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Sediment Accumulation in Fish Ponds; Its Potential for Agricultural Use

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ABSTRACT

An experiment was conducted at the World Fish Center in Egypt, to describe and quantify sediment and nutrient accumulation in semi-intensive tilapia ponds, evaluate the effect of input type and stocking density on sediment and nutrient accumulation and estimate accumulated sediment's potential for use in land-based agriculture. Sixteen 200 m² earthen (but with concrete walls) ponds were allocated 4 treatments with 4 replicates in a completely randomized 2x2 factorial design. The factors were input type (chicken manure at 50 kg dm / ha / day vs 25% protein pellets fed at 3% body weight day⁻¹) and stocking density (1 or 2 fishes / m²). All ponds were stocked with 20–25 g tilapia (*Oreochromis niloticus*) fingerlings and harvested after 4.5 months of culture. Ceramic tiles of 0.5 by 1 m² were installed horizontally at 5 cm depth in the sediment before pond filling and core sediment samples were taken above the ceramic tiles at monthly intervals for determination of sediment and nutrient accumulation. The quantified sediment and nutrient accumulation were used to estimate the fertilizer potential of pond sediment in land based agriculture. Up to173 tons of sediment / ha / cycle accumulated in the semi-intensive tilapia production ponds and contained nutrients that could potentially meet the nitrogen fertilizer requirement for 0.35–1.2 hectare and the potassium fertilizer requirement for 0.7 – 1.5 hectare at recommended Egyptian fertilization rates. 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.

Keywords: Quantify, sediment accumulation, nutrient accumulation, semi-intensive ponds.

1. Introduction

Sediment rich in organic matter, nitrogen and phosphorus, accumulates in fish ponds during culture [18, 23, 28, 51, 25, 10]. From a management perspective, accumulation of sediment is a menace as it fills ponds reducing their volume [10, 53]. 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 [13, 5] 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 [15, 25, 10]. On the other hand, management of the sediment removed from ponds becomes a scientific concern.

Disposal of pond sediments to natural systems possess an environmental threat [18, 51] and is a waste of valuable nutrients [29]. In China, Thailand and Vietnam, pond sediment has been used to fertilise crops and higher yields have been realised [31, 43]. Although pond sediment use in agriculture and its resultant positive impacts on crop yields in Asia are widely reported [45, 31, 43] the information is not supported scientifically [24, 20]. Lack of scientific documentation on quantitative and qualitative aspects of pond sediment hampers wider adoption and promotion of pond sediment use in agriculture [20].

The objectives of this paper are to (i) 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 / m²) affect the quantity and nutrient content of the accumulated sediment.

2. Materials and Methods

2.1 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 ponds with earthen bottoms and concrete walls 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 / day and stocked at a density of 1 and 2 fish / m^2 respectively. All the chicken manure used came from a common stock, obtained from one source before the start of the experiment and properly stored through out the experimental period. The composition of the manure was determined by obtaining 3 random samples from the heap, from which a composite sample was taken and analysed for Nitrogen, phosphorus and potassium. In treatments P_1 and P_2, fishes were fed floating 25% protein pellets at 3% body weight / day 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.

2.2 Water replacement; Fertilization, feeding, oxygen and temperature monitoring

Chicken manure was applied daily at 10 a.m by broadcasting all over the pond while the floating pellets were supplied twice a day at 10 a.m. and 3 p.m, also by broadcasting over the pond. 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) and temperature (°C) 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 did not finish the supplied ration. Thus, fish were fed *ad libitum* at the same hours as when fed 3% body weight. Daily records of the amounts of chicken manure or pellets supplied were kept and later summed to give weekly or monthly application rates. Water losses due to seepage and evaporation were replaced weekly.

2.3 Determination of sediment accumulation rate and quantification of accumulated sediment

In early spring (Egypt) 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. Since the ponds were left dry during winter, the sediment was made slightly wet, before starting to place the tiles, and care was taken to remove the soil uniformly and place it back as close to the original position as possible, so as to minimise the disturbance in soil structure and density. In each pond, 5 ceramic tiles measuring 0.5 m by 1 m were installed. The 5 ceramic tiles were distributed to cover the whole pond area and to represent the different sections of the pond (the deeper end, the shallow end, and in the middle. Sticks protruding above the water surface were put at each corner of each ceramic tile to mark tile locations in each pond and to ensure that disturbances by people survicing the ponds would be minimal. Sediment samples were collected monthly using a soil core sampler with

a 5 cm diameter [13, 14]. On each sampling date, two sediment cores from each ceramic tile were collected by pushing down the cores through the sediment until at the surface of the ceramic tile. 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 collected from the 5 ceramic tiles in a pond, the average dry bulk density (g /cm^3) of the top 5-cm sediment layer of each pond was calculated. The second sediment core from each ceramic tile was taken immediately to the pond embankment where the sediment depth was measured while the sample was still in the core liner tube.

The quantity of pond sediment in the layer above the ceramic tile was determined monthly as a product of the sediment depth on the ceramic tile, 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.

2.4 Quantification of sediment from various possible 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 1.3 m 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, 100 ml samples were put in previously cleaned, dried and weighed crucibles and dried in the oven at 105 °C. The dry crucibles were cooled in a desiccator and weighed. The increase in crucible weight represents the total solids in 100 ml and was used to estimate the total solids / liter. The volume of water added to ponds (in litres) was estimated and the amount of solids added calculated. It was assumed that the contribution by salts to the total solids was negligible since the canals contain fresh waters (salinity was not determined).

2.5 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 [22], (ii) in feed driven ponds, 15% of the feed offered is not eaten [13, 14, 38] and 30% of ingested feed is excreted as faeces [42] and (iii) 50% of the phytoplankton standing crop sediments daily [49]. To estimate the portion of plankton settling from the water column, primary productivity was estimated monthly using the free water method [21, 7, 9].

2.6 Quantification of nutrients' accumulation in the sediment

After the sediment depth was measured from the second sediment core taken on the ceramic tiles, the top 5 cm segment of each of the same sediment cores was transferred to a container. All the 5-cm segments from the 5 ceramic tiles in each pond within a sampling date were homogenously mixed to form a composite sample from which a sub-sample was

collected for soil nutrient analysis. The sub-samples were air dried and analysed for total nitrogen, available phosphorus, organic carbon and exchangeable potassium (only available forms of the soil nutrients were analysed since the objective was to quantify nutrients potentially available for land-based agriculture). Total nitrogen was analysed by the Kjeldahl method [41] and organic carbon by the Walkley-Black dichromate method [16]. 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 [16]. Exchangeable potassium was analysed by determining the exchangeable potassium in a cation exchange-replacing solution ($BaCl_2$) [16] followed by atomic absorption determination of potassium [41].

The quantity of available 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 the of culture period and the quantity by the beginning of the culture period was considered to represent the quantity by which nutrients accumulated during the culture period.

2.7 Nutrient budgets
Total nitrogen, available phosphorus and exchangeable 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 water and 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 total nitrogen, total phosphorus and exchangeable potassium contents determined. To estimate nutrient gains from stocked fish and pond inputs, proximate analyses were made of samples of fish, feed and manure.

To estimate nutrient losses through drainage, water column samples were taken before drainage. The water samples were collected from three points in a pond using a column sampler [9], mixed together and a one-litre sample collected from the homogenously mixed composite sample. Sub-samples drawn from the one-litre sample were analyzed for total nitrogen, total phosphorus and exchangeable potassium. Total nitrogen and total phosphorus in both samples of inflow water and of drainage water were analyzed through simultaneous persulphate digestion [20] followed by phenoldisulfonic acid method [6] for the nitrogen samples and ascorbic acid method [9] for the phosphorus samples (In the water samples total phosphorus was determined and not the available phosphorus as in the sediment samples so as to include available phosphorus utilised by the organic forms in the water). Exchangeable potassium in both water samples was analyzed by atomic absorption [41].

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 bond bottom and protruded to the water surface. A meter rule marked in centimetres was fixed on the inside of the PVC pipes with the zero cm mark at the surface end. The PVC 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 [37]. Rhizons are small suction probes made of a thin polymer tube with a 1 mm internal diameter and 0.1 micron pores, and are standard equipment used in soil science to sample soil moisture (Rhizon sampler from Eijkelkamp Agrisearch Equipment, http://www.eijkelkamp.com). The methodology of using Rhizons to sample seepage water in ponds has been tested and described by [37]. Two rhizons / pond 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. Seepage 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 total nitrogen, total phosphorus and exchangeable potassium together with drainage water samples and inflow water samples as described in the preceding text.

2.8 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 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.

3. Results
3.1 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 but effects due to input type or stocking density were not significant (Table 1). Sediment depths increased by about 3 cm/pond during the culture period while bulk densities declined by about 0.1–0.3 g/cm³ (Table 2). Over the experimental period, bulk densities were determined for the upper 5 cm. However, to quantify the pond sediment in the whole sediment layer above the ceramic tile, the bulk density for the total sediment depth above the ceramic tile was required. To address this oversight, two assumptions were made to estimate the maximum and minimum sediment accumulation (i) that the monthly bulk density of the total sediment layer above the

ceramic tile 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 tile, but below the upper 5 cm remained the same as that of the first month (maximum). Minimum sediment accumulation quantities ranged from less than 1 to 3.1 tons/pond/cycle while the maximum quantities ranged from 1.5–3.46 tons / pond / cycle and there were no differences between treatments (Table 2).

3.2 Sediment sources
Influent water contributed about 0.17 to 0.21 kg of sediment / pond 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 [22], organic inputs contributed at most 77 kg in CM_1 and CM_2 treatments. Assuming 15% of applied feed was uneaten [13, 14, 38] 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. Primary production during the entire culture period averaged 4.36, 3.94, 2.91 and 3.08 g C / m^2 / day in CM_1, CM_2, P_1 and P_2, respectively. Assuming 50% algal sedimentation day^{-1} [49], about 2.18, 1.87, 1.46 and 1.54 g C / m^2 / day 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 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).

3.3 Nutrient accumulation
3.3.1 Nitrogen and organic carbon
In all the treatments, nitrogen concentrations in the top 5cm 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).

3.3.2 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 in all the treatments (Table 3). In the nutrient budgets (Table 4), 62.5% (0.579 kg) and 65.3% (0.633 kg) 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.

3.3.3 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 (Table 3) while in the nutrient budgets (Table 4), total losses were higher than total inputs in all treatments by < 1 kg.

4. Discussion
4.1 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 / pond / cycle (Table 2) was estimated, which translates to about 173 tons / ha / cycle. Considered sediment sources (influent water and organic sedimentation) contributed less than 10% of the estimated accumulated sediment (Table 3).

On the average, a seasonal sediment deposition rate of about 200 tons / ha is reported for aquaculture ponds [3]. The majority of the accumulated sediment is said to originate from sediment load in influent water [7, 9, 2], inorganic solids from levee erosion [38, 51, 54] and sedimentation of organic inputs and wastes [19, 57, 23]. However, relative proportions of these sources have not been studied [23, 3]. 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 [51, 52] 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 [18], 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 ponds, though earthen, had concrete walls. However, sand drifting from pond banks and wind blown debris are possible sources of the accumulated sediment [23]. 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, [55] reported dust deposition rates ranging from 42–991 kg / ha / year. Assuming similar rates in the present study, about 0.3– 7.4 kg of sediment / pond / cycle would originate from dust deposition and would account for about 0.5% of the accumulated sediment. However, the above reported deposition rate was in a forest ecosystem and the current study was in a desert ecosystem hence the dust deposition rate in the study could be higher. Presence of other wind blown debris

such as leaves and sand from the pond banks could also increase the total deposition. Various studies by [53, 56, 59] reported increase in sediment depths ranging from 12cm - 33 cm in culture periods ranging from 1 year - 30 years of fish production.

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
Mean multi-comparison 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
Mean multi-comparison 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
Mean multi-comparison 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>…

The increase in sediemnt depth (pond sediment accumulation) was mainly attributed to erosion of pond levees due to instability of the banks in newly constructed ponds but it was also reported that sediment depths were higher in middle or deep areas and lower in shallow ends [53]. They explained the heterogeneity of sediment depths within the pond to be a result of movement of sediments from shallow to deeper areas of the ponds caused by water currents . The water currents were said to be caused by frequent summertime aeration which scour the pond bottoms. They also noted that movement of sediments from shallow to deeper parts may also be due to sediments resuspended by shear forces at the pond bottom which are caused by wind induced waves. In the present study, aeration was not used but resuspension of pond sediments caused by wind induced waves at the pond bottoms is a possibility. It is also possible that there may have been erosion of soil from under the concrete pond walls which would possibly contribute some amount of sediment accumulation in the pond bottoms. However, we do not have data or references by which we can quantify the possible contributions of sediment from uder the concrete and from resuspension of sediment.

It is apparent that after exploration of possible sources of sediment in ponds, we are unable to account for the majority of the estimated sediment accumulation in this study. This demonstrates the need for further studies to understand the process and for future studies to focus on developing methodologies of accounting for measured sediment accumulation since previous studies have attributed observed sediment accumulation mainly to erosion of levees, sediment load in inflow waters and sedimentation of organic inputs and wastes [38, 23, 53, 56] without assessment of the quantities in each.

The present study offers a beginning in the development of methodologies to study sediment accumulation by proposing a method in which hard surfaces (in this case ceramic tiles) are introduced into, or onto existing pond bottom to serve as a reference point from which the depth of sediment accumulation can be determined. Previous studies have determined the depth of sediment accumulation by obtaining the average depth of loosely consolidated sediment [9, 38, 53, 56] but this may include changes in sediment volume due to changes in pond sediment bulk density and not necessarily accumulation of external sediment.

While the placement of the hard surface at the pond bottom served to offer a reference point, it involved removal and subsequent placement of sediment on top of the hard surface which may cause some disturbance in structure and density of the pond bottom soils and may possibly lead to some artifacts. We tried to minimize these by slightly wetting the bottom sediment prior to placement of the ceramic tiles and taking care to remove the soil uniformly and placing it back as closely as possible to the original position. Also the tiles were marked clearly and their location was well visible to ensure minimal disturbance by people servicing the ponds. Since the soils were clay and very sticky, we believe the disturbance was minimal and since all subsequent sampling was done above the ceramic tiles any possible effects affected all samples uniformly. Future studies could explore the possibity of introducing hard surfaces that may not require removal of the soils, and also possibly larger surfaces to offer a larger sampling area. In this study we marked each sampled position with long labelled sticks to avoid sampling the same place in the subsequent sampling period.

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

An important observation 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 [51]. 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.

4.2 Nutrient accumulation
4.2.1 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. After the first 2 months of culture however, a decline of morning DO levels to below 2 mg / l (Figure 1) led to temporary suspension of feeding and fertilization and subsequent reduction of the quantities of fertilizer and feed (Figure 2). Reduction of organic inputs coupled with 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 [4] that is released from the water to the atmosphere and does not accumulate in the pond [8]. However, nitrogen losses are slight since ammonium, the end product of organic nitrogen mineralization is absorbed by the clay present in the sediment [4]. Inorganic nitrogen therefore accumulates whereas organic carbon declines [27], hence, the continued increase in pond sediment nitrogen with time even as organic carbon decreased.
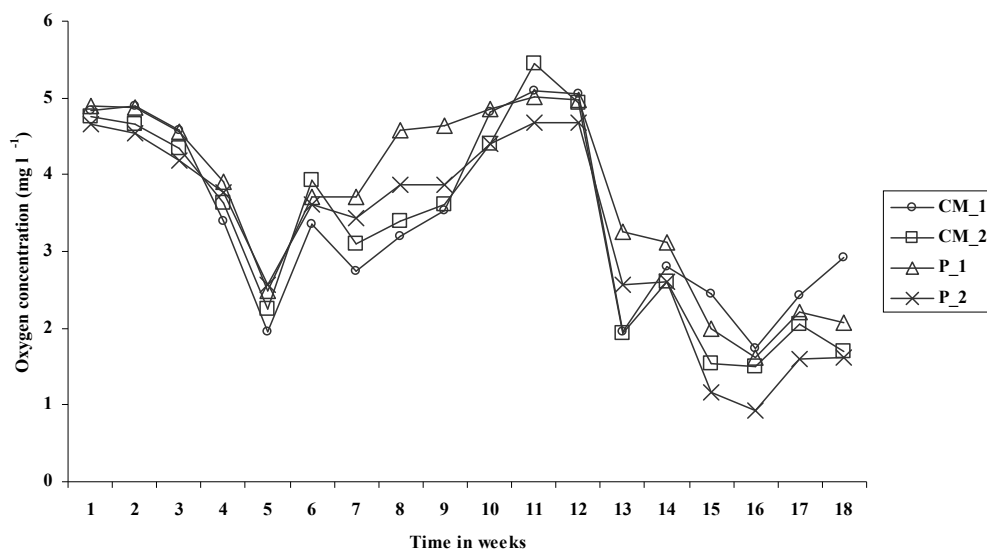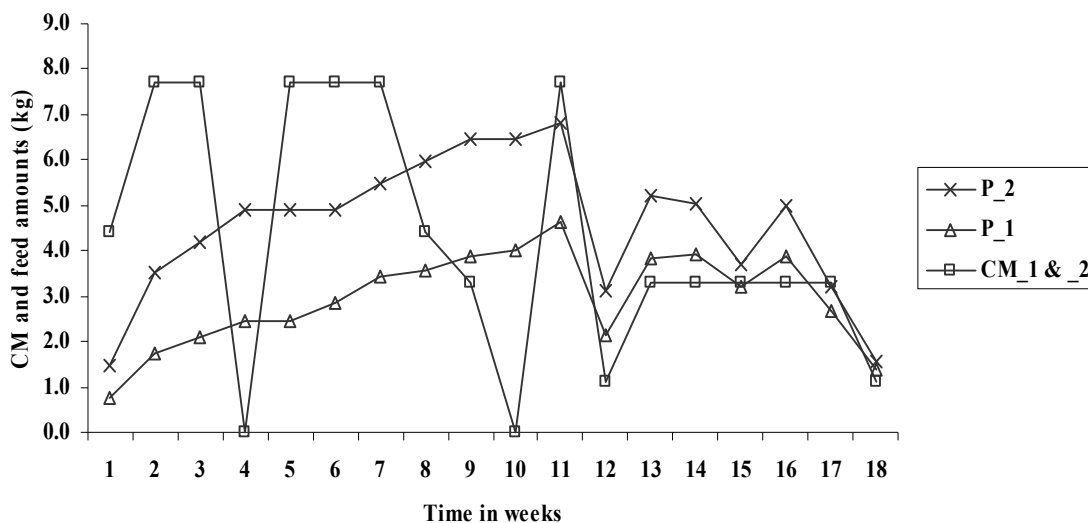

Fig 1: Oxygen concentrations during the culture period

Fig 2: Weekly chicken manure (CM) and feed amounts pond $^{-1}$ over the culture period

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 (Lin et al., 1988). Nitrogen fixation rates ranging from 6 – 57 mg N / m^2 / d in tropical fish ponds were reported by Lin et al. (1988) while [1] reported an average of 24 mg N / m^2 / d 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 [12].

4.2.2 Available phosphorus
Available phosphorus concentrations fluctuated over time (Table 1: mean multi-comparison 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% (0.013 kg) and 23.5% (0.09 kg) respectively which appears to support the possibility of available phosphorus loss from the sediment to the pond system. Contrarily, 62.5% (0.579 kg) and 65.3% (0.633 kg) 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 [8] 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 [50]. 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 [36]. 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 [50]. 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. [33] 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, and potential of pond sediment as an agricultural input, future studies should measure both total and available phosphorus. This is because while the inorganic forms of phosphorus (and other nutrients as well) in pond sediments will be immediately available to plants, organic forms will become available after some time through microbial activity. Quantification of the total phosphorus in the pond sediments is therefore also important because once the pond sediment is used as an agricultural input, the total phosphorus added to the fields, especially in poor soils will be important in building the long term fertility of the soils. In sediments of aquaculture ponds that have been used for periods ranging from 1 year to 30 years, various studies have reported total phosphorus concentrations ranging from 0.334 to 1.73 g/kg while the available phosphorus concentrations ranged 0.005 to 0.022 g / kg [58, 59, 35, 59]. It was noted that the total phosphorus increased with pond age and organic phosphorus formed 23-60% of the total phosphorus [48, 35, 11].

4.2.3 Potassium
The decrease in sediment potassium concentration after one month (Table 1) may be attributed to ion exchange reactions [17]. 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 in all treatments (Table 4) while the apparent loss from the sediment was about 3-4 kg / pond (Table 3). It is possible that part of the potassium was leached to the deeper layers of the pond sediments.

4.3 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 – > 300 kg 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 / growing season (Table 5). In Egypt, the location of the study site (and in many other countries in Africa), corn is one of the main food crops and the recommended nitrogen, phosphorus and potassium fertilization rates are 286, 200 and 85 kg / ha respectively (personal communication, Agricultural officer, Zagazig, Egypt). At the observed sediment and nutrient accumulation rates, accumulated sediment ha / 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 but only less than 1% of the phosphorus fertilizer requirement. It is important to note that the culture cycle in the present study was short (4.5 months) and the ponds were newly constructed, thus with longer culture periods and older fertilized or fed fish ponds and with higher intensities of nutrient inputs, the nutrient quantities could be higher. [60] found one hectare of old pond sediment to be equivalent to 2.8 tons of urea and 3 tons of TSP while Yang et al. (2002) reported the same to be equivalent to 3.44 – 3.92 tons of urea and 4.11 – 4.81 of TSP. Elsewhere, the fertilizer value of sediment of one hectare tilapia fingerling production pond at the Asian Institute of Technology (AIT) was reported to be equivalent to 6.26 tons of urea and 1.96 tons of TSP

[47] while [39] reported nutrient accumulation rates in fish pond sediments averaging 10 kg of total nitrogen and 2.9 kg of total phosphorus / ha / day.

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

Besides the fertilizing potential of aquaculture pond sediments, the organic matter in the accumulated sediment can improve the condition of agricultural soils. In the present study, organic matter rates of 2.2–3.8% (2 times organic carbon values, Table 1) were observed, translating to 1.8–5 tons of organic matter in the accumulated sediment (Table 5). Other studies have reported organic matter rates ranging from 1 – over 10% in various culture systems [58, 13, 14, 59]. This high content of organic matter can play a major role in soil aggregate formation [40] and hence improve soil physical and chemical conditions which in turn facilitate crop production. Application of pond sediment that is enriched with organic matter to heavy soils (which possess low aeration porosity, reduced infiltration rates and have high run off which accelerate removal of fertile top soil through erosion) can improve the soil texture by forming soil aggregation and aeration porosity thus increasing infiltration while reducing surface run off and its associated nutrient losses [32]. In course textured soils, addition of organic matter rich pond sediment can reduce infiltration rate by reducing soil macro pores thus increasing water holding capacity and stability of such soils [34].

The foregoing results and discussion show that substantial quantities of sediment accumulate in fish ponds and that the quality of the accumulated sediment is potentially beneficial for land crop production. However future research will need to address the practical aspects of pond sediment utilization in agriculture. Removal of accumulated sediment from the ponds is labor intensive and the removed sediment may need to be dried, stored and essentially transported to the crop fields which may not only be labor intensive but also costly. Studies on these practical aspects of pond sediment utilization in agricultural production are scanty. [61] experimented on the recovery of nutrients from pond mud by lotus through a co-culture of tilapia and lotus. The Lotus seedlings were transplanted to ponds prior to pond filling and the ponds were filled when the height of lotus had increased to beyond 50 cm. The results indicated that in one year, 2.4 tons of nitrogen and 1 ton of phosphorus accumulated in a 1- ha pond. Of these accumulated nutrients, the lotus was able to remove 300 kg of nitrogen and 43 kg of phosphorus through in cooperation to its biomass. Elsewhere, [44] documented the production of vegetables from drained ponds in Malawi while others have documented that in Vietnam (and other Asian countries), farmers remove pond sediment and dispose it on adjacent pond dykes where they grow fruits and vegetables to utilize the nutrients in the disposed pond sediments [26, 43, 39]. However, in both Malawi and Vietnam, these activities of pond sediment utilization to grow vegetables and fruits started as farmers' initiatives.

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
Drainge	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
Drainge	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
Drainge	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**

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

Parameters	Treatments							
	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

The farmers report increased food security and incomes but scientific studies to determine the economic benefits have not been conducted so far. In Thailand, Rahman and [46] reported that application of tilapia pond soil to farm soil provided the required amount of phosphorus to morning glory and also significantly improved the soil aggregate stability. It therefore may be economically feasible to utilize pond sediments in crop fields that are adjacent to the fish ponds so as to minimize transport costs. The sediment could be removed from the ponds and directly disposed to the crop fields where it is left to dry and later mixed with the farm soil at the onset of the rains. In African farming, soil nutrient replenishment through application of inorganic fertilizers is constrained by high costs that make them unaffordable to most rural poor farmers (FAO, 1995, Nandwa and Bekunda, 1998, Gruhn et al., 2000). However in such set ups, cheap labor is usually available on farm and hence it may be easier for such farmers to afford the harvesting of enriched pond sediment when it is available on farm than to purchase inorganic fertilizer

5. Conclusion

The study showed that, up to173 tons of pond sediment could accumulate in semi-intensive tilapia production ponds / ha / cycle. 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. Declining quantities of sediment available phosphorus in the study suggest that accumulation of phosphorus in pond sediment may be in non available forms. The accumulated sediment is rich in nitrogen, exchangeable potassium and organic matter, hence has a high potential as nitrogen and potassium fertilizer and as a soil conditioner. Nevertheless, field trials to evaluate its fertilizing effect on important agricultural crops, to evaluate practical ways of its utilization as well as the economic benefits are recommended.

6. Acknowledgements

7. References

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