorus and potassium.

Statistical analyses

To evaluate the effect of input type and different stocking density on sediment and nutrient accumulation, data on monthly pond sediment depths and sediment nutrient concentrations, were analysed by two-way ANOVA (repeated measurements) with stocking density and nutrient input type as the main factors and sampling time as sub-factor, as shown in the following statistical model:

$$Y_{ijkl} = \mu + S_i + N_k + (SxN)_{ik} + e_{ijk} + T_l + (SxT)_{il} + (NxT)_{kl} + (SxNxT)_{ikl} + e_{ijkl}$$

where, Y_{ijkl} = observed value; μ = overall mean; S_i = effect of stocking density (i=2); N_k = effect of nutrient input type (k = 2); $(S+N)_{ik}$ = effect of interaction between stocking density and nutrient input type; e_{ijk} = error 1 (j = 4 replicates); T_l = effect of sampling date (l = 5); $(SxT)_{il}$ = interaction of stocking density and sampling time; $(NxT)_{kl}$= interaction of nutrient input type and sampling time; $(SxNxT)_{ikl}$ = interaction of stocking density and nutrient input type and sampling time; e_{ijkl} = error 2. The analyses were run in SAS (version 8.2) statistical software package (SAS Institute Inc., Cary, NC 27513, USA). Means were isolated by Tukey and differences were considered significant at an alpha level of 0.05. Before the ANOVA and multi-comparison tests of means, normality tests were performed on the data and arc sine transformations done for data obtained in % values such as the sediment nutrient concentrations.

Results

Sediment accumulation

In all the treatments, sediment depths on the ceramic tiles increased significantly while bulk densities (upper 5-cm sediment layer) declined significantly over time. For both sediment depth and bulk density, effects due to input type or stocking density were not significant (Table 1). Sediment depths increased by about 3 cm pond^{-1} during the culture period while bulk densities declined by about 0.1 – 0.3 g cc^{-3} (Table 2). Minimum sediment accumulation quantities ranged from less than 1 to 3.1 while the maximum quantities were 1.5 – 3.46 tons pond^{-1} cycle^{-1}. There were no significant differences between treatments (Table 2).

Table 1. ANOVA and multi-comparison test of means (Tukey) of sediment depths (cm), sediment nutrient concentrations (%) and sediment bulk density (g cm^{-3}).

Variables:	Sediment depth	Nitrogen	Available phosphorus	Exchangeable potassium	Organic carbon	Soil bulk density
ANOVA models						
Significance	***	***	***	***	***	*
Coeff. determination (r^2)	0.87	0.93	0.77	0.85	0.78	0.55
Multi-comparison of means by input type						
CM	7.47	0.12	0.003	0.09	1.5	0.60
P	7.45	0.11	0.004	0.09	1.5	0.63
Multi-comparison of means by stocking density						
1	7.31	0.12	0.004	0.009	1.5	0.64
2	7.61	0.11	0.004	0.009	1.6	0.59
Multi-comparison of means by culture months						
1	5.8^{d}	0.05^{d}	0.005^{b}	0.11^{b}	1.1^{b}	0.70^{a}
2	6.6^{c}	0.09^{c}	0.001^{c}	0.13^{ab}	1.6^{a}	0.60^{ab}
3	7.6^{b}	0.13^{b}	0.008^{a}	0.07^{c}	1.9^{a}	0.59^{ab}
4	8.6^{a}	0.14^{b}	0.004^{bc}	0.07^{c}	1.7^{a}	0.63^{ab}
5	8.8^{a}	0.18^{a}	0.0005^{c}	0.07^{c}	1.3^{b}	0.56^{b}

There were no significant effects on means due to input type or stocking density.
Coeff. = coefficient and ***= significant at 0.001 level. Same letters in the mean multi-comparison columns indicate no significant difference at the 0.05 level. a>b>…

Sediment sources

Influent water contributed about 0.17 to 0.21 kg of sediment pond^{-1} during the entire culture period (Table 2). From the organic inputs, a total of 77 kg of manure was added to treatments CM_1 and CM_2, 82.9 kg of feed to P_2 and 53.6 kg of feed to P_1 (Figure 1). Assuming minimal consumption of manure by fish (Hargreaves, 1998), organic inputs contributed at most 77 kg in CM_1 and CM_2 treatments. Assuming 15% of applied feed was uneaten (Boyd and Tucker, 1995) and 30% of ingested feed was excreted (Porter et al., 1997), uneaten feed and faecal solids contributed 12.4 and 21.1 kg, respectively in P_2 and 8.4 and 13.7 kg, respectively, in P_1

Table 2: Multi-comparison tests (Tukey) of sediment accumulation means by treatment (±stdev)

Parameters	Treatments CM_1		CM_2		P_1		P_2	
Sediment accumulation								
Sediment depths(cm) during culture months								
First	5.6 ± 0.57		6.1 ± 0.57		5.9 ± 0.69		5.6 ± 0.54	
Second	6.4 ± 0.44		6.9 ± 1.09		6.3 ± 0.38		6.9 ± 0.36	
Third	7.3 ± 0.82		7.8 ± 0.32		7.4 ± 0.63		7.8 ± 0.82	
Fourth	8.2 ± 0.37		8.9 ± 0.87		8.7 ± 1.54		8.6 ± 0.45	
Fifth	8.6 ± 0.45		8.9 ± 0.84		8.7 ± 1.26		8.8 ± 0.45	
Accumulated sediment layer (cm)	3.0		2.8		2.9		3.2	
Soil bulk density (g cm^{-3}) during culture months								
First	0.63 ± 0.09		0.75 ± 0.11		0.71 ± 0.09		0.72 ± 0.18	
Second	0.63 ± 0.19		0.58 ±0.11		0.59 ± 0.07		0.59 ± 0.07	
Third	0.63 ± 0.17		0.58 ± 0.1		0.67 ± 0.11		0.47 ± 0.05	
Fourth	0.59 ±0.15		0.55 ± 0.11		0.68 ± 0.13		0.70 ± 0.28	
Fifth	0.59 ± 0.17		0.47 ± 0.05		0.64 ± 0.09		0.55 ± 0.28	
Pond sediment quantity (tons pond^{-1}) above ceramic	minimum	maximum	minimum	maximum	minimum	maximum	minimum	maximum
First	7.06 ± 0.80	7.06 ± 0.80	9.05 ±1.51	9.05 ± 1.51	8.40 ± 1.47	8.40 ± 1.47	8.08 ± 2.66	8.08 ± 2.66
Second	8.03 ± 2.41	8.05 ± 2.10	8.17 ± 2.75	8.64 ± 2.76	7.47 ± 1.32	7.73 ± 0.87	8.22 ± 1.09	8.66 ± 1.33
Third	9.04 ± 2.13	9.18 ± 0.92	8.94 ± 1.31	9.91 ± 0.46	9.83 ± 1.82	9.99 ± 1.08	7.22 ± 0.28	8.59 ± 0.84
Fourth	9.82 ± 2.70	10.01 ± 2.15	9.60 ± 1.09	11.30 ± 0.83	11.66 ± 2.86	11.94 ± 2.78	11.9 ± 4.79	12.08 ± 3.91
Fifth	10.16 ± 2.69	10.52 ± 1.96	8.27 ± 1.28	10.55 ± 2.10	11.20 ± 2.26	11.67 ± 2.18	9.75 ± 5.56	10.86 ± 4.21
Quantity of accumulated sediment over the culture period (tons pond^{-1} cycle)	3.1	3.46	-0.78	1.5	2.8	3.3	1.67	2.8
Sediment sources								
Influent water (kg pond^{-1} culture period^{-1})	0.19 ± 0.01		0.21 ± 0.07		0.20 ± 0.02		0.17 ± 0.03	
Estimated sedimentation from organic sources (kg)	137.79		129.21		62.9		76.47	
Total (kg)	137.79		129.21		62.9		76.47	
% of accumulated sediment accounted by influent water and organic sources	4.4	4.0	-	8.6	2.5	1.9	4.6	2.7

Treatment means were not significant for all parameters ($P > 0.05$)

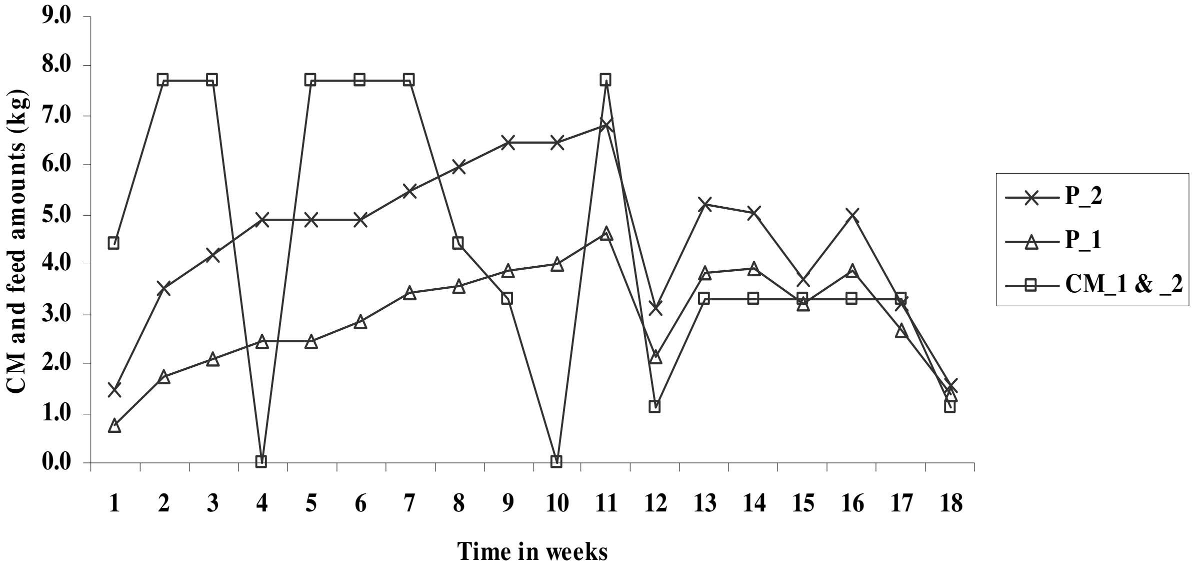

Figure 1: Weekly chicken manure (CM) and feed amounts pond $^{-1}$ over the culture period

Primary production during the entire culture period averaged 4.36, 3.94, 2.91 and 3.08 g C m^{-2} day^{-1} in CM_1, CM_2, P_1 and P_2, respectively. Assuming 50% algal sedimentation day^{-1} (Schroeder et al., 1991), about 2.18, 1.87, 1.46 and 1.54 g C m^{-2} day^{-1} of plankton accumulated at the sediment surface in CM_1, CM_2, P_1 and P_2, respectively, and translates to about 60.6, 52.0, 40.6 and 42.8 kg pond^{-1} in CM_1, CM_2, P_1 and P_2, respectively, over the culture period. In total, contribution to sediment accumulation by organic sources (uneaten inputs, faecal matter and plankton sedimentation) amounts to 137.6, 129, 62.7 and 76.3 kg in CM_1, CM_2, P_1 and P_2, respectively (Table 2).

Nutrient accumulation

Nitrogen and organic carbon

In all the treatments, nitrogen concentrations in the top 5-cm pond sediment layer increased significantly over time while organic carbon concentrations increased in the first 3 months and after decreased to almost the original levels (Table 1 – multi-comparison tests of nitrogen means by month). For both nitrogen and organic carbon, there were no significant effects due to input type or stocking density (Table 1). Monthly quantifications of pond sediment nitrogen in the upper 5-cm layer show that the quantity of nitrogen increased by 4.77 - 7.74 kg during the culture period with no significant effects due to treatments (Table 3). However, in the nutrient budgets, when this quantity is assumed to be the nitrogen accumulation in the pond sediment, total nitrogen losses from the ponds are higher than the total nitrogen gains in all treatments by 2.3 - 5.7 kg (Table 4).

Available phosphorus

Available phosphorus concentrations decreased in the first month of culture, increased in the second month, then decreased in the third and fourth months to concentrations lower than those at the beginning of the culture period (Table 1 –multi-comparison tests of available phosphorus means by month). Effects due to input type or stocking density were not significant (Table 1). By the end of the culture period, the quantity of available phosphorus in the top 5 cm was lower than that at the beginning by about 0.3 kg pond^{-1} in all the treatments (Table 3). In the nutrient budgets (Table 4), 62.5% (0.579kg) and 65.3% (0.633kg) of the available phosphorus input in CM_1 and CM_2 was not accounted for in fish harvest, drainage and seepage, while in P_1 and P_2, losses to fish harvest, drainage and seepage were higher than gains by 0.013 kg and 0.09 kg, respectively.

Potassium

Exchangeable potassium concentrations decreased significantly after one month, then stabilized for the rest of the culture period (Table 1 –multi-comparison tests of exchangeable potassium means by month). Differences due to input type or stocking density were not significant (Table 1). By the end of the culture period, the quantity in the top 5 cm sediment layer was lower by 3 - 4 kg pond^{-1} (Table 3) while in the nutrient budgets (Table 4), total losses were higher than total inputs in all treatments by < 1 kg.

Discussion

Sediment accumulation

During the culture period, pond sediment depths increased in all treatments while bulk densities declined (Table 2). Taking into account possible minimum and maximum changes in sediment bulk density, up to 3.46 tons of sediment accumulation per pond per cycle (Table 2) was estimated, which translates to about 173 tons ha^{-1} per cycle. However, considered sediment sources (influent water and organic sedimentation) contributed less than 10% of the estimated accumulated sediment (Table 3).

Table 3: Multi-comparison tests (tukey) of sediment nutrient accumulation means by treatment (±stdev)

Parameters	Treatments CM_1	CM_2	P_1	P_2
Nutrient quantity in top 5-cm sediment layer (kg pond^{-1})				
Nitrogen				
First	3.69 ± 0.81	3.51 ± 0.51	3.86 ± 0.59	3.71 ± 0.48
Second	5.49 ± 0.82	4.88 ± 1.36	5.73 ± 2.09	5.88 ± 2.01
Third	8.97 ± 2.92	7.45 ± 1.93	7.74 ± 1.80	6.42 ± 1.65
Fourth	9.15 ± 2.28	6.85 ± 1.59	8.94 ± 1.66	8.69 ± 2.26
Fifth	11.43 ± 4.78	8.59 ± 1.36	11.02 ± 1.84	8.48 ± 3.58
Apparent accumulation (kg pond^{-1} cycle^{-1})	7.74	5.08	7.16	4.77
Available phosphorus				
First	0.32 ± 0.07	0.32 ± 0.08	0.33 ± 0.15	0.34 ± 0.06
Second	0.10 ± 0.03	0.09 ± 0.08	0.11 ± 0.07	0.05 ± 0.04
Third	0.55 ± 0.16	0.39 ± 0.08	0.47 ± 0.10	0.37 ± 0.12
Fourth	0.22 ± 0.16	0.09 ± 0.05	0.17 ± 0.08	0.25 ± 0.19
Fifth	0.04 ± 0.02	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01
Apparent loss (kg pond^{-1} cycle^{-1})	0.28	0.30	0.31	0.32
Exchangeable potassium				
First	7.12 ± 0.54	6.22 ± 3.13	8.45 ± 1.1	8.44 ± 2.2
Second	7.79 ± 2.01	8.50 ± 2.14	7.78 ± 2.65	7.26 ± 0.6
Third	4.48 ± 1.64	3.78 ± 1.03	4.40 ± 1.1	3.27 ± 0.64
Fourth	4.00 ± 1.03	3.69 ± 0.79	4.42 ± 0.89	4.73 ± 1.77
Fifth	4.21 ± 1.06	3.59 ± 0.78	4.67 ± 0.14	4.09 ± 2.50
Apparent loss (kg pond^{-1} cycle^{-1})	2.91	2.63	3.78	4.34

Treatment means were not significant for all parameters ($P > 0.05$)

Table 4: Nutrient budgets

Variable	Nitrogen		Phosphorus		Potassium	
	g pond^{-1}	%	g pond^{-1}	%	g pond^{-1}	%
Treatment CM_1						
Gains						
Feed/fertilizer	3973	74.5	710	76.6	109.5	2.2
Fish stock	129	2.4	53	5.7	5	0.1
Inflow water	1232	23.1	164	17.7	4882	97.8
Total	**5334**	**100**	**927**	**100**	**4996.5**	**100**
Other nutrient source	5279		0		474.5	
Losses						
Fish harvest	762	14.3	248	26.8	55	11.0
Drainage	1897	35.6	75	8.1	4238	84.8
Seepage	212	4.0	25	2.7	1178	23.6
Pond sediment	7742	145.1	0	0	0	0
Total	**10613**	**198.9**	**348**	**37.6**	**5471**	**119.4**
Unaccounted for	0	0	579	62.5	0	0
Treatment CM_2						
Gains						
Feed/fertilizer	3973	73.4	710	73.2	109.5	2.3
Fish stock	253	4.7	104	10.7	10	0.2
Inflow water	1186	21.9	157	16.1	4685	97.5
Total	**5412**	**100**	**970**	**100**	**4804.5**	**100**
Other nutrient source	2613		0		872.5	
Losses						
Fish harvest	731	13.5	245	25.3	61	1.3
Drainage	1863	34.4	77	7.9	4377	91.1
Seepage	350	6.5	15	1.5	1239	25.8
Pond sediment	5081	93.9	0	0	0	0
Total	**8025**	**148.3**	**337**	**34.7**	**5677**	**118.2**
Unaccounted for	0	0	633	65.3	0	0
Treatment P_1						
Gains						
Feed/fertilizer	2412	64.8	10.8	4.8	20.4	0.4
Fish stock	124	3.3	51	22.9	5	0.1
Inflow water	1187	31.9	161	72.2	4837	99.5
Total	**3722**	**100**	**223**	**100**	**4862**	**100**
Other nutrient source	5705		13		303	
Losses						
Fish harvest	605	16.3	154	69.1	45	0.9
Drainage	1474	39.6	73	32.7	4294	88.3
Seepage	185	5.0	9	4	826	17
Pond sediment	7163	192.5	0	0	0	0
Total	**9427**	**253.4**	**236**	**105.8**	**5165**	**106.2**
Treatment P_2						
Gains						
Feed/fertilizer	3727	71.8	16.8	5.8	31.5	0.6
Fish stock	252	4.9	103	35.3	10	0.2
Inflow water	1210	23.3	172	58.9	5205	99.2
Total	**5189**	**100**	**291.8**	**100**	**5246.5**	**100**
Other nutrient source	2344		90.2		925.5	
Losses						
Fish harvest	898	17.3	266	91.2	78	1.5
Drainage	1585	30.5	104	35.6	5035	96
Seepage	281	5.4	12	4.1	1059	20.2
Pond sediment	4769	91.8	0	0	0	0
Total	**7533**	**145**	**382**	**130.9**	**6172**	**117.7**

On the average, a seasonal sediment deposition rate of about 200 tons ha^{-1} is reported for aquaculture ponds (Avinimelech and Ritvo, 2003). The majority of the accumulated sediment is said to originate from sediment load in influent water (Boyd, 1992; Anon, 1994), inorganic solids from levee erosion (Munsiri et al., 1995; Smith, 1996) and sedimentation of organic inputs and wastes (Gowen et al., 1990; Wahab and Stirling, 1991; Hopkins et al., 1994). However, relative proportions of these sources have not been studied (Hopkins et al, 1994; Avinimelech and Ritvo, 2003). In this study, estimation of the relative proportion of influent water and organic inputs shows that together they only account for less than 10% of the accumulated sediment. Hence, they are not major sources of the accumulated sediment. Similar observations and conclusions were made by Smith (1995; 1996) when he found that the rate of sediment accumulation was not related to organic inputs and that the level of suspended material in influent water was low. Elsewhere, solids budgets by Funge-Smith and Briggs (1994), also showed that the major source of sediments (88 – 93%) in shrimp ponds in Thailand was the erosion of pond soil, and, although applied feed was a significant source of organic matter (31 -50%), it contributed only 4 – 7% of accumulated total solids.

In this study, erosion of pond walls is not a possible major source of the accumulated sediment since the walls were made of concrete. However, sand drifting from pond banks and wind blown debris are possible sources of the accumulated sediment (Hopkins et al., 1994). The proportion of their contribution to sediment accumulation is however unknown since they have not been determined before and were not determined in this study too. In a study to determine the nutrient input by Harmattan dust to a forest ecosystem in West Africa, Stoorvogel et al. (1997) reported dust deposition rates ranging from 42 – 991 kg ha^{-1} year^{-1}. Assuming similar rates in the present study, about 0.3 – 7.4 kg of sediment pond^{-1} cycle^{-1} would originate from dust deposition. This would account for less than 0.5% of the accumulated sediment. Even if the presence of other wind blown debris such as leaves and sand from the pond banks were considered, it is unlikely that their total deposition could account for more than 5% of the measured accumulation.

Apparently, after exploration of possible sources of sediment in ponds, we are unable to account for over 85% of the estimated sediment accumulation in this study. This demonstrates the need for further studies to understand the process. A point to note from the present results is the importance of temporal bulk density measurements in the quantification of sediment accumulation. Previous studies have measured sediment depths and assumed a constant bulk density (Boyd, 1995; Smith, 1996). However, the results show that in some cases the increase in pond sediment depths could be due to changes in pond sediment volumes as a result of decline in sediment bulk densities and may not necessarily be due to sediment accumulation (Table 2: CM_2). Measuring the change in pond sediment depths and assuming a constant bulk density from beginning to end may lead to overestimation of the accumulated sediment, while assuming the final bulk density only, may lead to underestimation.

Nutrient accumulation

Nitrogen and organic Carbon

The increase in concentration of sediment organic carbon in the first months of culture can be attributed to organic inputs in the form of organic fertilizers and feeds. However, after the first 2 months of culture, a decline of morning DO levels to below 2 mg l^{-1} (Figure 2) led to temporary suspension of feeding and fertilization and subsequent reduction of the quantities of fertilizer and feed (Figure 1). Reduction of organic inputs coupled with

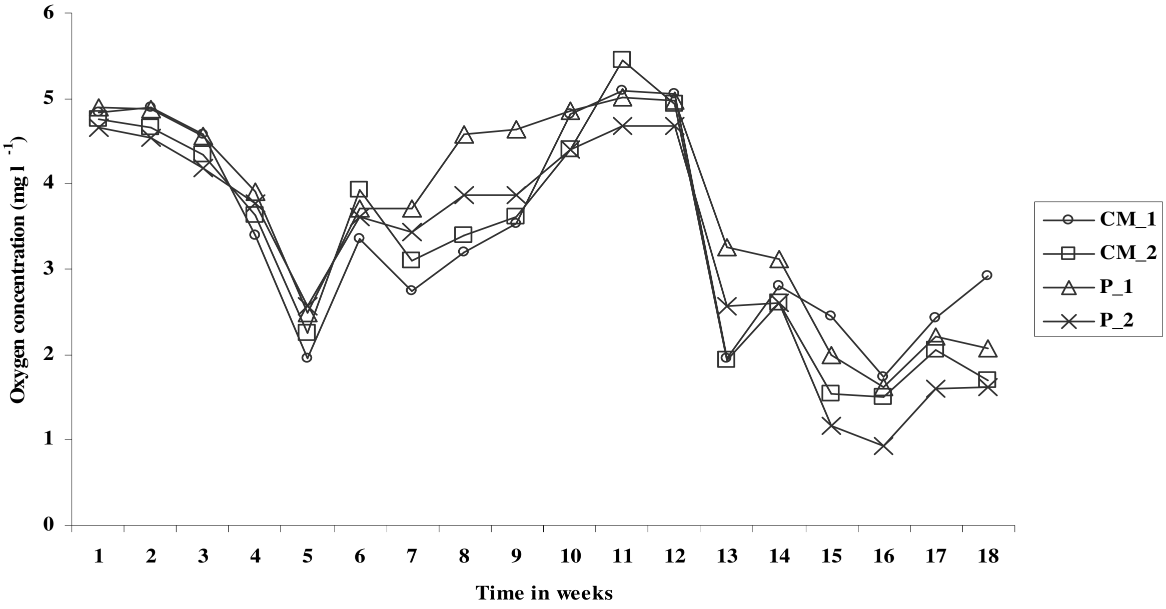

Figure 2: Oxygen concentrations during the culture period

consumption of organic matter by respiration is likely to have contributed to the decrease in organic carbon. During respiration, the sediment's organic carbon is consumed and converted mostly to CO_2 (Avnimelech and Lacher 1979) that is released from the water to the atmosphere and does not accumulate in the pond (Boyd, 1985). However, nitrogen losses are slight since ammonium, the end product of organic nitrogen mineralization is absorbed by the clay present in the sediment (Avnimelech and Lacher 1979). Therefore, inorganic nitrogen accumulates whereas organic carbon declines (Kochba et al, 1994), and hence, the continued increase in pond sediment nitrogen with time even as organic carbon decreased (Table 1- multi-comparison of means by culture months).

In the nutrient quantifications, the increase in the quantity of nitrogen in the top 5-cm layer during the culture period (Table 3) was taken to represent the quantity of accumulated nitrogen in the pond sediments and was used in the nutrient budgets. However, the nutrient budgets had a negative balance (Table 4). In all the treatments, the total nitrogen losses from the ponds were higher than the total nitrogen gains by 2.3 - 5.7 kg (Table 3). This implies the presence of other sources of nitrogen input into the ponds other than those considered and may be attributed to nitrogen fixation. Nitrogen fixation by blue green algae, that are a common occurrence in fish ponds, has been reported to contribute significant amounts of nitrogen inputs in ponds. Nitrogen fixation rates ranging from 6 – 57 mg N m^{-2} d^{-1} in tropical fish ponds were reported by Lin et al. (1988) while Acosta-Nasser et al. (1994) reported an average of 24 mg N m^{-2} d^{-1} in a tropical fresh water fish pond stocked with hybrid *Oreochromis niloticus* and fed on a pelleted feed. Nitrogen fixation is recognized as an important source of nitrogen in ponds but was not measured in this study. Due to lack of easily applied methods to measure it, nitrogen fixation is often not measured in many nutrient dynamic studies (Boyd, 1982).

Available phosphorus

Available phosphorus concentrations fluctuated over time (Table 1: multi-comparison of means by culture months). By the end of the culture period, the quantity in the top 5 cm was lower than at the beginning (Table 3), implying that pond sediment lost available phosphorus during the culture period. The nutrient budgets (Table 4) show that, in P_1 and

P_2, total available phosphorus losses were higher than gains by 5.5% (0.013kg) and 23.5% (0.09kg) respectively which appears to support the possibility of available phosphorus loss from the sediment to the pond system. Contrarily, 62.5% (0.579kg) and 65.3% (0.633kg) of the available phosphorus input in CM_1 and CM_2 was not accounted for in fish harvest, drainage and seepage, which implies accumulation in the pond sediment. These contradictions in the results could be due to the small quantities of available phosphorus involved (total inputs of less than 1 kg). Thus, the discrepancies could be due to analytical errors as observed by Boyd (1985), that detection of small changes in phosphorus in bottom soils is difficult within a single crop. On the other hand, the main reason for phosphorus accumulation in sediments is due to its adsorption by mud (Shrestha and Lin, 1996). The adsorption results from the transformation of water-soluble forms of phosphorus into less soluble or insoluble ones, bound to divalent and trivalent cations on the soil solid phase (Morel et al, 1989). The adsorbed phosphate on oxides or clays may be covered by more oxides or become a part of a crystalline oxide, thus a tendency for the solubility of the adsorbed phosphate to decline with time (Shrestha and Lin, 1996). This may be the case in the manured treatments where, although the nutrient budgets imply phosphate accumulation, it was not observed since only the available phosphorus was measured and not the total phosphorus. Masuda & Boyd (1994) found that the phosphorus pool in the pond soil was over 500 times greater than that of pond water but most of the soil phosphorus was strongly adsorbed and unavailable. They concluded that most of the phosphorus added to fish ponds ends up in the soil in an unavailable form and the present results appear to conform to this conclusion. However, for further understanding of phosphorus availability, future studies should measure both total and available phosphorus.

Potassium

The decrease in sediment potassium concentration after one month (Table 1) may be attributed to ion exchange reactions (Chikafumbwa, 1996). Potassium concentration in the sediment may have been higher than that in the overlying pond water, hence potassium ions were released from the pond sediment to the water column until equilibrium was established and maintained afterwards. In the nutrient budgets (Table 4), higher total losses than total inputs imply that there was another source of exchangeable potassium other than feed/fertilizer, stocked fish and inflow. The ‘other source’ could be the pond sediment. However, the contribution of exchangeable potassium by ‘other source’ was less than 1 kg pond^{-1} in all treatments (Table 4) while the apparent loss from the sediment was about 3 - 4 kg pond^{-1} (Table 3). It is possible that part of the potassium was leached to the deeper layers of the pond sediments.

Pond sediment potential as a crop fertilizer

Assuming the estimated quantities of the accumulated sediment was harvested for use in agriculture, estimates of the potentially available nutrients were calculated. The estimated quantities of the accumulated sediment could contain from 100 – > 300kg of nitrogen, 1.8 – 5 tons of organic matter (twice the values of organic carbon), 0.2 – 1.1 kg of available phosphorus and 50 – 125 kg of exchangeable potassium ha^{-1} per growing season (Table 5). In Egypt (the location of the study site), corn is one of the main food crops and the recommended nitrogen, phosphorus and potassium fertilization rates are 286, 200 and 85 kg ha^{-1} respectively. At the observed sediment and nutrient accumulation rates, accumulated sediment ha^{-1} cycle^{-1} could potentially meet the nitrogen fertilizer requirement for 0.35 – 1.2 hectare, and the potassium fertilizer requirement for 0.7 – 1.5 hectare but only less than 1% of the phosphorus fertilizer requirement. In addition, organic matter in the accumulated sediment can improve the condition of the agricultural soil through increased water holding capacity, aeration and stability (Miller and Donahue, 1990). However, in the build up of a data base towards the promotion of pond sediment as an agricultural input, field trials to evaluate its fertilizing effect on important agricultural crops, would add further valuable information.

Table 5: Quantity of nutrients in the accumulated sediment and its potential for land based agriculture

	Treatments							
Parameters	CM_1		CM_2		P_1		P_2	
	minimum	maximum	minimum	maximum	minimum	maximum	minimum	maximum
Accumulated sediment quantity (tons pond^{-1} cycle)	3.1	3.46	-0.78	1.5	2.8	3.3	1.67	2.8
Nitrogen								
Concentration at harvest (g kg^{-1})	1.9	1.9	1.9	1.9	1.7	1.7	1.6	0.16
Quantity in accumulated sediment (kg pond^{-1})	5.89	6.57	0	2.85	4.76	5.61	2.67	4.48
Quantity in accumulated sediment (kg ha^{-1})	295	329	0	143	238	281	124	224
Organic carbon								
Concentration at harvest (g kg^{-1})	14.5	14.5	12.5	12.5	11.7	11.7	12.7	1.27
Quantity in accumulated sediment (kg pond^{-1})	45.0	50.2	0	18.8	32.8	38.6	21.2	35.6
Quantity in accumulated sediment (tons ha^{-1})	2.3	2.5	0	0.9	1.6	1.9	1.1	1.8
Available phosphorus								
Concentration at harvest (g kg^{-1})	0.0063	0.0063	0.0038	0.0038	0.0033	0.0033	0.0035	3.5
Quantity in accumulated sediment (kg pond^{-1})	0.019	0.022	0	0.006	0.009	0.011	0.006	0.010
Quantity in accumulated sediment (kg ha^{-1})	0.97	1.1	0	0.28	0.46	0.54	0.29	0.49
Potassium								
Concentration at harvest (g kg^{-1})	0.072	0.072	0.077	0.077	0.074	0.074	0.073	0.073
Quantity in accumulated sediment (kg pond^{-1})	2.23	2.49	0	1.16	2.07	2.44	1.22	2.04
Quantity in accumulated sediment (kg ha^{-1})	112	125	0	58	104	122	61	102

Conclusion

The study showed that, up to 173 tons of pond sediment, ha^{-1} cycle $^{-1}$, could accumulate in semi-intensive tilapia production ponds. While the major source of the accumulated sediment could not be explained, influent water and organic pond inputs were not major sources and temporal measurements of sediment bulk densities were found to be important for accurate estimates of accumulated sediment. Nutrients released during mineralization of the organic inputs enriched the accumulated sediment, especially with nitrogen. The accumulated sediment is rich in nitrogen, exchangeable potassium, and organic matter. As such, it has a high potential as a nitrogen and potassium fertilizer, and as a soil conditioner. Declining quantities of sediment available phosphorus in the study suggest that accumulation of phosphorus in pond sediment may be in non available forms.

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Chapter 5

Rhizons improved estimation of nutrient losses due to seepage in aquaculture ponds

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Abstract

The use of rhizons to collect seepage water samples in aquaculture ponds was tested by installing two 10-cm rhizons, per pond, in 16 tilapia ponds. Using the rhizons, it was possible to directly extract water from the sediment, and determine its nutrient concentration. Nutrient concentrations in seepage water were significantly higher than in pond water, contrary to the common assumption of equal nutrient concentration of solutes in pond water and seepage water. Calculation of nutrient losses due to seepage from ponds based on pond water nutrient concentrations was found to result in a consistent underestimation. Direct sampling of bottom water using rhizons provided a standardized and easy to use method to quantify nutrient losses due to seepage from earthen pond soils.

Muendo, P. N., J. J. Stoorvogel, E.N. Gamal and M. C. J. Verdegem, 2005. Rhizons improved estimation of nutrient losses due to seepage in aquaculture ponds. Aquaculture Research 36: 1333 – 1336. Short communication

Seepage is one of the largest water losses in static ponds accounting for about 30 – 70% of total pond water losses (Boyd, 1982b; Green and Boyd, 1995; Ahmad et al., 1996). Reported seepage rates vary substantially from location to location (Stone and Boyd, 1989), and range from a mean of 0 –9 cm day^{-1} (Boyd, 1982; Diana *et al.*, 1985; Teichert – Coddington *et al.*, 1988; Stone and Boyd, 1989; Green and Boyd, 1995, Nath and Bolte, 1998) or up to 900 m^3 ha^{-1} day^{-1}. Seepage not only constitutes loss of pond water but also leaches nutrients (Teichert –Coddington *et al.*,, 1989). Estimation of nutrient losses due to seepage in ponds is one of the difficulties encountered in pond nutrient dynamic studies since there is no standard method for sampling seepage water. Pond nutrient losses due to seepage have thus been quantified by assuming identical nutrient concentrations in seepage water and pond water (Boyd, 1985; Briggs and Funge-Smith 1994). However, higher nutrient concentrations in pore water than in pond water were observed by Masuda and Boyd (1994) and Jimenez-Montealegre et al. (2005). It is therefore, highly likely that the nutrient-seepage-loss is underestimated by assuming identical nutrient concentration for seepage water and pond water. Such underestimation further contributes to difficulties encountered in achieving balanced nutrient budgets in ponds. A reliable method to extract seepage water in ponds for the direct determination of nutrient concentrations is thus essential.

Jimenez-Montealegre et al. (2005) obtained pore water by centrifugation of the top 5-cm layer of pond sediments. This method allows for direct sampling of pore water but obtaining soil cores from ponds and centrifuging the samples is both tedious and time consuming. Moreover, some soil particles may remain in the supernatant and lead to overestimation of the nutrient concentrations. Masuda and Boyd (1994) obtained soil pore water using a household filter element connected to a 500-ml vacuum flask and a hand operated vacuum pump. The filter element was placed approximately 10 cm below the mud surface and left in place during the entire sampling period. The vacuum pump reduced the pressure within the system and pore water could be collected. This method has less time requirements and causes little disturbance of the bottom sediments as the equipment is installed once at the beginning of the experiment. However, it is not a standardized procedure and in case of many ponds, the manual operation of the hand pump is tedious too.

This short communication describes a novel method in which a similar principle as in Masuda and Boyd (1994) is applied to obtain seepage water directly. It is standard methodology developed in soil science to sample soil moisture from the vadous zone. The method involves the use of small suction probes called rhizons*. Rhizons are made of a thin polymer tube with a 1 mm internal diameter and 0.1 micron pores. The small size of rhizons results in a minimal disturbance of the original soil profile while the small pore size ensures exclusion of any soil or organic particles. Once installed before pond filling they can be left in place the entire period ensuring minimum disturbance of the pond bottoms during sampling periods.

The method was tested in sixteen 200-m^2 tilapia ponds at The World Fish Centre's Africa and West Asia Regional Center at Abbassa (Egypt). Two 10-cm long rhizons were placed 10 cm below the bottom surface of each pond before ponds were filled with water. The rhizons were connected to plastic extension tubes, 1.3m long with an internal diameter of 1 mm and extended to above the water surface. To obtain seepage water samples, the rhizons were connected to 10 ml vacuum tubes through the extension tubes and left in place for 2-3 hours after which the water filled tubes were removed. Five water filled tubes were collected from each pond each month and the samples pooled to form a 50 ml water sample. The pooled samples were taken to the laboratory for analysis of nitrogen, phosphorus and potassium. Each time seepage water samples were collected from the rhizons, pond water samples were also collected using a water column sampler (Boyd and Tucker, 1992) and analysed for the same nutrients.

In the laboratory, seepage and pond water samples were analysed for total phosphorus by persulphate digestion (Gross and Boyd, 1998) followed by ascorbic acid analysis (Boyd and Tucker, 1992), total nitrogen by persulphate digestion (Gross and Boyd, 1998)

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* *Rhizon sampler from Eijkelkamp Agrisearch Equipment, http://www.eijkelkamp.com*

followed by phenoldisulfinic acid analysis (Boyd, 1979), and potassium by atomic absorption (Page et al. 1982). Pond water samples were analysed for soluble reactive phosphorus by ascorbic acid method (Boyd and Tucker, 1992), total ammonia nitrogen by phenate method (APHA, 1995), nitrite nitrogen by diazotization method (Boyd and Tucker, 1992), nitrate nitrogen by phenoldisulfinic acid method (Boyd, 1979), and potassium by atomic absorption (Page et al. 1982). All inorganic species of nitrogen in pond water were summed up to give the total inorganic nitrogen.

For quantification of nutrient losses due to seepage, the amount of water lost through seepage was measured by periodic observations of water levels in air tight closed PVC pipes installed in the ponds. The PVC pipes (8 cm diameter, 1.5 m long) were pushed 30cm into the pond bottom and protruded to the water surface. A ruler marked in cm was fixed in the inside of each PVC pipe and the pipes were filled with water to the zero mark. Changes in water levels inside the pipe reflected water losses due to seepage. The volume of water loss to seepage and the quantity of nutrient loss due to seepage were calculated as shown below:

Volume of water loss to seepage (litres) =Change in water level inside the PVC pipe (m) X pond area (m^2) X 1000

Quantity of nutrient loss (g) = (nutrient concentration in pond or seepage water (mgl^{-1}) X volume of water loss due to seepage (litres))/1000

The null hypothesis that nutrient concentrations in rhizon samples did not differ from those in pond water concentrations was tested using a Students *t*-test at a confidence level of 95% using the data from all 16 ponds. The analysis was run by SPSS (version 11.2) statistical software package (SPSS, Chicago).

The mean nitrogen, phosphorus and potassium concentrations in seepage water were significantly higher than in pond water at all the sampling times (Figure 1).

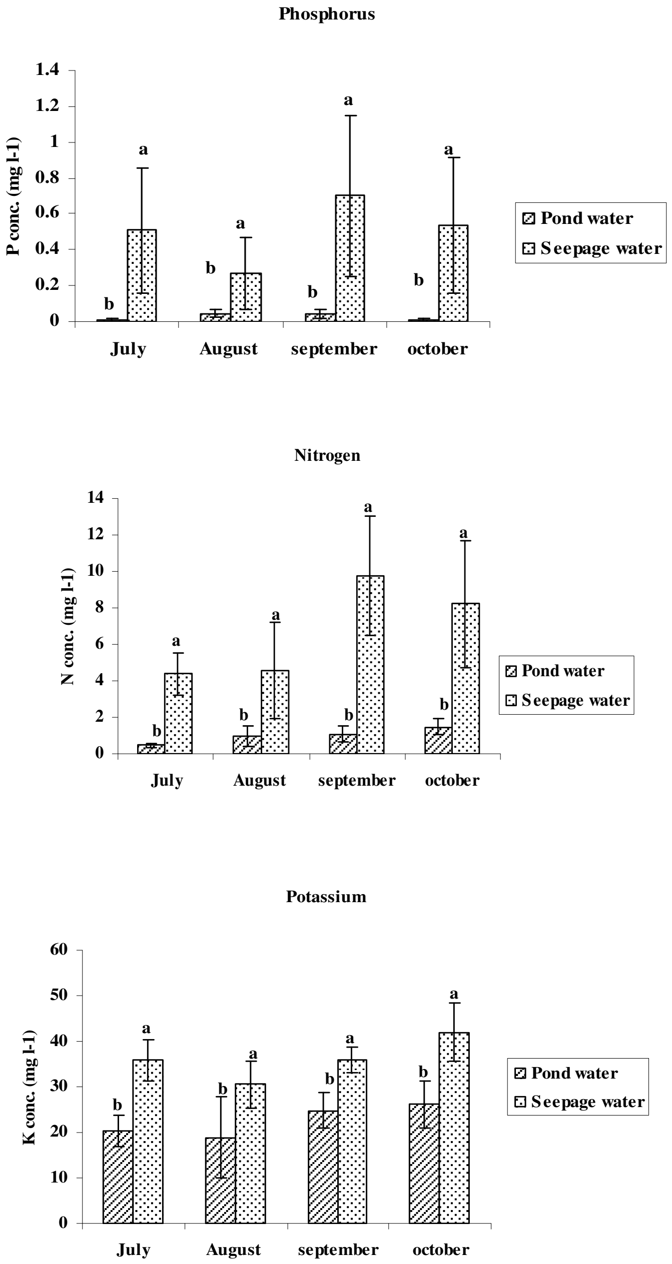

Figure 1: Nitrogen, phosphorus and potassium concentrations in pond water and seepage water samples in all the sampling months. Letters above the error bars indicate significant difference in the means at 0.01 level (results of t-test), a>b.

Calculation of nutrient losses due to seepage from ponds based on pond water nutrient concentrations resulted in consistent underestimation (Table 1). In this experiment, on average for the whole period (4 months), nitrogen loss would have been underestimated by a factor of 6.5, phosphorus loss by a factor of 20.9 and potassium loss by a factor of 1.6 (Table 1). The results conform to earlier observations (Masuda and Boyd, 1994; Jimenez-Montealegre, 2001) that the chemical composition of pore water (and hence water seeping out of ponds) is different from that of the pond water. Mineralization of ammonia during organic matter decomposition and solubility of iron phosphates due to reduced redox potentials at the sediment water interface contribute to the higher nutrient concentrations in pore water (Boyd 1982a, Lofgren and Bostrom 1989, Sondergaard 1990, Masuda and Boyd, 1994).

The assumption of identical chemical composition in seepage water and pond water therefore results in underestimation of nutrient losses due to seepage. Direct sampling of bottom water using rhizons combined with seepage volume measurements provides a standardized and easy to use method to quantify nutrient losses due to seepage from earthen pond soils. Using this method it will be possible to improve the precision of nutrient budgets, especially in ponds with high seepage losses.

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Table 1: Mean (± stdev) water volume and quantity of nutrient loss (g) through seepage pond^{-1} month^{-1} and magnitude of error (underestimation factor) by assuming that concentration of nutrient in seepage water is the same as in pond water

Month	Volume of seepage (litres)	Nitrogen			Phosphorus			Potassium		
		pond water	seepage water	under-estimation factor	pond water	seepage water	Under-estimation factor	pond water	seepage water	Under-estimation factor
July	3375 ± 1310	1.56 ± 0.8	14.31 ± 5.9	9.20	0.04 ± 0.0	2.92 ± 4.8	73.00	68.69 ± 28.7	121.58 ± 50.4	1.77
August	4363 ± 1694	4.60 ± 3.9	21.02 ± 15.6	4.57	0.20 ± 0.1	1.72 ± 2.1	8.60	76.71 ± 35.8	136.06 ± 65.9	1.77
Sept.	6725 ± 3720	7.76 ± 7.6	62.70 ± 36.0	8.08	0.27 ± 0.2	4.91± 4.3	18.19	164.89 ± 90.3	240.74 ± 125.6	1.46
Oct.	4275 ± 1912	6.65 ± 4.8	35.14 ± 18.8	5.29	0.05 ± 0.0	2.06 ± 1.3	41.20	110.16 ± 44.7	179.23 ± 77.6	1.63
Total		20.56	133.17	6.48	0.56	11.62	20.89	420.45	677.61	1.61

CHAPTER 6

General discussion

Aquaculture ponds play an important role in the nutrient cycling through mixed farming systems. Nutrients contained in by-products of terrestrial farming can contribute to the production of aquatic food products. In turn, nutrient-rich water and sediment from ponds can provide irrigation water or fertilizer for terrestrial cropping (Jamu and Piedrahita, 2002). Thus, integration of an aquaculture component into agricultural farming systems can result in improved nutrient use efficiencies and besides, it also can improve ecological sustainability (Pillay, 1994; Naylor, 200). Despite the compatibility of objectives and ensuing benefits, integration of aquaculture with terrestrial farming is not widespread, often because of insufficient knowledge of the benefits to each of the various components of the farming systems (Hopkins and Bowman, 1993; Lin and Yi, 2003). In many cases, fish has been considered as the only product from the aquaculture component, thereby neglecting the potential role of fish pond sediments and water (Brankeret, 1979; Little and Muir, 1987; Pillay, 1994).

This thesis analyzed the role of the pond in nutrient trapping and nutrient use efficiency in integrated farming systems. The technical feasibility of developing integrated aquaculture – agriculture (IAA) systems in traditional agricultural farming systems was explored and their benefits evaluated and quantified in Chapter 2, the nutrient efficiency of agricultural by-products such as crop residues and animal manure for fish production investigated in Chapter 3 and nutrient accumulation in pond sediments quantified and their potential for agricultural use estimated in chapters 4 and 5. In this chapter, the results, their practical implications, and the future perspectives are discussed.

The technical feasibility of IAA systems, their effect on nutrient cycling and the resultant benefits in terms of farm productivity and soil fertility was illustrated for a case study in Kenya (chapter 2). The results showed that utilization of agricultural by- products results in considerable aquaculture production (chapter 3) and that, substantial quantities of sediment and nutrients retained in the pond have a high potential for agricultural use (chapter 4). Over 300 tons ha^{-1} $year^{-1}$ (173 tons per ha per 5 month cycle) of pond sediment accumulated, which had the potential to meet the nitrogen and potassium requirement for over 1.5 ha of maize (chapter 4). Besides the nutritive value, the pond sediment contained high amounts of organic matter which when added to agricultural soils, especially in heavy clay and in light sandy soils, can be a valuable soil conditioner, improving the soil structure and increasing water holding capacity. It is apparent that the benefits from fish ponds in IAA systems are more related to the use of pond sediment in agriculture, than to the production of fish alone.

In many integrated farming systems, aquaculture has been considered separately from agriculture and also, has not been given the same priority. Use of available land and nutrient inputs for agricultural production takes priority and when practiced, aquaculture is secondary to agriculture (FAO, 1997; Nhan et al., unpublished). This thesis has however demonstrated that integration of aquaculture is not a threat to agricultural production (chapter 2). The loss of agricultural production from the small piece of agricultural land that is converted to fish ponds, is adequately compensated by the opportunity for higher efficiency in assimilation of agricultural wastes and the availability of pond sediment for agricultural soil improvement, resulting in higher agricultural production, besides increased diversity in crop production (this thesis, chapter 2; Mathias, 1998)

In other cases in developing countries, the development of aquaculture itself is low and is hampered by lack of fish feeds (Omondi et al., 2001). Semi-intensive fish culture has been based on nutritionally complete feeds (Liti et al, 2005), because they are said to boost pond production beyond that achievable with fertilization (Hepher, 1978; Diana et al., 1991; 1994). Besides their unavailability, these feeds are costly and lead to increased production costs and reduced profits, forming an impediment to aquaculture development (Omondi et al, 2001).

In this thesis (chapter 3), the results suggested that fish yields, comparable with those obtained with formulated diets, were possible with organic fertilization alone. Similar results have also been reported by other researchers (Schroeder, 1983; Knud-Hansen et al., 1993; Lochmann and Phillips, 1996). The ecological pathways also suggested that in formulated feed driven ponds, the growth of fish was based on natural foods, just as in organically fertilized ponds (chapter 3). This implies that formulated feeds acted as organic fertilizers. While the significance of formulated feeds on semi-intensive pond culture needs to be further evaluated (Green et al. 2002), the results show that formulated diets are not a pre-requisite to high production in semi-intensive aquaculture, and hence should not impair aquaculture development.

Besides, the results in chapter 2 and 4 demonstrate that the role of aquaculture is beyond the production of fish alone. Rather, aquaculture has an important role in agricultural development and apparently, the benefits of IAA systems seem to be more with terrestrial crops through pond sediment and pond water nutrient cycling than with the aquatic crops (this thesis - chapter 2; Prein et al., 1996; Williams, 1997; Pant et al., 2004). In Ghana, Ruddle (1996) found that water used for vegetables had more impact on cash generation and food security than the limited output of fish from small ponds. Similarly, in Malawi and Northeast Thailand, small holder farmers were found to be more interested in ponds during prolonged periods of drought, principally for the value of the water stored for vegetable and livestock production rather than stocked fish (Noble, 1996; Surintaraseree and Little, 1998). Thus, for small scale farmers in developing countries, aquaculture should not be promoted as a stand-alone activity. Rather, for greater achievements towards food security, rural aquaculture needs to be promoted in the context of integrated aquaculture-agriculture development (Edwards, 2000). Extension services should focus on educating rural people, to recognise the value of ponds in more holistic terms (Edwards and Demaine, 1997).

Conclusions and future perspectives

The study results demonstrated the technical feasibility of IAA systems from a bio-physical point of view and the possibility to address the issues of soil fertility and food security in Africa through IAA. Nevertheless, the development and expansion of IAA systems still requires the consideration of other potential constraints related to social, economic and institutional aspects (Edwards, 2000). The development of the IAA systems does not only entail the linkage of two different activities. Rather, IAA systems are new farming systems themselves, which need further development and optimization. Because aquaculture is a relatively unknown farming practice in Africa, and also, still in many parts in Asia, stimulating the development of IAA systems is not an easy task (Edwards, 1996; Lewis, 1998). As such, the provision of knowledge or institutional support in the form of extension services for aquaculture development needs careful consideration.

Further, research on the feasibility of IAA systems should also address consumer and farmer perceptions on the value of fish (Edwards, 1996), and assess the economic implications and impacts on the livelihood of farming households. The harvesting and transportation of pond sediments to fields for crop production are laborious activities. Therefore, the practical implications of labour availability for pond sediment use should be placed in a broad socio-economic context. The same holds when considering the various options available for water or land use.

Overall, the preliminary results show that investing in the further development of IAA-systems may be more efficient than looking for new sources of nutrient inputs in order to combat nutrient depletion in sub-Saharan agriculture.

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Summary

Rapid population growth in developing countries has resulted in increased demand for food, leading to increased pressure to extend land under cultivation and to intensify food production. Because most of the arable land has already been utilized, further intensification of agricultural production has involved conversion of marginal lands such as forest reserves, communal grazing lands and fragile areas such as river banks and steep hill slopes. Intensified crop production on marginal lands enhances the risk for soil degradation, like soil fertility decline. In many situations, inorganic fertilizers are not available or are too expensive, and efficient utilization of organic residues such as crop residues and manures is constrained by a temporal mismatch between availability and application. Diversification of farming activities potentially increases nutrient efficiencies. One promising additional activity is aquaculture and the development of integrated aquaculture - agriculture (IAA) systems.

Although integrated aquaculture – agriculture farming systems have been developed and practiced in some parts of Asia, they have not been widely adopted. In many developing countries, especially in Africa, aquaculture itself is still poorly developed. Aquaculture is considered separately from agriculture and its benefits are measured in terms of fish production, ignoring its role in nutrient cycling through integrated farming systems. Yet, the majority of nutrients entering ponds, including fertilizers, feeds and nutrients contained in inflows from channels or run-off from watersheds, accumulate in the sediment. These nutrients are a potential nutrient source for terrestrial agriculture.

This thesis explored the use of fish ponds as nutrient traps (besides fish production) to increase the nutrient use efficiency in mixed farming systems. Focus was put on (i) nutrient utilization efficiency of agricultural by-products such as crop residues and animal manure in aquaculture production, and(ii) in quantitative aspects of sediment and nutrient accumulation in aquaculture ponds, and pond sediments' potential as a fertilizer in land-based agriculture

In **chapter 2,** aquaculture components were ideotyped for existing agricultural farming systems and benefits from resultant ideotyped integrated aquaculture – agriculture (IAA) farming systems were evaluated and quantified. The results showed that integration of an aquaculture component in agricultural farming systems provided the opportunity to recycle eroded nutrients. In addition, aquaculture provided an opportunity to utilize nutrients from agricultural by-products otherwise lost through leaching during storage. As the majority of nutrients added to ponds accumulate in the sediment, nutrients are stored for later use. In different agro-ecological zones of the Kenyan highlands this practice reduced soil fertility decline by 23 – 35%, increased agricultural production by 2 – 26% and raised the overall farm food production by 22 – 70%. The results indicated that there may be more benefits from pond sediment utilization than fish production alone and also demonstrated that integration of aquaculture is not a threat to agricultural production. The nutrient storage capacity of ponds and the linked increase in productivity largely compensates for the small loss in land surface for crop production.

In **chapter 3**, the nutrient utilization efficiency of agricultural by-products in fish ponds was investigated and compared to that of supplemental foods. Using multivariate analyses, the trophic pathways in organically fertilized and feed driven semi-intensive culture environments were explored. By ANOVA models, water quality, sediment quality and tilapia growth and yields in the two environments were also compared. In both environments, a phytoplankton based food web dominated, and fish nutrition in both environments was mainly based on natural foods. Extrapolated fish yield data indicated that with equal nutrient input and stocking density, organically fertilized environments could achieve production rates similar to those in feed driven environments. The results challenge the general assumption that supplemental or complete foods are well utilized by tilapia in ponds and underscore the need for further research on fish nutrition in ponds.

In **chapter 4,** the sediment and nutrient accumulation in semi-intensive fish culture ponds within one culture period was quantified, the effect of input type (chicken manure vs. formulated feed) and stocking density (1 or 2 fishes m^{-2}) on sediment and nutrient

accumulation evaluated, and the accumulated sediment's potential for use in land-based agriculture estimated. An accumulation of up to 173 tons of sediment ha^{-1} $cycle^{-1}$ (5 months) was observed in the semi-intensive production ponds and contained between 100 – 300kg of nitrogen, 1.8 – 5 tons of organic matter, 0.2 – 1.1 kg of available phosphorus and 50 – 125 kg of exchangeable potassium. Both sediment and nutrient accumulation were not affected by input type or stocking density. The results indicated that often reported accumulation of phosphorus in pond sediment may be in non-available forms. However, accumulated sediment had a high potential as nitrogen and potassium fertilizer and as a soil conditioner. By recommended Egyptian fertilization rates, the accumulated nutrients during a tilapia production cycle could potentially meet the nitrogen fertilizer requirement for 0.35 – 1.2 hectare and the potassium fertilizer requirement for 0.7 – 1.5 hectare.

A part of the nutrients that accumulate in aquaculture ponds are lost through seepage. Normally, the assumption is made that seepage water and pond water have the same composition. In **chapter 5**, the use of rhizons as a standard methodology to measure the concentration of nutrients in seepage water was developed. The results showed that assuming identical chemical composition in seepage water and pond water results in an underestimation of nutrient losses due to seepage. Direct sampling of seepage water using rhizons provided a standardized and easy to use method to quantify nutrient losses due to seepage from earthen pond soils.

The findings of this thesis are discussed in **chapter 6** and main conclusions are given. The study demonstrated, from a bio-physical point of view, the technical feasibility of aquaculture - agricultural integration and the effect on nutrient cycling through the whole farming system. For further understanding of the benefits of IAA systems, future studies should asses the socio-economic feasibilities of IAA systems. The study has also shown that agricultural by-products do not necessarily result in lower fish production compared to the use of formulated feeds. The results stress the need to search for new concepts for pond nutrition, as the present use of formulated diets serves more as an expensive fertilizer than a direct feed.

Samenvatting

De toenemende bevolkingsgroei in ontwikkelingslanden gaat gepaard met een grotere vraag naar voedsel dat vervolgens leidt tot een groeiende vraag naar de uitbreiding van het areaal landbouwgronden en een intensivering van de voedselproductie. Omdat het meeste, voor landbouw geschikte, land reeds in gebruik is, heeft de uitbreiding van de agrarische productie tot gevolg gehad dat marginale gebieden (bosreservaten, gemeenschappelijke graaslandschappen en kwetsbare gebieden zoals rivieroevers en steile heuvelhellingen) zijn omgevormd tot landbouwgrond. Intensieve landbouw op aangrenzende stukken land vergroot het risico op bodemdegradatie, zoals het verminderen van de bodemvruchtbaarheid. In veel gevallen is anorganische mest niet beschikbaar of te duur, en efficiënt gebruik van organische residuen zoals gewasresten en mest is beperkt doordat de beschikbaarheid en het gebruik ervan niet gelijktijdig plaatsvindt. De diversificatie van de lanbouwsystemen kan mogelijk de nutriëntenefficiëntie vergroten. Een veelbelovende aanvullende activiteit is visteelt m.n. in combinatie met grondgebonden landbouw en veeteelt.

Hoewel geïntegreerde landbouw-visteelt systemen al zijn ontwikkeld en worden toegepast in sommige delen van Azië, worden ze nog niet wijdverspreid toegepast. In veel ontwikkelingslanden, en met name in Afrika, is visteelt zelf nog maar nauwelijks ontwikkeld. Visteelt vindt vaak onafhankelijk van de landbouw plaats in gespecialiseerde bedrijfssystemen. De voordelen van visteelt worden gemeten in termen van visproductie en de rol van visteelt in het recyclen van nutriënten door geïntegreerde systemen wordt daarmee verwaarloosd. De meerderheid van de nutriënten die de vijvers binnenkomt, inclusief mest, voedsel en nutriënten in de toevoer van kanalen en afvloei water van waterkeerpunten, hopen op in het sediment. Deze nutriënten zijn een potentiële bron van nutriënten voor de landbouwsystemen.

Dit proefschrift onderzocht het gebruik van visvijvers als "nutriënten val" (naast visproductie) om de efficiëntie van het nutriëntengebruik in gemengde bedrijfssystemen te verhogen. Nadruk werd gelegd op (i) de efficiëntie van nutriëntengebruik van bijproducten uit de landbouw zoals gewasresiduen en dierlijke mest in visteelt productie, en (ii) de kwantitatieve aspecten van sediment- en nutriëntenophoping in kweekvijvers en de potentie van het vijversediment als meststof in de landbouw.

In **hoofdstuk 2** zijn onderdelen van visteelt getypeerd voor bestaande landbouwkundige teeltsystemen. Voordelen van resulterende getypeerde geïntegreerde visteelt - landbouw (IAA) teeltsystemen zijn geëvalueerd en gekwantificeerd. De resultaten lieten zien dat integratie van een visteelt component in landbouwsystemen de gelegenheid biedt om geërodeerde nutriënten te recyclen. Bovendien konden door visteelt nutriënten van bijproducten van de landbouw gebruikt worden die anders verloren waren gegaan door verliezen tijdens opslag. Aangezien de meerderheid van de toegevoegde nutriënten aan vijvers accumuleren in het sediment, worden de nutriënten opgeslagen voor later gebruik. In verschillende agro-ecologische zones van de Keniaanse hooglanden verminderden deze geïntegreerde systemen de verliezen in bodemvruchtbaarheid met 23-35%, verhoogden ze de landbouwproductie met 2-26% en verhoogden ze de algemene voedselproductie met 22-70%. De resultaten geven aan dat er meer voordelen zijn van het gebruik van vijversediment dan visproductie en lieten ook zien dat integratie van viskweek geen bedreiging is voor landbouwproductie. De nutriëntenopslagcapaciteit van vijvers en de daarmee verbonden verhoging in productiviteit compenseert in hoge mate voor de kleine verliezen in landoppervlakte voor gewasproductie.

In **hoofdstuk 3** is de efficiëntie van het nutriëntenverbruik van landbouwkundige bijproducten in visvijvers onderzocht en vergeleken met dat van supplementenvoeders. Gebruikmakend van multivariate analyse is het nutriëntenweb in organisch bemeste en voedselgedreven semi-intensieve kweekomgevingen onderzocht. Waterkwaliteit, sedimentkwaliteit en Tilapia groei en opbrengst in deze twee omgevingen zijn vergeleken. In beide omgevingen domineerde een fytoplankton gebaseerd voedselweb en visvoeding in beide omgevingen was voornamelijk gebaseerd op natuurlijk voedsel. Geëxtrapoleerde data van visproductie lieten zien dat bij gelijke nutriënteninput en visdichtheid, organisch bemeste omgevingen dezelfde productie snelheden konden bereiken dan in voedselgedreven omgevingen. De resultaten trekken de algemene aanname dat supplementen of complete voeders goed gebruikt worden door Tilapia in vijvers in twijfel en onderstrepen de behoefte aan verder onderzoek naar visvoeding in vijvers.

In **hoofdstuk 4** zijn de sediment- en nutriëntenaccumulatie in semi-intensieve visvijvers binnen een kweekperiode gekwantificeerd, het effect van het type bemesting (kippenmest vs. samengesteld voer) en visdichtheid (1 of 2 vissen per m^2) op sediment en nutriënten accumulatie geëvalueerd, en de potentie van het geaccumuleerde sediment geschat voor gebruik in landbouwsystemen. Een accumulatie tot 173 ton sediment ha^{-1} $cyclus^{-1}$ (5 maanden) werd gemeten in de semi-intensieve productievijvers en bevatte tussen 100-300 kg stikstof, 1.8-5 ton organische stof, 0.2-1.1 kg beschikbare fosfor en 50-125 kg uitwisselbaar kalium. Sediment- en nutriënten-accumulatie worden niet beïnvloed door het type bemesting of visdichtheid. De resultaten impliceren dat de vaak gerapporteerde ophoping van fosfor in vijversediment in niet-beschikbare vormen plaatsvindt. Echter, opgehoopt sediment had een hoog potentieel als stikstof en kalium meststof en als bodemconditioner. Op basis van aanbevolen Egyptische bemestingsadviezen kunnen de opgehoopte nutriënten tijdens een Tilapia productiecyclus in 1 ha vijver voldoen aan de stikstof- en kaliumbehoefte voor 0.35-1.2 en 0.7-1.5 hectare maïs, respectievelijk, voldoen.

Een deel van de nutriënten dat ophoopt in visvijvers gaat verloren door langzaam uitspoelen. Normaal gezien wordt aangenomen dat het drainage water en vijverwater dezelfde samenstelling hebben. In **hoofdstuk 5** is het gebruik van rhizons als standaard methodologie ontwikkeld om nutriëntenconcentratie in infiltratiewater te meten. De resultaten lieten zien dat de aanname dat drainagewater en vijverwater éénzelfde chemische samenstelling hebben resulteert in een onderschatting van nutriëntenverliezen door infiltratie. Het direct bemonsteren van drainage water gebruikmakend van rhizons geeft een gestandaardiseerde en eenvoudige methode om nutriëntenverliezen te kwantificeren die veroorzaakt zijn door infiltratie in vijverbodems.

In **hoofdstuk 6** zijn de resultaten van dit proefschrift bediscussieerd en conclusies zijn geformuleerd. Dit proefschrift liet vanuit een biofysisch oogpunt de technische haalbaarheid van visteelt-landbouw integratie en het effect op nutriënten-recycling door het hele bedrijfssysteem zien. Voor een beter begrip van de voordelen van deze geïntegreerde systemen moeten toekomstige studies zich richten op hun sociaal-economische haalbaarheid. Dit proefschrift heeft ook laten zien dat landbouwkundige bijproducten niet per definitie resulteren in een lagere visproductie vergeleken met het gebruik van samengestelde visvoeders. De resultaten benadrukken de behoefte om nieuwe concepten voor vijvervoeding te onderzoeken, omdat het tegenwoordige gebruik van samengestelde voeders meer als een dure meststof dient dan als direct opneembaar voedsel.

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PhD training and education plan

Training and Supervision Plan		**Graduate School WIAS**
Name PhD student	PATRICIA NDUKU MUENDO	
Project title	The role of fish ponds in the nutrient dynamics of mixed farming systems.	
Group	Aquaculture and Fisheries Group	
Daily supervisor(s)	Marc C.J. Verdegem, Jetse J. Stoorvogel	
Supervisor(s)	Prof. J.A.J. Verreth	
Project term	from 19/02/2002	until 09/06/2006
Submitted	date 04/05/2006	first plan / midterm / **certificate**

EDUCATION AND TRAINING (minimum 30, maximum 60 credits)		
The Basic Package (minimum 3 credits)	year	credits *
WIAS Introduction Course (mandatory)	2003	
Course on philosophy of science and/or ethics (mandatory)	2003	
Subtotal Basic Package		**3**
Scientific Exposure (conferences, seminars and presentations, minimum 8 credits)	year	
International conferences *(minimum 3 credits)*		
7th Asian Fisheries Forum 2004, Penang, Malaysia, 30 Nov. - 4 Dec. 2004	2004	
World Aquaculture Society, Bali, Indonesia, 9 - 13 May 2005	2005	
Seminars and workshops		
WIAS Science Day 2002, 2003, 2004, 2005	2002-2005	
WIAS Seminar, 12 Dec. 2003: 'Ecosystem approaches in food production'	2003	
INREF - POND Scientific Workshop, 14 April 2005	2005	
POND-LIVE Workshop, Penang, Malaysia, 28 - 29 Nov. 2004	2004	
WIAS seminar, 23 May 05: 'Vitality of fish: aspects at organism and system level'	2005	
INREF-POND Symposium, Cantho, Vietnam, 25 - 28 April	2006	
Presentations *(minimum 4 original presentations of which at least 1 oral, 1 credit each)*		
WIAS Science Day 2004 - poster: Sediment accumulation in fish ponds: a crop fertilizer?	2004	
Oral presentation Asian Fisheries Forum	2004	
Oral presentation POND-LIVE Workshop	2004	
Oral presentation, WAS - Bali	2005	
Oral presentation, INREF-POND scientific workshop	2005	
Oral presentation, INREF-POND symposium, Cantho, Vietnam	2006	
Subtotal International Exposure		**14**
In-Depth Studies (minimum 6 credits, of which minimum 4 at PhD level)	year	
Disciplinary and interdisciplinary courses		
Aqualabs course in Hungary	2005	
Advanced statistics courses		
WIAS course 'Design of Animal Experiments'	2005	
PE&RC Graduate School course 'Basic Statistics'	2005	
PE&RC Graduate School course 'Advanced Statistics'	2006	
Subtotal In-Depth Studies		**6**
Professional Skills Support Courses (minimum 3 credits)	year	
Techniques for Writing and Presenting a Scientific Paper	2005	
Project and Time Management	2005	
Carreer Perspectives	2005	
Subtotal Professional Skills Support Courses		**4**
Research Skills Training (optional)	year	
Preparing own PhD research proposal (maximum 6 credits)	2002	
Subtotal Research Skills Training		**6**
Didactic Skills Training (optional)	year	
Supervising theses *(max 2 credits per MSc major, 1.5 c MSc minor, 1 c BSc thesis)*		
Major MSc thesis (Pham Minh Duc): Nutrient accumulation in pond sediments	2004	
Subtotal Didactic Skills Training		**2**
Education and Training Total (minimum 30, maximum 60 credits)		**35**

* one ECTS credit equals a study load of approximately 28 hours

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To my parents, my brothers and sister, thank you for your support, encouragement, and prayers.

Patricia

Curriculum vitae

Patricia Nduku Muendo was born to Mr. & Mrs. William Mwau, on 27th July, 1970, in Machakos, Kenya. After completion of her primary and secondary education, she joined Nairobi University, Kenya, from where she graduated in July, 1995, with a BSc. degree in Botany/Zoology (a major in aquatic ecology). In August – December, 1995, she worked as a research assistant with the Tana –Athi River Development Project (supervisor: Prof. Ken Mavuti, Nairobi University). In February, 1996, she accepted a job from the Teachers Service Commission (TSC) and taught biology, chemistry and mathematics at Wakaela Secondary School, Machakos. In October, 1996, she was awarded an MSc. Scholarship from The University of Nairobi, and resigned from teaching. From October, 1997 to April, 1999, she worked with the PD/A CRSP (Pond Dynamics/Aquaculture Collaborative Research Support Programme), Sagana Fish Farm, Kenya, as an MSc. researcher. Her MSc. thesis studied the nutrient dynamics (nitrogen and phosphorus) in tilapia (*oreochromis niloticus*)/Catfish (clarius gariepinus) polyculture ponds, and evaluated the pollution potential of the pond effluents. She graduated in 2000 with a MSc. degree in Zoology (Hydrobiology). After graduation, she continued working with PD/A CRSP as a research assistant until October, 2001 when she was awarded a PhD scholarship through the INREF-POND project of Wageningen University, The Netherlands, in collaboration with the WorldFish Center, Egypt. From February, 2002 to June, 2006, she worked on the PhD research.

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List of publications and conference proceedings

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