Thammasat Int. J. Sc. Tech., Vol. 9, No. 4, October-December 2004

Agricultural Use of Fishpond Sediment for Environmental Amelioration

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Abstract

Inland aquaculture is one of the promising livelihoods in Asian countries. Over time, accumulation of sediments reduces the capacity of fishponds and threatens the farmers engaged in this industry. Removal and disposal of sediment in fishponds are practiced, but lead to environmental degradation. Nitrate contamination of groundwater and eutrophication of surface water are two major concerns associated with improper sediment disposal, which have not yet attracted due attention from researchers. On the other hand, pond sediment is enriched with organic matter, nitrogen, phosphorus, and macro and micronutrients as well, and hence, it can be a potential fertilizer supplement and soil conditioner, which could enhance the soil environment for crops. Agricultural uses of sediment would lead to reduced fertilizer inputs, thus increasing economic benefits while reducing the negative impacts on aquaculture and on the environment, which is promising towards a new dimension in sustainable agriculture-aquaculture integrated farming systems.

Development of appropriate management of pond sediment is therefore a challenge. This article elucidates the agricultural value of fishpond sediment, and identifies both the ways of using it for agricultural purposes and future research priorities.

Keywords: fishpond sediment, agricultural uses, sustainable agriculture-aquaculture

1. Introduction

A high population pressure is characteristic of many developing countries especially in Asia and therefore, intensive and efficient use of available lands and inland waters for more food production is needed. Aquaculture has been widely developed in recent years for food security and income generation [1]. Diversification of cultured species and intensification of production systems are the prerequisites for high fish yields. Successful management of tropical fish ponds for biologically optimal fish growth requires supply of necessary pond inputs including nutrients in a balanced manner via fertilization and supplementary feeding [2]. A large amount of green manures and animal manures are also applied to fishponds, thus leading to organic matter (OM) accumulating in pond bottoms over the years. Formulated complete feed is applied in intensive fish culture systems, which eventually generates a large amount of organic wastes. Thus regular feeding and fertilization in fishponds result in the accumulation of OM, nitrogen (N) and phosphorus (P) in sediment. With nutrient budgeting, Olah et al. [3] reported that 30-95% of the N applied to fishponds accumulated in the sediment. Similarly, Boyd [4] showed that a higher fraction of P compounds applied to ponds also ended up in the sediment.

The accumulation of sediment enriched with OM and nutrients is a major concern affecting the intensification and management in ponds [4]. Organic matter accumulation rates of 100-1500 g m^{-2} d^{-1} have been reported in intensive tilapia (*Oreochromis niloticus*) ponds [5]. Excessive accumulation of OM not only reduces the pond depth and space available for fish [6], but also makes the water environment unfavorable for fish growth. At shallow depths pond water warms up rapidly in the daytime, and temperature fluctuates greatly, and this condition favors the rapid growth of aquatic macrophytes. Furthermore, increasing OM deposition increases microbial activities, thereby increasing demand for oxygen resulting in the depletion of dissolved oxygen in the pond water, which makes the pond environment unfavorable for aquatic lives, and the fish will become stressed and susceptible to diseases [6]. Therefore, maintenance of pond volume and its environment by sediment removal is a conducive practice for economical fish production. Two key issues that arise with the sediment removal are the dumping sites for sediments and waste of the large amount of nutrients embedded in sediments. Nutrients that are released from sediment over time may pollute underground and surface water due to percolation and surface run off. Nitrate contamination of ground water is already a crucial problem in some Asian countries, where water in some wells contains nitrate levels above the permissible limit [7]. Phosphorus is also a potential pollutant that restricts the use of surface water [8], which is also responsible for eutrophication of surface water. Therefore, pond sediment has become a potential source of pollution around fish farms, where deterioration of environmental quality has already become a widespread concern. This demands the development for appropriate management strategies for pond sediment disposal. Use of such pond sediment in agricultural lands as fertilizer supplements and soil conditioners would be the best management option. This requires both quantitative and qualitative information on the compositions of pond sediment including nutrients and OM, but such information is scarce. Furthermore, no research has so far been conducted to determine the soil conditioning potential of fishpond sediment. This article attempts to provide a review on the nutritional aspects of pond sediment and identify its agricultural uses and to highlight research priorities for making use of sediment to prevent environmental degradation.

2. Sources of nutrients in pond sediment

Organic and inorganic fertilizers, and fish feed are the two major external sources of nutrients in pond. Ponds are fertilized with both organic and inorganic fertilizers throughout the world to stimulate the growth of phytoplankton, and thereby to increase fish yield.

The use of animal manures is an integration of traditional agriculture, which uses available on-farm resources within reach of many small-scale fish farms in Asia. The amounts of nutrients found were 28 mg N kg^{-1}, 13.6 mg P kg^{-1} and 11.8 mg K kg^{-1} in pig manure, 37.7 mg N kg^{-1}, 18.9 mg P kg^{-1} and 17.6 mg K kg^{-1} in poultry manure, and 19.1 mg N kg^{-1}, 5.6 mg P kg^{-1} and 14.0 mg K kg^{-1} in cattle manure [9]. Although most of the elementary nutrients are necessary for the growth of aquatic organisms, N and P have the greatest importance to primary production. Optimal rates of N and P for fishponds are 4 and 1 kg ha^{-1} d^{-1}, respectively [10], which is equivalent to 1,460 kg N and 362 kg P ha^{-1} yr^{-1}. In the Republic of Korea a cropland of one hectare receives fertilizers of approximately 452 kg per year, which is the highest fertilization for a cropland in Asia [11]. Accordingly, the amount of fertilizers applied in fishponds is approximately four times higher than fertilizers applied on croplands, of which undissolved portions of fertilizers apparently settle and mix with pond sediment. This makes pond sediments rich in nutrients.

Fish feed is another important source of nutrients in the pond systems. The production of 100 t of fish biomass requires 39 t of feed in semi-intensive systems, while in intensive systems the feed requirement goes up to 260 t [12]. Complete feed materials are applied at higher rates in intensive aquaculture where natural foods play a minor role. Natural foods are the only source of fish nutrients in intensive systems without nutritional inputs provided intentionally by humans. Natural foods predominate in semi-intensive systems where fertilizers and supplementary feed are applied to supplement the natural foods.

3. Occurrence of OM and nutrients in the pond systems

The nutrients added to pond water from fertilizer, unconsumed feed, fish feces, and fish metabolites account for organic material. Suspended solids, P and N are of greatest concern for their potential impacts on pond effluents and on the environment. Only less than 30% of the feed or fertilizer N and P added to ponds is recovered in the harvest of fish [13], and the remainder is lost to the pond effluent and sediment. Nitrogen, P and K are the three major nutrient elements available in sediment. It is also a source of some micronutrients. In a perennial pond, sediment contains OM, total N, available P, Fe, and exchangeable Ca and K in ranges of 4.5 to 13.1 g kg^{-1}, 900 to 2000 mg kg^{-1}, 70.0-112.0 mg kg^{-1}, 24.2-47.8 mg kg^{-1}, and 87.8-130.8 mg kg^{-1}, respectively [14].

Organic matter accumulation rates of 0.87 g m^{-2} d^{-1} have been reported for intensive polyculture ponds [15], while in intensive tilapia ponds the rates range from 100-1500 g m^{-2} d^{-1} [5]. However, there is conflicting evidence as to the rate of OM accumulation: it increases in bottom soils with time until an equilibrium concentration is attained [4]. It has been shown that new ponds have lower concentrations of soil OM than older ponds, but information on the rate of increase over time is lacking [16]. Therefore, further studies are needed on chemical characteristics in pond sediment for fish species of interest [1].

The major sources of N and P in fishponds are fertilizers and feed. Addition of manure and feed provides organic N and P, while inorganic forms come from chemical fertilizers [4]. Algae cells generally take N as NO_3^-, while aquatic plants take NH_4^+ [17]. The plankton initially absorbs appreciable amount of added P within a few hours after application. Total and particulate P increases due to decay of dead plankton and suspension of soil particles [18]. When organisms die, they become OM and deposit in sediment [18]. The organic form of the sediment constitutes about 35-40% of the total P [19].

A small portion of the feed applied to ponds is accumulated in fish. In earthen carp ponds Avnimelech [20] reported that only 25% N and 20% P of the feed were recovered in harvested fish, and the rest is accumulated in pond sediments. It was also estimated that only 25.5% organic carbon, and 26.8% N were harvested in fish in catfish (*Clarias macrocephalus*) ponds [20]. In polyculture ponds having common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), tilapia (*Oreochromis niloticus*) and grass carp (*Ctenopharyngodon idella*), about 11-16% of the applied N was recovered in fish at harvest and the rest (84-89% N) was released to the pond environment [21]. In tilapia monoculture system the corresponding values were 18-21% and 79-82% respectively [22]. Acosta-Nassar et al. [23] found that only 17.5% of the applied N is accumulated in fish, 1% lost through denitrification and about 65% is accumulated in pond sediment.

Boyd and Musig [24] found that if 0.30 mg orthophosphate is applied per liter of pond water, about 70-90% of P is deposited in sediments. Sediments rich in P tend to release a higher fraction of P to water, and this increases with increasing pH of the sediment [4]. Bio-disturbance by benthivorous fish facilitates the penetration of dissolved oxygen into pores of sediment, and this enhances the mineralization of organic P trapped in sediment. Furthermore, PO_4^{-3}-P trapped between sediment particles are liberated into the water when sediment particles are mixed up and re-suspended due to the activities of benthivorous fishes.

Yang and Hu [25] found one hectare of old pond sediment it to be equivalent to 2.8 t of urea and 3.0 t of triple super phosphate (TSP), while Yang et al. [26] reported it to be equivalent to 3.44 to 3.92 t urea and 4.11 to 4.81 t TSP. The fertilizer value of sediment in a one-hectare tilapia fingerling production pond at AIT was equivalent to 6.26 t urea and 1.96 t TSP [27]

These research findings show a clear scenario of N and P contents in pond sediment and its potential as an organic fertilizer for agricultural production. Therefore, further research needs to be aimed at either recycling these nutrients in ponds for fish culture and/or utilizing them in crop production.

4. Pond sediment and agriculture

4.1 Sediment as a soil conditioner

Inappropriate land management has resulted in the deterioration of soil quality in many agricultural areas of the world [28]. This has further resulted in deterioration of soil health in terms of both physical and chemical conditions. Benjamin et al. [29] reported that soil physical condition could substantially influence crop production. Poor soil physical conditions restrict water intake into the soil, its retention and subsequent movement from soil to plant root as well as plant root development, soil aeration and associated biological activities. There are many organic and inorganic amendments that are claimed to improve soil physical conditions, but pond sediment did not get any attention as a conditioner. The pond sediments contain higher amounts of OM, i.e. 4.98-6.20% in semi-intensive tilapia ponds stocked at 1.1 fish m^{-2} [30], while 10.34% was found in channel catfish ponds in the United States [4]. Properties of fishpond sediment and compost are given in Table 1. The high content of OM can play a major role in soil aggregate formation [31], thus improving physical and chemical soil conditions, thus facilitating crop production. Effectiveness of pond sediment as a soil conditioner could be assessed using a variety of soil physical and chemical parameters such as rate of infiltration, soil aggregate stability, soil water retention, bulk density, soil porosity, texture, and nutrient availability etc.

Soil infiltration, water content and soil texture

Infiltration, the process of water entry into the soil determines how much water will enter the unsaturated zone of soil. It is of paramount importance to the water economy of plant communities, recharge of aquifers, regulation of surface runoff and soil erosion. Water content in soil is mainly dependant upon the amount of OM and clay in the soil. Water directly or indirectly affects most soil physical, chemical, and biological properties and processes. Organic matter itself holds water and decreases soil surface crusting, which enables the infiltration of water into the soil. The field capacity of a soil increases from about 7% (by volume) to about 53% as the clay content increases from 0 to 60% [32]. In the presence of water, sediment appeared to resemble the clay fraction, which in turn increases the field capacity [27]. In addition, old humified OM fraction is most abundant in pond sediment, which could attract water molecules to its negatively charged surface, thereby maintaining a higher field capacity.

Soil texture has a profound influence on soil aeration, water and nutrient-holding capacity and root penetration by plants. Since, heavy soils usually possess low aeration porosity, reduced infiltration rates and increased runoff can result. Runoff from cultivated soils deprives the availability of water to crops and also accelerates removal of fertile topsoil through soil erosion, thus promoting soil fertility depletion [33]. Soils at the surface are mostly compact with reduced infiltration rates, which lead to anaerobic conditions, reduced biological activities and increased nutrient deficiencies. Under such conditions, application of pond sediment enriched with OM can improve heavy soils by forming soil aggregation and increase aeration porosity that eventually ameliorates soil infiltration and other beneficial characteristics [34], while reducing surface runoff and its associated nutrient losses.

In coarse textured soils (i.e. sandy soils) where agricultural productivity is limited due to low water holding capacity, high infiltration rates and deep percolation and low cation exchange capacity soil conditioners are effective in adjusting such characteristics [35]. In such a situation, addition of fishpond sediment will be effective in reducing the infiltration rate by improving the soil structure and micropores, and decreasing macropores, which eventually increase water holding capacity.

Aggregate stability

A group of primary soil particles which coheres to each other more strongly than surrounding particles, is called a soil aggregate. A good structure is important for sustaining long-term crop productivity, which influences water retention, resistance to erosion, nutrient availability and crop growth and development [36]. Soil aggregation facilitates water infiltration, provides adequate habitat space for soil organisms, supplies adequate oxygen to root and plants, and prevents soil erosion [37]. Soil structural degradation is common in intensively cultivated lands due to depletion of OM; therefore, one strategy to improve soil structure is to build OM pools that facilitate soil aggregation [38]. Organic matter increases soil aggregate stability by slowing water uptake by aggregates [36]. The OM content of pond sediment is higher than in most agricultural soils. The major components of OM responsible in stabilizing soil aggregates are humic substances namely humic acid, fulvic acids and humin, which result from the microbial breakdown of OM. The size and stability of soil aggregates are related to their clay mineral compositions and contents. Soils dominated by clay minerals with a high specific surface area have a high capacity for absorbing humic substances and hence for stabilizing aggregates. Aggregate stability depends on the physical and chemical interactions of organic compounds with clay and fine silt particles [39]. The suspended and finer particles that have higher fractions of clay settle and accumulate in sediment of fishponds. In sediment of recently drained ponds, a clay content of 56.9% was found [4]. In an ongoing study at AIT, it was found that addition of 25 and 50% (by weight) pond sediment significantly increased water stable aggregates in soils from 20.58% (control) to 28.16% and 34.12%, respectively [27]. Therefore, if pond sediment is applied to agricultural soils the organic residue, detritus and clay particles of sediment would bind soil particles to form aggregates.

Bulk density and soil porosity

Bulk density is the most commonly used indicator to monitor changes in soil conditions [29]. In loam and silt loam soils bulk density values less than 1.40g/cc and 1.30g/cc respectively, are considered approximate, and bulk densities higher than these values may affect root development and its activation, hence affecting the overall plant growth [40]. Any activity that decreases soil porosity, in turn, increases bulk density. Adverse effects of higher bulk densities will be mainly on lowering pore space, which eventually lowers soil aeration, and restricts root penetration and drainage of excess water. As OM is beneficial for the formation of soil aggregates, pond sediment has the potential to decrease the bulk density of soil to favorable levels [41].

A soil with a high proportion of sand possesses a greater amount of macropore space than a fine-grained clay soil. Sandy soils are more susceptible to fast drying because of faster drainage by gravity due to the high proportion of macropores. Water is held more tightly in clay soils due to the abundance of micro pores. The superior quality of soil structure could be developed by adding organic matter and readjusting macropores, thereby increasing the storage and transmission pores with increased aggregate stability [31]. Therefore, addition of pond sediment to agricultural soils usually will favor the development of soil structure, hence favoring root penetration, aeration, water retention and movement, thus increasing the potential productivity.

Nutrient availability

The use of soil as a medium of crop production is one of the primary interests of agriculturists [29]. Soil fertility status often changes in response to land use and management practices [42]. Nutrient depletion of soils is considered as a threat to the sustainability of agriculture. Application of pond sediment, where applicable, increases nutrient levels in soils. The inorganic forms of nutrients in pond sediment will be immediately available to plants. The organic forms of nutrients in sediment take time to make them available to plants through microbial breakdown. Pond sediment generally contains higher amounts of OM than agricultural soils. Part of this OM decomposes rapidly and provides nutrients to plants, more resistant and partly decomposed OM is broken down over a 3 to 5 years period, and old humified OM decomposes very slowly and helps maintain aggregate stability. Schepers and Mosier [43] estimated that about 2% of the total organic N in the surface of 30 cm is mineralized annually, thus a soil with 1% OM content could be expected to mineralize and supply approximately 45kg N ha^{-1} yr^{-1}. As pond sediment contains a higher amount of OM, it would be an excellent source of nitrogen to crops.

Thorough decomposition of OM in sediment can provide a relatively labile form of P to crops. During microbial decomposition, organic acids are released, which may help to dissolve soil mineral P. When pond soils are acidic, a large amount of liming materials is applied to ponds in order to increase bottom soil pH [4]. Pond bottom mud having a pH of 4.0 was raised to 8.0 by adding 10 kg $CaCO_3$ per m^3 in a tilapia fishpond [27]. Therefore, application of these sediments to agricultural soils increases the soil pH, and increases the nutrients availability. The maximum availability of P in mineral soils occurs between soil pH 6.0 to 7.0, and in this pH range, formation of complex compounds through Fe^{3+} and Al^{3+} is remote [4].

4.2 Sediment as a nutrient supplement for crops

Fishpond sediment is an important resource enriched with plant nutrients and OM. Organic matter plays a vital role in maintaining or improving soil quality. It is the key quality factor that determines the degree of nutrient retention in soil [42]. Pond sediment is rich in N, P, and K, and other macro and micronutrients. If nutrient requirements of a crop and the nutrient availability in pond sediment and agricultural soils are known, sediment can be successfully utilized to provide its nutrients together with inorganic fertilizer(s). The crops utilize nutrients in sediment, thus reducing possibilities for environmental pollution. Thus, pond sediment can be used for a successful integration between aquaculture and agriculture. In a study, sediment of tilapia fingerling production ponds at the Asian Institute of Technology (AIT), Thailand and a potting media composed of sediment-compost mixture (2:1) were analyzed for different parameters prior to growing morning glory plants in pots (Table 2). The sediment was dominant in clay (clay content was 65%), and hence was mixed with compost to make it favorable for plant growing. The water used for irrigation was also analyzed (each day 600ml of water were applied per pot) and the results are shown in Table 2.

Roots and shoot (edible part) of morning glory plants were analyzed at harvest (i.e. 45 days after sowing) for N, P and K and found to contain different amounts of nutrients in the edible part and the root samples (Table 3) [27]. After subtracting the nutrients supplied by both compost and irrigation water, it was found that the fishpond sediment provided about 62% of the available N, 67% of the available P, and 64% of the available K for plant uptake. The recovered fractions of N, P and K were found to be 38%, 14% and 53%, respectively. Hoffman *et al.* [44] reported that mean recovery of fertilizer N rarely exceeds 30-40%. Roberts [45] found a P recovery of 10-30%, and a wide range of K recovery (20-60%). This shows the importance of pond sediment and the potential to supply N, P and K to plants, and hence its usefulness in the integrated farming systems.

A wide range of integrated farming systems is found in Bangladesh, China, India, Indonesia, Malaysia, Thailand and Vietnam, where fishponds play a vital role in the maintenance of productivity [46]. The purposes of integration of these activities are intensification of land and time, increased diversification, improvement of natural resource use efficiency, increased productivity, and sustainability [47]. A fishpond performs multiple roles and functions in the over all production of a farm. Integration of ponds with crops brings benefits of recycling crops residues as feeds and also pond sediments as fertilizers for crop [48], in addition to the use of pond water for irrigation. Pond sediment becomes a major source of nutrients for the crops grown on a dike. Before the ninth century, fruit crops were grown on the dike, in addition to fish culture in the pond. Sediment can be applied on the dike, on which short and medium-term crops, i.e. vegetables and fruit crops can be grown, which can bring multiple benefits to the farmers. The residue and/or by-products can be reused for other animals and fish as well, thus recycling nutrients between the pond and the dike. Integration of an aquatic component into farming systems can considerably improve the nutrient use efficiency. Due to these reasons, pond sediment has been widely used in different types of integrated farming systems over centuries in China. However, these systems have not been studied for the quantification of nutrient contents of sediment nor the efficiency of nutrient use. A number of development programs has been aimed to promote the farming systems of South and South East Asia, but nutrient availability and recycling potential have not adequately been given due attention. There is a high potential to grow different fruits crops such as banana, papaya, guava, etc. as well as solanaceae and cucurbitaceae vegetables and beans on the dike with the use of pond sediment. This can improve the performance of the integrated systems and enhance income generation and enhancement of farmers.

4.3 Sediment as an ingredient in potting media

The nutrients and OM contents of sediments are rather high [4]. These parameters qualify pond sediment to be used as an effective ingredient in potting media. As sediment contains 4.98 to 6.20% OM [30] and bulk density of 0.6 to 1.0 g cc^{-1}, by mixing with sand the sediment based potting media can successfully be used in nursery culture, green house studies and home gardening. Furthermore, due to its high nutrient contents (2800 mg N kg^{-1} [27], 70.0 to 112.0 mg P kg-1 [14], and 507 mg K kg^{-1} [27]) it can also be used in mushroom culture as a substrate, and in pasture, fruit orchards, and turf grass production, etc. This information qualifies the utilization of fishpond sediment and its potential in agriculture.

5. Conclusions and recommendations

Nutrients in the pond systems are necessary to produce natural food for fish. These nutrients are applied to ponds via feed materials and with fertilizers. A large amount of applied fertilizer nutrients remain unused, thus accumulating in organic matter and in the bottom sediment. Again, through resuspension, chemical transformations and microbial breakdown of OM, nutrients in sediment could be partially released to pond water. This is a continuous process, which affects primary productivity and subsequent fish yield. But very little effort has been made to improve the reuse and recycling of these nutrients in the sediment for natural food production in ponds and thereby for fish production, which is an area of interest for further research.

Sediment can be a potential source of environmental pollution if not managed judiciously. To avoid or reduce the environmental pollution, utilization of nutrients and OM of pond sediment for economic activities, such as crop production, nursery pot culture, horticultural activities, etc. can be considered as viable management options. Therefore, such research areas can be chosen for addressing these important issues. Interdisciplinary research is needed for environmentally sound and sustainable agriculture-aquaculture technologies, which could eventually provide a multitude of benefits not only to resource-poor fish farmers, but also to the consuming sectors and overall environment.

Sediment can be used as a soil conditioner to improve the physical conditions of agricultural soils. It has a potential as an ingredient in potting media for growing various crops and raising seedlings in pots. However, to make the best use of sediment for crop production, its nutritive value and rate of nutrient release and effectiveness as soil conditioner must first be assessed. Scientific information regarding nutrient quality, potential fertilizer value and efficiency of sediment use for crop production are still lacking. Nutrients and OM build up as well as its microbial breakdown in the pond sediments are a continuous process, in which OM content would not increase infinitely. However, scientific information regarding quantification of nutrients and OM accumulation and microbial breakdown over time in sediment of various pond aquaculture systems is scarce, which warrants further research activities.

6. References

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Table 1. Properties of fishpond sediment and sewage sludge compost

Parameters	**Fishpond sediment**	**Sewage sludge compost**
Organic matter content	49.8 to 62.0 g kg^{-1} [30]	In sewage sludge 530 g kg^{-1} [49]
Bulk density	0.6 to 1.0 g cc^{-1} In pond bottom sediment [4, 27]	Low
Clay content	50 to 60% [4, 27]	-
Nutrient content	N 2.80 g kg^{-1} [27] P 0.07 to 0.11 g kg^{-1} [14], and K 0.51 g kg^{-1} [27]	N 25.8 g kg^{-1}, P 7.3 g kg^{-1}, and K 4.8 g kg^{-1} [50]
PH	7.2 – 8.2 [27]	7.2 [50]
Water holding capacity	47.0 to 50.0% of water content at field capacity [27]	23.86% of water content [50]
Humic substances	Humic acid, fulvic acid and humin etc. released through decomposition of organic matter in sediment [4]	Humic acid, fulvic acid and humin etc. released through decomposition of organic matter in compost
Microbes/detritus	Present in sediment in large numbers [4]. Good for aggregate stability and other microbial activities in soils	Many pathogenic bacteria, viruses and helminthic ova present in different kind of wastes, which could be inactivated through composting [50]

Table 2. Characterization of pond sludge and sludge-compost mixture [27]

Item	pH	OM g kg^{-1}	T-N g kg^{-1}	Available N mg kg^{-1}	Available P mg kg^{-1}	TP mg kg^{-1}	K mg kg^{-1}
Sediment	7.2	64.7	2.80	150	89.15	195.57	378
Sediment -compost (2:1)	7.1	75.6	2.60	120	115.35	240.25	507
Irrigation water	-	-	-	1.43 mg l^{-1}*	0.005 mg l^{-1}**	-	4 mg l^{-1}

*Available nitrogen in water (NH_4^+-N and NO_3^--N); **SRP = Soluble reactive phosphorus;

Table 3. Potential of fish pond sediment to supply nutrients to morning glory in terms of tissue analysis [27]

Plant parts	Mean nutrient concentrations in morning glory, %			Dry matter yield g pot^{-1}
	N	P	K	
Edible part	0.84 (0.12)	0.14 (0.02)	2.58 (0.37)	14.30
Roots	0.24 (0.08)	0.12 (0.04)	2.26 (0.76)	33.61
Total plant (edible + roots)	0.42 (0.20)	0.13 (0.06)	2.35 (1.13)	47.91
Recovered fractions	38%	14%	53%	
SCNC	62%	67%	64%	

(Values given in the parenthesis are the total amount of nutrient uptake by morning glory (g pot^{-1});
SCNC = sludge contribution to nutrient supply for crop)