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 Quality on the Production of Oreochromis

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Changes in pond water quality subsequent to loading of four types of organic materials were examined in relation to growth and net yield of hand-sexed male <u>Oreochromis</u> <u>niloticus (L.)</u>. The experiment was conducted over 150 days at the Rwasave Fishery Research Station of the Université Nationale du Rwanda (Central East Africa) during the dry season 1987. Mixed green grasses (GG), composted green grass (CS), compost mixed with cow manure (CM), and compost enriched with vinasse (CV) were applied in triplicate to earthen ponds (600 m² each). Ponds received an initial organic input of 2260 kg dry matter/ha one week prior to stocking of <u>O</u>. <u>niloticus</u> at a density of 1 fish/m². Subsequent inputs were applied biweekly at a rate of 270 kg dry matter/ha.

Significantly lower DO levels, significantly higher total alkalinity and hardness, greater total phosphorus and chlorophyll <u>a</u> concentrations were recorded in ponds

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receiving GG than in ponds receiving other treatments. Oxygen depletion did not cause noticeable effects on fish growth and survival. Diel patterns of top and bottom DO showed that ponds mixed over night and stratified during the day. No significant differences were detected for treatment effects on other water quality variables. High correlations were found between OC input and both total alkalinity (r= 0.80) and hardness (r= 0.75). Chlorophyll a levels were relatively low, but a substantial increase in phytoplankton production was observed over time and reached an average of 32 mg/m³ in GG-treated ponds. <u>O. niloticus</u> in ponds receiving GG grew with a daily weight gain of 0.50 ± 0.17 g/d and provided a net fish yield of $4.59 \pm$ 1.50 kg/ha/d, which were significantly higher than that from CS treatment ($P \le 0.05$). Compost-cow manure and compostvinasse mixtures provided intermediate results and were not significantly different in terms of fish growth and net yield (P>0.05). Mean survival of Oreochromis niloticus ranged between 80-91%. Multivariate statistical analyses demonstrated that treatment differences in fish production performance should be attributed to differences in input OC contents and their direct influence on total alkalinity, hardness and primary production. Weak correlations between net fish yield and chlorophyll <u>a</u> concentration in the water (r= 0.54) suggested that the primary feeding pathway was probably via the direct consumption of green grasses, detritus, and heterotrophic organisms.

INTERACTIONS OF ORGANIC INPUT TYPES AND WATER QUALITY ON THE PRODUCTION OF <u>Oreochromis niloticus</u> (<u>Linnaeus, 1757</u>) IN RWANDAN PONDS

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INTERACTIONS OF ORGANIC INPUT TYPES AND WATER QUALITY ON THE PRODUCTION OF <u>Oreochromis</u> <u>niloticus</u> (<u>Linnaeus, 1757</u>) IN RWANDAN PONDS

INTRODUCTION

The pond culture of <u>Oreochromis niloticus L. (Tilapia</u> <u>nilotica</u>) and other warmwater fish has been extensively studied in most tropical areas. However, limited work has been performed to study the highland African pond ecosystems and their potential for fish production. Rwanda, where Tilapia culture began only about forty years ago (Bardach et al., 1972; Balarin, 1979; Moehl et al., 1988; and Hishamunda, 1988b), exemplifies the highland African environment.

Only recently, fish culture activities conducted in Rwanda by the National Fish Culture Project and the research projects carried out by the Collaborative Research Support Program (CRSP)/Pond Dynamics and Aquaculture demonstrated that Tilapia culture in Rwanda is promising under conditions of appropriate management schemes. Well-managed ponds generally produce 1500-2000 kg of fish/ha/year or more, with <u>O. niloticus</u> showing better performances than <u>O. macrochir</u> and <u>Tilapia rendalli</u> (Hanson et al., 1988 and Moehl et al., 1988). Located in high altitude areas of Central East Africa, Rwanda has fish ponds at elevations between 1300 and 2500m. Here air and water temperatures are lower than in many other tropical areas, however, mean morning temperatures (21°C) and afternoon temperatures (26°C) in the pond water are adequate for Tilapia rearing (Moehl et al., 1988).

A constraint to the rapid expansion of aquaculture in Rwanda and other developing countries is the shortage and high cost of supplemental feeds and inorganic fertilizers. Increased fish production in Rwanda requires organic inputs because of the lack of commercial animal feeds, scarce agro-industrial by-products, and expensive chemical fertilizers. Predictions for a successful fish culture program require the development of appropriate pond management practices leading to increased pond production based on the use of available organic materials.

The relatively low natural productivity of Rwandan fish ponds (ranging from 50-300 kg/ha/year) can be enhanced to more than 2000 kg/ha/year by maximizing or optimizing nutrient inputs (Hanson and Rwangano, 1986; Hanson et al., 1988; Moehl et al., 1988; Hishamunda, 1988a). However, family subsistence farming characterizing Rwandan agriculture as well as the land tenure system is the major limiting factor to the development of an intensive fish culture. New strategies have to be outlined, examined and

adopted. Moehl and co-workers (1988) stated that fish farming in Rwanda must rely primarily on the use of organic fertilizers. Compost and manures were identified as the main inputs, supplemented by some agriculture or industrial by-products as food sources, namely leafy materials (cabbage, sweet potatoes, colocasia, carrots, manioc, amaranthus, ...), and rice and wheat brans (Moehl et al., 1988 and Hishamunda, 1988a).

The use of fresh grass, crop residues, compost and livestock manure has been identified as low-cost practices that can increase the pond productivity for fish. Hishamunda (1988a) reported that for ponds producing more than 20 kg of fish/are/year, 83% received compost and 75% were rice bran-fed. Moehl et al. (1988) recommended the use of a compost:livestock manure ratio of 4:1 by volume. Hishamunda (1988a) suggested that 1 m³ of compost/are should be applied initially, followed by 0.1 m³ compost/are per week during the grow-out period, plus a supplemental feeding at a 1:10 rice bran: fish biomass ratio. This ratio was progressively reduced to 0.2:10 as the fish gain weight. Lower yields were associated with the addition of lower inputs to fish ponds.

Nevertheless, investigations of pond production processes using such organic inputs have not scientifically and statistically analyzed the organic material pathways, nor quantified the effects on natural food webs and on water quality that culminate in increases of fish production. Yet, the utilization of various agroindustrial and household wastes as main sources of fish food and pond nutrients is very common in Zaïre (Low,1985), Uganda (Semakula and Makoro, 1967; Bardach et al. 1972), Nigeria (Ofuka and Marriott, 1980), Congo (Hickling, 1972; Bardach et al., 1972), Central African Republic (van der Lingen, 1967b), and other countries (Miller, 1976). It is essential to assess the effects of single input source and combined materials on the pond system in order to optimize input composition and application rates best suited for enhancing pond productivity.

This investigation was designed to analyze the differential impacts of four different organic nutrient sources available in Rwanda on pond water quality in relation to pond productivity for <u>O. niloticus</u>. Multivariate procedures were used to analyze relationships between input characteristics, water quality variables, and fish growth and yield. The input materials were: (1) green grass; (2) composted grass; (3) a mixture of composted grass and cow manure; and (4) a mixture of composted grass and vinasse, a by-product from the distillation of sugar cane molasses.

Specific objectives were: (1) analyze physico-chemical changes occurring in the water column subsequent to organic materials loading; (2) evaluate the effects of organic fertilization on growth and yield of <u>O. niloticus</u> (L.) in tropical freshwater ponds; (3) investigate the relationships between <u>O. niloticus</u> growth, net yield, and measured water quality variables as influenced by the different organic treatments. It was assumed that the use of organic matter induces changes in water chemistry and biology of the ponds, and therefore, changes in pond productivity in terms of fish yield.

RELATED LITERATURE REVIEW

A problem facing fish farmers in developing tropical nations is that of finding adequate and economical sources of fish feed ingredients and fertilizers suitable for an intensive fish culture program. In most developing countries, commercially produced inputs are often imported and unaffordable for rural farmers. Miller (1976) reviewed the use of inorganic and organic fertilizers and feeds in warmwater fish culture in Africa and concluded that costs of inorganic fertilizers were prohibitive for many African countries. The only apparent possibility for development of aquaculture in the short term is the application of organic fertilizers. High quality fish foods are limited in Africa, because fish culture must successfully compete with other forms of animal husbandry for feeds, with agriculture for manures and even for products suitable for human nutrition. But as agriculture develops in Africa, more by-products and waste products are becoming available for use in aquaculture (Miller, 1976). In the long term there is a need to develop sustainable, intensive farming systems able to afford feeds, organic and inorganic fertilizers, and to encourage integrated agriculturelivestock-fish farming systems.

Sources of organic fertilizers suitable for fish farming include: compost, green and animal manures,

household and slaughter-house wastes, and agro-industrial residues. At least some of these organic wastes could be recycled into fish flesh, because fish may be the most profitable animal product when grown on wastes (Edwards, 1980). Fish grow rapidly in tropical waters, and if wastes replace expensive sources of energy and other required nutrients, the cost of production is reduced. Fish farming is an efficient and appropriate alternative strategy of development for the production of protein-rich foods in developing countries. The Chinese produce about two-thirds of the World's yield of cultured fish (2.25 million tons annually) in ponds receiving composted human wastes, animal manures, rice brans, distillers by-products, and diverse materials gathered in the pond vicinity such as grass and snails (Wohlfarth, 1978). Use of organic inputs in Chinese aquaculture has been practiced for several centuries (Wohlfarth 1978; Edwards, 1980, and Chang, 1989), and recent advances in Asian countries have improved the profitability of fish farming (Edwards, 1980).

Since fish productivity in organic-loaded ponds depends both on aquatic production of natural foods and the nutritive value of organic input materials consumed directly by fish, it is essential that required nutrients are present. In the presence of adequate nutrients, primary production reaches a maximum of about 11 g organic

carbon (C)/ m^2 /day in tropical and subtropical climates (Schroeder, 1979; Zur, 1981; Colman and Edwards, 1987). Maximum values in the autotrophic food chain are not only limited by nutrient availability, but also by the amount of solar energy penetrating the pond water (Schroeder, 1978; Noriega-Curtis, 1979; Colman and Edwards, 1987). Also, other factors such as pH, temperature, competition and predation, etc..., affect autotrophic production. Growth of heterotrophs in the food chain is limited by oxygen and food availability. Like autotrophic production, heterotrophs can be increased considerably by appropriate pond management techniques (Schroeder, 1978).

Almazan and Boyd (1978) found that very soft waters (e.g. 10 mg/l total hardness and alkalinity) do not support adequate primary production. In soft water ponds or acid pond bottoms with a pH less than 6, total alkalinity, pH and primary production can be improved by liming (2 to 6 t $CaCO_3/ha$), and providing nutrients through fertilization. At least 0.2 ppm of phosphorus is required for acceptable levels of primary production, but extractable P in the pond soil may be transferred to the water (Schroeder, 1979).

The nutrient value of composts and manures varies widely depending largely on the source materials. Schroeder (1980) indicated that the C:N:P ratios of most manures are favorable for microbial production, but an optimum C:N:P

ratio for bacterial growth medium is about 20:1:0.2.

The average composition range of matured composts based on percentage dry weight was given by Biddlestone and Gray (1987): organic matter: 25-80; carbon: 8-50; nitrogen (as N): 0.4-3.5; phosphorus (as P): 0.1-1.6; potassium: 0.4-1.6; and CaO: 7.0-1.5. On a fresh weight basis, vegetable wastes were reported to contain 0.49% N, 0.12% P and 0.9% K; vegetable wastes and dung contained 0.43% N, 0.10% P and 1.0% K; mixed weeds: 0.40% N, 0.12% P and 1.3% K; garden compost: 0.4-3.5% N, 0.3-1.0% P and 0.2-0.3% K (Biddlestone and Gray, 1987). It appears that garden compost may contain more P than raw weeds or vegetable wastes, and tends to have a higher N content.

Phosphorus and nitrogen have received the greatest attention as nutrients required to enhance growth of organisms at the base of the aquatic food webs and needed to promote fish yields (Boyd, 1979 and Wetzel, 1983). Both N and P are supplied to fish ponds in the tropics to stimulate primary productivity for more intensive fish production based on natural food (Woynarovich, 1975), and to activate microbial growth (Schroeder, 1987).

Recently, in low alkalinity ponds fertilized with chicken manure or triple superphosphate and urea (phosphorus and nitrogen not limiting), McNabb et al.(1989) demonstrated that limitations in algal productivity and

yield of male <u>O. niloticus</u> were due to insufficient supply of dissolved inorganic carbon. The requirements for a good algal growth was reported as 40:7:1 weight ratio of inorganic carbon, nitrogen, and dissolved reactive phosphorus (Wetzel, 1983 and McNabb et al., 1989).

For the decomposition of organic matter, an initial C:N ratio of about 25:1 should be optimum if no nitrogen is lost (Biddlestone and Gray, 1987). A higher ratio, such as in low-protein plant residues, involves the oxidation of excess carbon, requiring the action of many successive generations of bacteria to attain a final C:N ratio of about 10:1. In the tropics, this ratio can be achieved within about 3 months, provided moisture is maintained at about 50-60% and temperature is about 55°C for microbial growth in on-land composts (Dalzell et al., 1979; Edwards et al., 1983; and Biddlestone and Gray, 1987). When C:N ratios are lower than 25:1 (as in the case of animal manures), nitrogen is lost as ammonia, especially in aerobic conditions. However, this is partially offset in aquatic medium by the activity of nitrogen-fixing bacteria (Biddlestone and Gray, 1987). Wetzel (1983) reported that N_2 fixation is dominated by blue-green algae such as Anabaena sp. and Microcystis sp., photosynthetic bacteria, and some heterotrophic bacteria comprising several species of Azotobacter and Clostridium pasteurianum.

Fish culturists can utilize mixtures of manures and plant residues to efficiently achieve adequate C:N:P ratios in composts. In order to obtain the highest fish yields from organic fertilizers, fish culture should be based on plankton feeders, and/or omnivores (Bardach et al., 1972; Torrans, 1986). Recent fish farming success in a number of Asian countries is based on the monoculture or polyculture of fish species feeding low on the food chain, and avoiding the energy loss encountered in subsequent trophic levels.

Among the most popular fish cultured are the tilapias, largely because of their adaptable feeding strategies and the ability to tolerate extremes in water quality. The culture of tilapias is widespread in Africa and throughout much of the tropical World (Fryer and Iles, 1972; Bardach et al., 1972; Balarin, 1979; Bowen, 1982; Trewavas, 1983).

Bowen (1982) stated that the planktivorous tilapias from Africa, particularly <u>O</u>. <u>niloticus</u> and <u>O</u>. <u>aureus</u>, were the most promising fish for the development of detrital-fed systems. <u>O</u>. <u>niloticus</u> has many advantageous characteristics for fish culture. It adapts to a wide range of water environments and various levels of organic loading (Torrans, 1986). Balarin (1979) summarized the water quality requirements for tilapias and reported lethal concentrations limits for dissolved oxygen (DO) as 2-3 mg/l and for CO_2 as greater than 72.6 mg/l. Lethal ammonia concentration was detected as greater than 4.0 mg/l at a pH of 7.3-7.5, and ammonia toxicity increases with increasing pH. <u>O. niloticus</u> has a high tolerance for low dissolved oxygen and survived in ponds in Sudan at a DO level of 1.2 mg/l (George, 1975).

Tilapia survive over the pH range of 5 to 11 and over the temperature range of 8 to 40°C, but Bardach et al. (1972) reported 11°C and 42°C as lethal for <u>O. niloticus</u>. Balarin (1979) estimated a temperature range of 21-32°C as the most favorable for tilapia culture, and salinity tolerances ranging from <20 ppt up to 35 ppt.

Various reports showed that <u>O</u>. <u>niloticus</u> has a considerable trophic plasticity, but the preference for a given type of food depends directly on its abundance in the pond environment. Chen (1976) and Huet (1972) noted that <u>O</u>. <u>niloticus</u> is omnivorous, but feeds mainly on phytoplankton and even parts of macrophytes. Trewavas (1983) and Tytler and Calow (1985) reported that <u>O</u>. <u>niloticus</u> is herbivorous, but mainly a microphytophage. At less than 6 cm total length, the species is omnivorous, actively feeding on zooplankton, hydracarines, various larvae and insects, and ingesting aufwuchs and detritus (Balarin, 1979 and Trewavas, 1983). The contribution of phytoplankton, mainly green and blue-green algae, becomes more significant for larger fish (Bardach et al., 1972; Moriarty, 1973; Moriarty and Moriarty, 1973a; Harwanimbaga, 1987; Harwanimbaga et al., 1988; Colman and Edwards, 1987; and Lowe-McConnell, 1987). The diet of large fish also includes zooplankton and micro-organisms associated with detritus (Moriarty, 1973; Moriarty and Moriarty, 1973a; Bowen, 1982; Edwards et al., 1983 and Harwanimbaga, 1987), and, if available, pelleted feeds (Ruwet et al., 1976; Miller, 1976; Bard et al., 1976; Coche, 1977 and Balarin, 1979). <u>O. niloticus</u> even produced significant yields when fed on compost aerobically produced from nightsoil (human feces) and water hyacinth (Edwards et al., 1983).

Bardach et al. (1972) reported that <u>O</u>. <u>niloticus</u> experimentally stocked at 2500 to 5000 fish/ha controlled filamentous algae and also fed on higher plants to the extent that it may be useful for weed control, though not as effectively as the strictly herbivorous <u>Tilapia</u> <u>melanopleura</u>.

In general, tilapias have proven capable of efficiently converting manures, grasses, low-cost cultured algae, and various low quality inexpensive agro-industrial by-products and wastes into high quality proteins. Investigations on the use and efficiency of these valuable resources have been performed in different countries with the objective of replacing part of or all supplemental

feeding.

The optimal use of organic inputs has been developed through the integrated livestock-agriculture-fish farming systems in order to optimize the use of organic wastes, and to reduce the cost of feeds and fertilizers. Studies have examined the efficacy of applying organic fertilizers from swine, cattle, sheep and poultry wastes to fish ponds containing a variety of fish species in various countries including the Philippines (Rabanal and Shang, 1976; Hopkins and Cruz, 1982), Indonesia (Bardach et al., 1972; Rabanal and Shang, 1976), Malaysia (Edwards, 1980), Thailand (Janesirisak, 1979; Edwards, 1980), Taiwan (Tang, 1970 and Chen, 1976), China (Hickling, 1962; Wohlfarth, 1978; Edwards, 1980; Matena and Berka, 1987; and Chang, 1989), Israel (Schroeder, 1975; Schroeder and Hepher, 1976; Schroeder, 1978; Degani et al., 1982; Sariq, 1982 and Wohlfarth and Hulata, 1987), Central and Eastern European countries and USSR (Huet, 1972; Martyshev, 1983 and Opuszynski, 1987) and throughout much of the tropical regions, including Africa (van der Lingen, 1967b; Vincke, 1976; Miller, 1976; George, 1976; Low, 1985; Habineza, 1986; Moehl et al., 1988; Hishamunda, 1988 a and b).

Bowen (1987) summarized organic matter decomposition processes into two different pathways: (1) soluble components are released by the action of various physical, chemical and biological agents, many of which convert dissolved organic matter back into particles; (2) insoluble plant tissues are progressively fragmented by the interaction of microorganisms, invertebrates and mechanical abrasion. In the course of detritus processing, the more labile components are lost or bound into recalcitrant organic complexes, while the more refractory organic components accumulate. In particular, lignocellulose, lumin and other refractory products that contain less digestible protein and energy forms accumulate in detritus. Bowen (1981, 1982) found that tilapias are able to digest non-living amorphous detritus, thus releasing the energy of complex amino-acids. Edwards et al. (1983) observed that O. <u>niloticus</u> in Thai ponds consumed compost directly (compost produced from nightsoil and water hyacinth by aerobic composting), and produced significant fish yields at a mean food conversion ratio of 7.4. A mean extrapolated yield of 3.6 t/ha/yr of O. niloticus was obtained with a relatively low feeding ratio. The growth obtained in this experiment was explained by the ability of the species to secrete gastric acid which lowered the stomach pH to about 1.2 (Moriarty, 1973; Moriarty and Moriarty, 1973a) and allowed hydrolysis of most of the available carbohydrate from the compost as an energy source, rather

than relying entirely on the feed value of the highly proteinaceous microbes (Bowen 1982). Edwards et al. (1983) reported that fish feeding trials were underway with both water hyacinth (C:N ratio of about 25) and rice straw composts. They stated that in the tropics, rice straw with an initial C:N ratio of about 100 can be decomposed in a few months to produce a compost with a C:N ratio of less than 20, provided adequate moisture (50-60%) for microbial growth are present. Also, composted grass and compost enriched by animal wastes can provide a sustainable fertilizing input for fish ponds. However, compared to the use of aerobically composted water hyacinth trials, lower fish production was found when compost made only from rice straw was used, suggesting that for the detritus consuming tilapias the C:N ratio of compost materials and the final compost may be critical for their use (Little and Muir, 1986). Edwards et al. (1983) concluded that the production and utilization of compost as feed for tilapias and as pond fertilizers may provide the necessary impetus to the development of low cost aquaculture systems suitable for poor farmers in the developing countries. According to Little and Muir (1986) aerobically processed composts have lost some nitrogen in the form of ammonia, especially if the nitrogen content was initially high. Phosphate and potash are more effectively conserved; carbon is lost in

large amounts as CO_2 , which may be an advantage since the product has a decreased oxygen demand compared to the raw materials.

Green manures in such forms as grass, crop or mangrove leaves or pond weeds, have been used in Europe, USSR, Asia and Africa as direct fish food sources and indirect pond fertilizers creating conditions for the mass-scale development of micro-organisms -- an important link in the food chain (Hickling, 1962; van der Lingen, 1967a; Miller 1976; Balarin, 1979; Edwards, 1980; Martyshev, 1983; and Low, 1985). Green manuring has found application in USSR commercial fisheries, where the efficacy of different plant species and groups has been studied (Martyshev, 1983). Martyshev affirmed that aquatic plants and terrestrial shore plants (including herbaceous weeds) as well as cultivated crops are suitable for pond green manuring. The initial link in the food chain - bacteria - develops better when soft meadow grasses are included. Manuring with leguminous plants increases the nitrogen content of the pond while other coarse grasses are mainly sources of organic carbon. With soft meadow plants and a pond water temperature of 25 to 30°C or higher, the bacterial population develops rapidly. At lower temperatures (16 to 19°C), bacterial development was slow (Martyshev, 1983). If coarse plants are used for manuring, bacteria develop

slowly even at higher temperatures, and nutrients from these plant materials are not released into water as quickly as those from soft plants.

Hickling (1962) reported that green manure was more frequently used in fish pond work than was compost. These green materials are valuable because decomposing tissues give up nutrients quickly into the pond water, and are a very good substratum for microorganisms and aquatic invertebrates which are fed upon by fish. Green manures promote the rapid development of bacteria and green algae, which serve as food for zooplankton. Green manure also favors the development of benthic organisms. Both chironomids and oligochaetes develop in pond areas covered with rotting plants (Martyshev, 1983). Coarse plants are less effective than soft ones, but they are used for green manuring purposes. USSR experience has shown that coarse plants can increase the outputs of fish by 50 to 100% with a reduction in the production costs by 20 to 30% (Martyshev, 1983). Unsatisfactory results from the use of green manures have been reported as caused by the rapid decay of these plant materials and subsequent deoxygenation (Semakula and Makoro, 1967; van der Lingen, 1967a; Miller, 1976). This resulted from practices such as scattering or heaping materials onto the bottom of drained ponds, and subsequently filling the ponds with water. This practice

produces anaerobic conditions, and may potentially generate toxic substances such as hydrogen sulfide, ammonia, and methane gas (Schroeder, 1980).

Due to the potential reduction in dissolved oxygen levels in the water when large amounts of organic matter are applied to ponds, it is preferable to pile or heap loosely these materials in wattled enclosures around the water's edge to restrict the anoxic zones instead of spreading over the entire pond surface or heaping onto pond bottoms (Bard et al., 1976; Balarin, 1979; Martyshev, 1983; Yamada, 1986). The materials should be periodically turned over to keep them loose, thus encouraging decomposition. Schroeder (1975) suggested the determination of the amounts that could be added safely to the pond, based on the BOD of the organic matter. Martyshev (1983) recommended that green manures should be applied at 3-4 tons/ha in unpolluted ponds that were open to winds and that contained a favorable dissolved oxygen concentration. He suggested a load of 1 to 2 tons/ha in ponds with low oxygen contents (measured at 5 to 8 a.m.), mildly polluted but not marshy, and devoid of blue-green algae.

For manures, Woynarovich (1975) suggested that manures be distributed over the pond water surface and dispersed in the water column, where abundant populations of reducing bacteria exist to decompose the organic matter into simpler

compounds for immediate utilization by phytoplankton. When fresh cow manure was applied alone, Schroeder (1978) concluded from Israeli experiences that the maximum amount that a pond can safely digest was about 70 to 140kg/ha/day. When mixed with composted grass, the amounts of cow manure needed can be reduced.

Van der Lingen (1967b) pointed out that manuring (including use of green-manure and composts) may not be economical for large-scale use due to the bulk and the resulting high labor and transportation costs. Manuring and organic fertilization are practices recommended where materials for fish culture are locally available at little or no cost (Hickling, 1962; and Miller, 1976). Results obtained from the FAO Regional Fisheries Project, comprising Central African Republic, Gabon, Cameroon and Congo, indicated that the use of organic fertilizers constitutes one of the best means of increasing fish production in the region (Miller, 1976 and Vincke, 1976).

In Rwandan fish culture, suggested volume ratio in the mixture of organic materials is 80% dried grass and 20% manure (Moehl et al., 1988). Field observations and survey in the rural sector indicated that this compost mixture was readily available to rural farmers. Experiments using compost with or without supplemental feeding (3% rice bran, based on fish biomass) to $\underline{0}$. <u>niloticus</u> stocked at two

different densities concluded that 1.0 m³ compost/are/month was appropriate. Higher average fish production (1910 kg/ha/yr) and smaller fish (\overline{X} = 97 g) were obtained at a stocking rate of 2 fish/1.5 m2, while lower average fish production (1390 kg/ha/yr) and bigger fish (\overline{X} = 133 g) were obtained at lower stocking rate of 1 fish/1.5 m² (Moehl et al., 1988). Although supplemental feeding with rice-bran as well as other agro-industrial by-products proved to be beneficial, their use in fish culture is limited to areas where these wastes are available. Most farmers supplement compost with leafy materials such as cabbage, sweet potatoes, manioc or colocasia leaves. Amounts of input materials (compost and/or other supplemental organic matter) applied have not been always quantified, and only the fish yields obtained have been reported. Little is known about the nutritive value of specific waste materials and the differential efficiencies in enhancing both pond water quality and fish production.

The aim of this study is to characterize green grass consisting of a mixture of herbaceous plants, and various composts (composted green grass, compost mixed with cow manure, and compost enriched with vinasse) and to evaluate these inputs as nutrient sources for the fish pond ecosystem. Relationships between input characteristics, physico-chemical responses of the pond water, and fish production were investigated.

MATERIALS AND METHODS

Site description.

The research was conducted at the Rwasave Fish Culture Station of the Université Nationale du Rwanda (Central East Africa) in Butare. The Station has a total area of 20 hectares of which about 8 ha are currently in earthen fish ponds (Figure 1). The experimental ponds were selected from pond series C and D. Each pond was 40 m x 15 m, with an average depth of 0.90 m. The maximum water depth is 130 cm near the monk and the minimum is 60-70 cm at the shoaling area opposite to the monk. Water samples taken from the water supply canal were characterized as follows: alkalinity of 17.0 mg CaCO3/1; total hardness of 43.3 mg CaCO3/1 and a pH ranging between 6.0 and 7.0. The physical characteristics of the site were reported by Rwangano and Rurangwa (1987) as: 1700 m altitude; 1200 mm average annual rainfall; 20.8°C average annual air temperature in 1986 (3.7°C minimum and 34.3°C maximum); 66% average relative air humidity (34% min.); 27.6°C average pond water temperature at 25 cm below surface (15°C min. and 30°C max.).



Figure 1. Diagram of the experimental ponds at the Rwasave Fish Culture Station, Rwanda. Total water surface area: 8 ha; experimental ponds: C, D series. Scale: Approximately 1:4500. One cm equals approximately 45 m. Sources and characterization of the input materials.

The input materials were green grass (GG), composted grass (CS), mixture of CS and cow manure (CM), and mixture of CS and vinasse (CV). Green grass was freshly cut from pond dikes and surrounding areas. The compost resulted from an on-land aerobic composting of fresh grass (piles of 2.5 cubic meter each) for 3 months. Grass was harvested every 3 to 4 months and consisted of a mixture of Cynodon <u>dactylon</u> (Umucaca), Crassocephalum bumbense (Iqifuraninda), Brachiaria sp., species of Digitalia and few Papyrus latifolia (Urukangaga). Cow manure was collected weekly from the farm of the Ecole Agri-Vétérinaire de Kabutare. About 300 liters of vinasse, a by-product from the distillation of sugar-cane molasses, was collected twice a week at the distillery unit of the UNR-CURPHAMETRA (University Research Center on the Pharmacopeia and Traditional Medicine).

Fresh grass, compost, cow manure, and vinasse were analyzed for percentage dry matter, percentage organic carbon, total nitrogen and total phosphorus. Two 100 g samples per treatment were dried in an oven at 60°C, cooled and weighed until a constant weight was obtained to estimate dry matter content. Two 100 g subsamples from dried and ground samples were analyzed for organic carbon (OC) following the Walkley-Black titrimetric method (Juo,

1978). Total nitrogen (N) determination in the plant materials was performed using the micro-Kjeldahl method. Phosphorus (P) was determined using the perchloric acid digestion (wet oxidation) followed by the colorimetric determination (Juo, 1978).

The mixtures, compost + cow manure (10%) and compost + vinasse (5 l per 10 kg of compost), were made based on organic C, N and P contents. The proximate composition of organic materials was determined before the start of experiment (Table 1).

Organic	Dry matter	Comp	y weight)	
material	(%)	oc	Total N	Total P
Vinasse (V)	-	-	0.76	0.11
Cow manure (M)	18.38	26.25	1.28	0.13
Fresh grass	20.25	38.60	2.27	0.17
Compost	27.13	26.87	4.10	0.59
Compost + M	24.60	28.70	3.90	0.61
Compost + V	22.75	28.50	3.43	0.55

Table 1. Average proximate composition of input materials.

To assess nutrient release during the decomposition process, organic input materials were sampled from pond enclosures once a month beginning the first week of treatment. Four samples per pond were taken, pooled and analyzed for percentage dry matter, percentage organic C, total N and total P. Pond preparation and experimental design.

Experimental ponds of 6 ares each were randomly selected to receive a given treatment. These ponds had a water pH ranging between 6 and 7 and alkalinity greater than 20 mg/l. Ponds inlets were screened to prevent entrance of wild fish. Wattled enclosures confining 10% of each pond's total surface area were constructed to receive the organic inputs. Organic materials were applied in four triplicate treatments: GG= green grass; CS= composted green grass; CM= compost mixed with cow manure and CV= compost enriched with vinasse. Treatments were analyzed for OC:N:P ratios (Table 2). Inputs were loaded into enclosures at 248.20 ± 0.30 kg dry weight/ha/week. Levels of application of raw materials were based on the percentage organic C, N, P, and dry matter content. Approximately 45% of the total loading was applied one week before the fish stocking and the remaining 55% was added at two-week intervals for 20 weeks. The high initial loading is recommended by the National Fish Culture Project Team. High loading was done to boost microbial production in the ponds, and to reduce any differences in the initial natural productivities. For all treatments, inputs were applied prior to stocking to avoid fish mortality that may result from DO depression in ponds loaded with organic materials. Heavy loading also helps to kill tadpoles that may develop in standing waters.

Experimental ponds	Treatments	Initial input kgDW/ha	Subsequent input rate kgDW/ha/2wks	Average weekly input kgDW/ha	Nutrient inputs kgDW/ha/week			00.00
					oc	N	P	ratios
C ₄ -C ₉ -D ₅	GG	2261.25	270.00	248.10	95.7	5.6	0.4	239:14.0:1
D ₂ -D ₃ -D ₇	CS	2260.50	271.25	248.65	66.6	10.2	1.5	45: 6.8:1
^C 1 ^{-D} 1 ^{-D} 4	CM	2255.00	270.60	248.05	71.2	9.7	1.5	48: 6.5:1
C ₃ -C ₅ -D ₁₁	CV	2260.00	270.00	248.00	70.7	8.5	1.4	51: 6.1:1

Table 2: Input rate and nutrient content of organic materials.

GG= green grass; CS= compost; CM= compost + cow manure; CV= compost + vinasse.
Water sampling and measurements.

At each sampling, one water sample per pond was collected by pooling three 90-cm column samples taken in the morning between 0530 and 0630 using PVC pipe samplers placed vertically in the pond. Weekly measurements included dissolved oxygen (DO), temperature, and pH. DO and water temperature were measured at 25 cm below water surface, mid-water depth and at 25 cm above pond bottom (about 90-100 cm below surface). Bi-weekly measurements (on even weeks) included total alkalinity, total hardness, total Kjeldahl-N, nitrate, total phosphorus and chlorophyll <u>a</u>. Monthly diel samples were taken at 4-hour intervals beginning at 0600, and DO, temperature, and pH were monitored. The diel sampling was performed the same day as the chlorophyll <u>a</u> measurements.

Analytical procedures for water samples followed the Standard Methods for the Examination of Water and Waste Water (APHA/AWWA/WPCF, 1985) with exceptions as noted. DO and temperatures were measured using the YSI Model 57 oxygen meter with probes, with \pm 0.1 mg/l and \pm 0.5 °C accuracy, respectively. DO was also determined in the laboratory using the Winkler (iodometric) method (Boyd, 1979 and APHA/AWWA/WPCF,1985). The pH was measured using the Orion Research Model 221 pH meter with electrodes (\pm 0.005 accuracy) carefully calibrated with pH 7.0 and 4.0 buffer solutions. Alkalinity and total hardness measurements used the potentiometric titration and the EDTA-titrimetric methods. Total Kjeldahl-N determination followed the analytical method used by the Michigan State University Limnological Research Laboratory (CRSP, 1985). Nitrate determination used the phenoldisulfonic acid procedure and spectrophotometry (Boyd 1979, pp.243-45).

Ammonia was monitored only at the beginning and the end of the experiment. Ammonia analysis followed the phenate method (Boyd 1979, pp.220-223) as an alternative to the Nessler method. Total phosphorus was determined following the persulfate digestion, and the stannous chloride methods (Boyd 1979, pp.255-59 and APHA/AWWA/WPCF 1985, pp.444-48). The pigments contained in the phytoplankton were extracted in acetone 90% and chlorophyll <u>a</u> concentrations were detected using a B&L Spectrophotometer Model 21 (Boyd 1979, pp.267-69 and APHA/AWWA/WPCF 1985, pp.1067-1070).

Physical measurements.

Physical measurements at the Rwasave Station included: solar radiation, rainfall, air temperatures, maximum and minimum pond temperatures, and secchi disk visibility. Solar radiation readings were recorded at 24-hour intervals from an integrating solar monitor with a quantum sensor

installed at the study site on the laboratory roof.

Rainfall and air maximum-minimum temperatures readings were also performed at 24-hour intervals on three rain gauges and three maximum-minimum thermometers, respectively. Readings were recorded and averaged. Pond temperature extremes were measured weekly in three ponds. Two maximum-minimum thermometers were placed in each pond, one at 25 cm below the water surface, and another at 25 cm above the pond bottom. Average temperatures were reported. Secchi disk visibility was measured bi-weekly (on even weeks) at 0700 in the morning, and on the same days as chlorophyll <u>a</u> analyses.

Fish sampling and measurements.

O. niloticus (L.) fingerlings from the same parental stock were hand-sexed twice by visual inspection of external genitalia. Males were stocked into the experimental ponds at a rate of 1 fish/m2. Fingerlings averaged 37.2 g when stocked. The experiment extended for 150 days during the dry season (May 26, 1987 until October 22, 1987). Ponds were stocked with fish distributed in groups of 100 individuals. Ten fish per group were selected for individual weight (g) and total length (cm) measurements. Groups were randomly assigned to ponds with each pond receiving 6 groups and 600 fish total . Average weight and mean total length at stocking were calculated for each experimental pond.

At 30-day intervals, a grab sample of at least 60 fish per pond was taken with a net and weighed as a group. A sub-sample of 25 (or 10% if the grab sample included more than 250 fish) was selected for individual weight and length measurements. Average weight, mean total length, mean daily weight gain and specific growth rate per treatment were calculated. The mean daily growth rate was calculated using the expression:

Daily growth rate (g) =
$$\frac{W_{t2} - W_{t1}}{t_2 - t_1}$$
, where:

 $t_2 - t_1 = time interval or number of days on trial;$ W_{t2} = average fish weight (g) at the end of the timeperiod; and W_{t1} = average fish weight (g) at the beginningof the considered period.

The daily specific growth rate DSGR (%g/day) was calculated from $k = \frac{dW/dt}{W} = \frac{\ln W_{t2} - \ln W_{t1}}{t_2 - t_1}$, expressed as %,

where k is an instantaneous coefficient of growth relative to body weight (Viola and Arieli, 1983; Siddiqui et al., 1988 and Hepher, 1988).

During the monthly sampling, tilapia fingerlings were counted and weighed. Also, fish health was checked in order to consider and report any disease incidence.

Ponds were drained after 150 days. All fish were

weighed, counted and measured individually. Total fish biomass (kg) per pond was recorded. Net productivity (kg/ha/day), average weight, mean total length, and survival at harvest (% of initial stock) were calculated. Calculations for net productivity per treatment took into account the eventual reproduction and mortality as shown in the following expression:

 $[(W_{T} + RW_{T}) - (W_{0} - \{(W_{0}/N_{0})(N_{0} - N_{T})\})]40.56, where:$ $W_{0} = \text{initial weight (kg); } W_{T} = \text{final weight (kg);}$ $RW_{T} = \text{final weight of fingerlings produced (kg);}$ $N_{0} = \text{number of fish at stocking and } N_{T} = \text{final fish number.}$ The coefficient 40.56 = (100/6)(365/150) is used to extrapolate the yield per hectare per year.

Methods of statistical analyses.

Statistical comparisons between treatments and between ponds were run by computer AST Premium/386C IBM compatible, utilizing the one-way analysis of variance in STATGRAPHICS 3.0 package. Measured water variables, fish weight, total length, growth rates and net yield were the factors under investigation. The analysis tested differential effects of the four treatments on pond productivity. Scheffé multiple range test and the least significant difference contrasts (LSD) were used to test for differences among means when F values from ANOVA were significant ($P \le 0.05$). Detrended Correspondence Analysis (DCA) was applied to a standardized data matrix containing values for all measured variables on input characteristics, water quality variables, and fish data recorded in 12 experimental ponds.

Although DCA was conceived to analyze ecological relationships between species assemblages as influenced by sites and environmental factors, the program is also capable of identifying relationships between various measured variables in concordance with site characteristics (McIntire, C. David, 1989, personal communication). The algorithm is an eigenvector ordination technique which consists of a two-way averaging procedure. Although based on Reciprocal Averaging (RA), the method of detrending used in DCA has the advantage of correcting the two major faults of RA: the arch distortion of the second axis and compression of first axis ends relative to the middle (Gauch, 1982). DCA provided site ordinations as weighted averages of the variable levels, and concurrently ordered the variables on the basis of the site ordination scores (Hill 1973, 1974, and 1979).

To examine the affinities among the considered variables in relationship to their levels in the sampled ponds, both variables and sites were ordered along DCA ordination axes. The vectors of both variable and site ordination scores were rescaled from 0 to 100 using an

appropriate scaling program. The relationships between the input and water quality variables as affecting fish growth and productivity were confirmed by further analyses using correlation and multiple regression (performed after a stepwise factor selection procedure) conducted on measured variables.

RESULTS AND INTERPRETATION

Decomposition patterns of fresh grass and various composts loaded in fish ponds.

The green grass (GG), compost (CS), compost-cow manure (CM) and compost-vinasse (CV) mixtures underwent decomposition processes leading to a release of nutrients into the water. Concentrations of organic carbon (OC), total nitrogen and phosphorus in organic materials in ponds were measured over the 150-day experiment (Figure 2). During the first month, the organic carbon content decreased sharply in GG for 6% and in CM for 4%, but it increased later for about 8% and approached an equilibrium point at the end of the experiment. Organic carbon in CS and CV inputs sampled from ponds increased about 7% throughout the experiment, but approached equilibrium toward the end of the experiment (Figure 2a). The carbon:nitrogen ratios in inputs sampled from ponds generally increased until 120 days, and then shifted perhaps due to additional nitrogen from the decomposing autotrophs and heterotrophs. These ratios increased from 17:1 to 22:1 and then dropped to 20:1 in GG. The changes in CS, CM and CV were comparable. Their OC:N ratios increased from about 7:1 to 14:1, and shifted to 10:1 during the last month of the experiment.

At the start of the experiment, organic carbon in CS, CM and CV were low because of losses resulting from aerobic composting of the initial materials prior to their introduction into ponds (Schroeder, 1987, Biddlestone and Gray, 1987). Biddlestone and Gray (1987) noted that the breakdown of organic materials during composting results in the loss of approximately 30-40% of the organic matter as carbon dioxide and water.

The general increase of OC over time after the first month resulted from the accumulation of organic matter applied bi-weekly into ponds as well as organic compounds from organisms flourishing on vegetal wastes. The rate of accumulation was lower with GG, suggesting that fresh plant materials comprise less refractory compounds and decomposition proceeded more rapidly.

Total nitrogen and phosphorus displayed a general trend to decrease, at least until the fourth month for total nitrogen. Total nitrogen concentrations were lower in GG treatment and varied from 2.3 to 1.8%, while they fluctuated from 4.1 to 2.4% in the other treatments (Figure 2b). Total phosphorus was also lower in GG and fluctuated from 75 to 200 ppm, but phosphorus declined from about 600 ppm to 200 ppm over the first 120 days in the other three treatments. Phosphorus reached equilibrium during the last 30 days of the experiment (Figure 2c).



Figure 2. Fluctuations of organic carbon (a), total Kjeldahl-nitrogen (b), and total phosphorus (c) concentrations in the organic matter in ponds. Organic inputs total phosphorus (c) concentrations in the organic matter in power GG= green grass; CS= compost; CM= compost + cow manure; CV= compost + vinasse. ω



Figure 2, continued.

Effects of green grass and composted organic wastes on water quality.

Dissolved oxygen, temperature, secchi disc visibility, pH, alkalinity, total hardness, total nitrogen, nitrate, ammonia, total phosphorus and chlorophyll <u>a</u> levels in the water were measured during the experiment (Table 3).

a. Dissolved oxygen.

The lowest concentrations and the largest fluctuations in dissolved oxygen (DO) occurred in the surface of ponds receiving the GG treatment (Table 3 and Figure 3a). Dissolved oxygen in surface water reached a minimum mean value of 2.2 mg/l during the first two months. During that same period, DO levels at the pond bottoms dropped from about 2.20 mg/l to 1.50-1.80 mg/l (Figure 3b) due to the heavy initial loading of organic matter and high BOD and COD in decomposing materials.

As expected, strong inverse relationships were found between dissolved oxygen concentrations in the water and the organic carbon content of the input materials. The correlation coefficients were -0.88 and -0.92 for DO at the surface and at the pond bottom, respectively, showing the magnitude of oxygen demand especially in the hypolimnion of ponds fertilized with materials high in organic carbon. Boyd (1979) and Wetzel (1983) noted that the oxidation of organic carbon at the pond bottom results in high respiratory quotients (RQ=CO₂ released/O₂ consumed).

Bottom DO levels were significantly different between green grass-treated ponds and the other treatments ($P \le 0.05$). Differences in DO concentrations at the surface were not significant between treatments after the first 3 months.

DO levels in GG treatment increased after the second month, but decreased during the last 30 days of the experiment (Figure 3a and b). Dissolved oxygen levels stayed high (5 to 6.5 mg/l) in ponds receiving CS, CM and CV treatments until the fourth month. DO concentrations dropped thereafter for all treatments, presumably because of the increasing respiration of the increasing phytoplankton community, the organisms associated with the accumulated organic matter, and fish.

Darameters					
measured ^a	GG	CS		СМ	CV
Temperature(*C)	20.65 <u>+</u> 0.46	20.35 <u>+</u>	0.47	20.33 ± 0.54	20.51 ± 0.45
Secchi disc visibility(cm)	35.86 <u>+</u> 13.95	32.57 ±	6.17	32.65 <u>+</u> 10.03	35.04 ± 8.12
DO at 25cm below surface (mg/l)	2.83 ± 1.16	5.22 ±	1.02	5.04 ± 1.02	5.32 ± 1.12
DO at mi-depth (approx. 65cm)	2.07 ± 0.81	5.86 ±	0.53	5.66 ± 0.62	5.61 \pm 0.44
DO at 25cm above pond bottom	2.05 ± 0.80 [*]	5.73 <u>+</u>	0.49	5.57 ± 0.64	5.55 ± 0.49
рH	6.48 ± 0.18	6.43 ±	0.23	6.53 ± 0.19	6.61 <u>+</u> 0.36
Total alkalinity (mgCaCO,/l)	46.43 ±11.01 [*]	26.98 <u>+</u>	5.66	30.78 ± 6.43	31.59 ± 6.04
Total hardness (mgCaCO./1)	72.06 <u>+</u> 14.69 [*]	49.57 ±	8.12	53.73 <u>+</u> 8.18	56.94 ± 8.71
Total Kjeldahl-N (mg/l)	1.66 <u>+</u> 1.04	1.09 ±	0.63	1.51 ± 0.74	1.26 ± 0.72
Nitrate-N(mg/1)	0.12 ± 0.01	0.39 ±	0.09	0.16 <u>+</u> 0.04	0.61 ± 1.38
Total ammonia-N (mg/l)	0.13 ± 0.09	0.12 ±	0.09	0.14 <u>+</u> 0.08	0.10 ± 0.08
Total phosphorus (mg/l)	0.32 ± 0.13	0.26 <u>+</u>	0.07	0.25 <u>+</u> 0.05	0.29 ± 0.14
Chlorophyll <u>a</u> (mg/m ³)	17.11 <u>+</u> 13.09	15.11 ±1	0.01	15.22 <u>+</u> 12.30	13.65 ± 5.59

Table 3. Water chemistry for each treatment in ponds stocked with <u>Oreochromis niloticus</u> (L).

^a values are means and standard deviations based on 30 observations for each treatment, except for total ammonia-nitrogen: six observations both at start and end of the study; and for morning dissolved oxygen, pH and temperature: 60 observations. Values for pH were computed as geometric means $=\log_{10}(\text{mean}[\text{H}^+])$, using H⁺=10^{pH} for each value considered in the computation.

Level significantly different from values shown in other columns. Variability in the water quality parameters was detected using 95% Scheffé intervals for mean or 95% LSD intervals when Scheffé failed despite the significance of F-value ($P \le 0.05$).

GG= green grass; CS= compost; CM= compost mixed with cow manure; CV= compost mixed with vinasse.

Figure 3. Dissolved oxygen concentrations through time for water samples taken at 25 cm below the surface (a) and at 90-100 cm below the surface (b). Organic inputs were: GG= green grass;CS= compost; CM= compost + cow manure; CV= compost + vinasse.



Figure 3

b. Diel temperature, dissolved oxygen, and pH fluctuations.

Diel measurements over the entire 150-day period were pooled to indicate the differences in DO concentrations associated with each treatment. Diel top dissolved oxygen concentrations in all cases increased rapidly after sunrise and decreased with the approach of sunset. Lower DO levels occurred consistently for GG treatments at the surface and the pond bottoms (Figure 4a and b).

Top and bottom DO levels at dawn were similar and ranged between 1.5 and 3 mg/l, because the ponds typically stratified during the day and mixed over night when upper layers of water cooled by conduction and wind action. Mixing lowered the surface DO and increased the bottom DO. Surface DO in the afternoon fluctuated between 5 and 9.0 mg/l, while bottom oxygen concentrations at that time were between 0.5 and 2.0 mg/l (Table 4). The diurnal changes in DO concentrations in ponds receiving GG treatment was about 4.0 mg/l as compared to about 3.0 mg/l or less for the other treatments. This indicated a higher community metabolism rate for the GG treatment. Diel DO concentrations above pond bottoms were lower for the GG treatment and did not show any greater diel changes than other Surface water temperatures recorded on diel treatments. measurements from June through September 1987 (Figure 4c)

showed no differences between treatments. Fluctuations over time occurred, with morning minimum temperatures and maximum in the afternoon (around 14:00). Levels of pH (Figure 4d) followed the same pattern as for DO and fluctuated between 6.3-7.50 at dawn and 6.5-8.0 in the afternoon for all treatments. The CS treatment had higher pH levels. From August through October, however, DO levels and variations in all ponds were similar, perhaps because of the increased algal production in all treatments.

		Mean DO at 25cm below surface (mg/l)			Mean DO at above pond		25 cm bottom			Mean		- <u> </u>	
Date	Time	GG	CS	<u> </u>		<u></u>		07					
								CM	Cv	GG	CS	CM	CV
June	0600	2.60	6.50	6.77	6 07	2 E7 [*]	6 40						
July	0600	1.77	5 33	5 40	5 27	2.3/	0.40	0.03	6.20	6.43	6.38	6.55	6.58
Aug.	0600	3.13	5.50	4 93	5.37	1.//	5.2/	5.37	5.27	6.45	6.31	6.55	6.50
Sept	0600	2.10	4 37	4 20	3.70	2.90	4.07	4.60	4.50	6.61	6.64	6.68	6.96
		2.20		4.20	4.03	2.10	4.23	4.10	6.20	6.57	6.54	6.60	6.76
June	1400	6.80	8.60	8.87	7.83	1.98	5.93	5 93	7 20	6 70 [*]	7 5 6		
July	1400	4.63	7.47	7.53	8.20	1.70	3.97	3 77	4 90	6 72	1.30	7.63	7.18
Aug.	1400	8.13	7.93	8.00	9.13	0.87	3.00	2 47	3 67	7 50	0.94	7.08	7.00
Sept	1400	6.03	6.47	6.50	7.23	0.53	2.00	2.13	2 87	6 99	7 13	7.40	7.97
									2.07	0.30	/.13	/.18	1.38
June	1800	7.00	8.67	9.07	8.00	1.77	5.67	6.37	6 33	6 99 [*]	7 60	1	
July	1800	4.90	6.33	7.63	7.77	1.50	3.40	3.23	4.37	6 78	7 11	7.71	7.39
Aug.	1800	8.80	8.33	8.37	9.73	0.67	2.43	1.97	3 5 3	7 69	7 27	7.10	/.11
Sept	1800	6.07	6.67	6.80	6.87	0.47	1.37	1.97	2.60	7 01	7.37	7.47	8.06
									2.00	/.01	1.00	/.12	7.28
June	2200	5.17	7.67	8.10	7.20	0.93	5.00	5.30	5 63	6 68	7 00		
July	2200	3.57	6.67	6.67	6.83	0.70	2.17	2 73	4 20	6 63	1.00	1.20	7.05
Aug.	2200	6.33	7.10	7.13	8.07	0.60	1.10	1 27	1 77	7 00	0.00	0.85	6.80
Sept	2200	4.67	5.20	5.30	5.87	0.40	1.53	1 47	2 03	6 90	7.05	7.12	7.95
									2.03	0.00	0.01	0.91	7.06
June	0600	2.33	6.17	6.47	5.77	2.30	6 07	6 27	5 67	C 15			
July	0600	1.60	5.13	5.03	4.97	1.53	4 90	4 70	1.67	0.43	5.45	6.62	6.63
Aug.	0600	2.73	5.53	4.73	5.87	2.63	2 93	3 60	3 00	0.48	0.36	6.58	6.56
Sept	0600	2.00	3.63	3.40	3.93	2.00	2.73	3.70	3.00	0.01	0.04	6.70	7.46
						2	5.5/	3.13	3.90	0.4/	6.37	6.51	6.58

Table 4. Diel pH levels and DO fluctuations in pond water on June 23-24, July 21-22, August 18-19 and September 15-16, 1987.

Significant differences were between GG and other treatments, $P \le 0.05$. There were no significant differences between treatments for DO and pH levels in all other cases.

DO= dissolved oxygen; GG= green grass; CS= compost; CM= compost mixed with cow manure; CV= compost mixed with vinasse.

Figure 4. Diel fluctuations of dissolved oxygen (a:surface; b: pond bottoms), water temperature (c), and pH (d); June through September 1987. Organic inputs were: GG= green grass; CS= compost; CM= compost + cow manure; CV= compost + vinasse.



Figure 4

c. Differential effects of treatments on water quality.

Solar radiation and water quality variables were measured for each treatment over the experimental period (Figure 5). The pH ranged between 6.0 and 7.1 and increased through time for all treatments (Figure 5a). The minimum temperature recorded at surface layer was 16°C and the maximum was about 29°C. Water temperature averaged 21-22°C and gradually decreased from May to October (Figure 5b). The fluctuations of about 6°C from later August to mi-September were associated with climatic changes: solar radiation averaged 27 $E/m^2/day$ and fluctuations were the largest between 17.5-38.0 $E/m^2/day$ in August-September (Figure 5c), and some rain was recorded since then (0-40 mm/day).

Based on the analysis of variance, data collected at each monthly sampling indicated no significant differences between treatment means for pH, temperature, secchi disc visibility, total kjeldahl-nitrogen, nitrate-nitrogen, total ammonia-nitrogen, total phosphorus, and chlorophyll <u>a</u> concentrations in water (P>0.05). In addition to differences already reported for DO levels between treatments, significant differences between GG treatment and other treatments were also found for mean total alkalinity and total hardness, $P \leq 0.05$ (Table 3).

Total phosphorus concentrations in the water increased rapidly in GG-treated ponds, and reached the highest level of about 0.40 mg/l at the fourth month and then decreased in all treatments (Figure 5d) when it was utilized by the increasing algal population. Chlorophyll <u>a</u> levels were relatively low, but a substantial increase in phytoplankton production was observed over time (Figure 5e), from chlorophyll <u>a</u> concentrations of about 6 mg/m³ at start to an average of 16-32 mg/m³. Ponds receiving the green grass treatment developed more phytoplankton than ponds receiving the other 3 input types. A maximum of 42 mg/m³ for chlorophyll <u>a</u> concentrations was estimated for pond C₄. The overall low algal production was attributed to low fertilization levels and to input quality.

Chlorophyll <u>a</u> correlated highly with total nitrogen (r= 0.66) and with total phosphorus (r= 0.68) concentrations in the water. Chlorophyll <u>a</u> also showed a positive correlation with organic carbon input (r= 0.55), but an inverse relationship with input nitrogen (r= -0.46) and phosphorus (r= -0.40) from organic materials. Secchi disc visibility varied between 14-70 cm. The r value of 0.06 between chlorophyll <u>a</u> and secchi disc visibility showed that water turbidity was not associated with algal production.

Figure 5. Variations of weekly pH (a), water minimummaximum temperatures (b), solar radiation (c) and average total phosphorus concentrations (d) in pond water over the 150-day trial period. Min. and Max.= minimum and maximum temperatures, respectively; top and bottom refer to measurements at 25 cm and at 90-100 cm below surface, respectively. Fluctuations of chlorophyll <u>a</u> (e), total nitrogen

(f), alkalinity (g) and hardness (h) concentrations in pond water during the 150-day trial period. Organic inputs were: GG= green grass; CS= compost; CM= compost + cow manure; CV= compost + vinasse.



a Max-top + Max-bottom + Min-top + Min-bottom

Figure 5







Figure 5, continued.



Figure 5, continued.

0 H water nitrogen concentrations were most probably two transition in trophic levels. second Mineralized nutrients became available beginning with the environment immobilize denitrification, treatment, but levels decreased sharply during the first start that recycling by algae. months prevailed during the first 60 days were favorable Total in all treatments, except in ponds receiving month nitrogen the oxidized (Figure for their (Figure a heterotrophic 5£). levels 5f), however, perhaps respiration and growth (Boyd, 1979) forms of The low dissolved oxygen levels in water Subsequent nitrogen process were high in which organisms fluctuations from as at p the water result the the result SD ţ Ín 0 H ρ

high phytoplankton growth. bicarbonate ions dissociate and liberate CO_2 necessary ponds fertilized with GG (Figure 5g and h). carbonate hardness alkalinity ranged Alkalinity and hardness were alkalinity is between in all treatments, indicating that ω 5 mg/1 and 99 mg/1 and exceeded total was present (Boyd, important because carbonate significantly higher 1979). Total hardness some non-A reasonably and for 1.

phosphorus, and differences (Figure further Individual variations <u>6)</u>. analysis and for mean chlorophy11 total hardness, of variance identified in **(**2) pond concentrations responses total nitrogen, significant were 1 n the observed water total

Figure 6. 95% confidence intervals for mean total hardness (a), Kjeldahlnitrogen (b), total phosphorus (c), and chlorophyll <u>a</u> (d) concentrations in ponds. Treatments were assigned as follows: ponds $C_4-C_9-D_5$: green grass; $D_2-D_3-D_7$: compost; $C_1-D_1-D_4$: compost + cow manure; $C_3-C_5-D_{11}$: compost + vinasse.



Figure 6

Effects of green grass and composted organic wastes on the growth and net yield of <u>Oreochromis niloticus</u> (<u>L.</u>) in ponds.

<u>Oreochromis niloticus</u> fingerlings were stocked at an average weight of 37.2 g. After 150 days of growth, fish attained an average weight of 83.4 g. Significant differences were found between treatments for mean final weight, daily growth and specific growth rates, and net fish yield, $P \le 0.05$ (Table 5). For all variables measured on <u>O. niloticus</u>, better performance was achieved in ponds receiving fresh grass (Figure 7a and b). Compost-cow manure and compost-vinasse mixtures were not significantly different in terms of their influence on fish growth and production. An even lower performance was recorded for <u>O. niloticus</u> in ponds receiving compost as the sole input (Table 5). The highest daily growth rate averaged 0.50 g (GG) and the lowest averaged 0.21 g (CS).

Mean survival of <u>O. niloticus</u> was high and ranged between 80-91%. Lowest and highest average survivals occurred in CS and GG treatments, respectively.

Some reproduction was recorded at harvest, fingerlings averaging 5 g in wet weight were found in ponds C_5 -CV (44), D_1 -CM (133), D_3 -CS (118) and D_5 -GG (197). Few fingerlings were found in other ponds but no reproduction occurred in ponds C_4 -GG and C_1 -CM.

	Treatment designation							
Parameters measured ^a	GG	CS	СМ	CV				
Mean initial weight ^{b*} (g)	33.84 ± 0.89	37.39 ± 3.47	37.99 ± 2.31	37.66 ± 1.48				
Mean final weight (g)	110.98 <u>+</u> 24.55 ^{c*}	69.00 <u>+</u> 9.45 ^d	80.67 <u>+</u> 12.81	° 79.06 <u>+</u> 16.95 ^f				
Daily weight gain (g/day)	$0.50 \pm 0.17^*$	0.24 ± 0.11	0.29 <u>+</u> 0.07	0.28 ± 0.10				
Specific growth rate (%g/day)	$0.75 \pm 0.16^{*}$	0.41 ± 0.12	0.50 <u>+</u> 0.07	0.49 ± 0.12				
Mean initial total length ^b (cm)	12.27 <u>+</u> 0.15	12.38 ± 0.32	11.88 ± 0.27	11.88 <u>+</u> 0.47				
Mean final total length (cm)	$18.30 \pm 1.04^{\circ}$	16.73 <u>+</u> 0.64 ^d	16.63 ± 0.69	² 16.53 <u>+</u> 0.66 ^f				
Net fish yield ^g (kg/ha/day)	4.59 <u>+</u> 1.45 ^{**} (39.8%)	1.72 <u>+</u> 0.49 (15.0%)	2.66 ± 0.93 (23.1%)	2.55 ± 0.80 (22.1%)				
Survival (%)	90.4	81.2	89.7	89.5				
Total weight of reproduction ^h (g	1500 (212) J)	900 (158)	350 (139)	2310 (486)				

Table 5. Growth, survival and net yield $(\pm SD)$ of <u>Oreochromis</u> <u>niloticus</u> (<u>L</u>) in ponds during a 150-day rearing period.

^a Treatments were in triplicate. Each experimental pond was 600m² in surface area, and stocking density was 1 fish/m².

^bValues based on 180 observations for each treatment.

- c.d.e.f Values based on 1628, 1461, 1614 and 1610 observations for each treatment: GG, CS, CM, and CV, respectively.
 - ⁹Numbers in parenthesis represent the percentage of total net fish yield from all ponds.

"Values in parenthesis are total number of fingerlings.

- Significantly different from other treatments, $P \leq 0.05$.
- ** Significantly different from treatment CS ($P \le 0.05$). No significant difference was found between treatment CM and CV (P > 0.05) in terms of net fish yield.

SD= standard deviations; GG= green grass; CS= compost; CM= compost mixed with cow manure; CV= compost mixed with vinasse. Figure 7. Average weight (a) and total length (b) of <u>Oreochromis niloticus</u> in relation to four different organic treatments. Organic inputs were: GG= green grass; CS= compost; CM= compost+cow manure; CV= compost+vinasse.



Figure 7

Significant differences were detected between treatments GG and CS for net fish yield ($P \le 0.05$), but not between treatments CM and CV (Table 5). Also, least significant differences were found between ponds C_4 , C_9 and D_3 . Pond D_3 was fertilized with compost alone and showed the lowest net fish production (1.16 kg/ha/day), while ponds C_4 and C_9 - which received green grass - produced at the highest rate of 6.15 and 4.32 kg/ha/day, respectively. Comparable magnitude in differences were also found for mean fish sample weight and daily growth rates for these ponds.
Multivariate approach to the analysis of relationships between <u>Oreochromis niloticus</u> (<u>L.</u>) production performance and water quality variables as influenced by organic loadings in ponds.

Analysis of the complex interrelationships between fish yields, physico-chemical and biological factors in the pond ecosystem required the use of multivariate analytical procedures. Detrended Correspondence Analysis (DCA) was selected to analyze data and aid in defining differences and similarities of treatments relative to their effects on water quality, fish growth and net yield. Ordination axis one from DCA analysis of the 12 ponds subjected to organic fertilization exhibits distinct contrasts between ponds receiving GG treatment and those where compost alone was applied (Figure 8a). GG and CS treatments/ponds are clustered at opposite ends of axis one, while ponds receiving CM and CV treatments do not show any definite relationship. DCA ordination axis 2 reveals contrasting responses especially between ponds C_5 and D_{11} which received CV treatment.

DCA ordination of the 19 variables considered in this study showed distinct clusters (Figure 8b) indicating close correspondence relative to the configuration of the site scores. For aid in interpretation, site ordination scores were correlated with each individual variable (Table 6).

	D	CA
Parameter	Axis 1	Axis 2
Input dry matter (%)	0.21	-0.31
Organic carbon input (kg/ha/week)	0.84	-0.28
Total nitrogen input (kg/ha/week)	-0.93	0.18
Total phosphorus input (kg/ha/week)	-0.91	0.36
Total alkalinity(mg CaCO ₃ /1)	0.79	-0.02
Total hardness (mg CaCO ₃ /l)	0.78	-0.04
DO(mg/l) at 25cm below surface	-0.83	0.10
DO(mg/l) at mi-depth	-0.85	0.19
DO(mg/l) at 25cm above bottom	-0.86	0.20
Temperature (°C)	0.56	-0.21
Total nitrogen (mg/l)	0.29	0.21
Total NH ₄ -N (mg/l)	0.02	-0.68
NO ₃ -N (mg/l)	-0.26	-0.03
Total phosphorus(mg/l)	0.36	0.70
Secchi disc (cm)	0.40	-0.41
Chlorophyll <u>a</u> (mg/m ³)	0.26	0.67
Daily growth rate (g/day)	0.76	0.25
Average fish weight (g)	0.63	0.39
Net fish yield(kg/ha/day)	0.84	0.05

Table 6. Pearson correlation coefficients for relationships between DCA ordination scores for pond-treatments (axes 1 and 2), physicochemical variables of inputs, water quality, and fish performance parameters.

Figure 8. (a): DCA ordination of samples from 12 ponds fertilized with four triplicate organic treatments; (b): DCA ordination of 19 variables measured on organic inputs, pond water quality, fish growth and net yield. Organic inputs were: GG= green grass; CS= compost; CM= compost + cow manure; CV= compost + vinasse. Variables measured on organic input materials were: DM_pc= dry matter content (%); OC_inpt= organic carbon input; N_inpt= total nitrogen input; and P_inpt= total phosphorus input. Water quality measurements were: dissolved oxygen at 25 cm below surface (DOtop), at mid-water depth (DOmid), and at 90-100 cm below surface (DObot); NO₃-N= nitrate-nitrogen; NH₄-N= ammonia-nitrogen; Tot-N= total nitrogen; Tot-P= total phosphorus; Chlor-a= chlorophyll <u>a</u>; Alka= alkalinity; Hard= hardness; Temp= temperature; and Svis= Secchi disc visibility. Fish performance parameters were: MnFWt= mean fish weight; DGR= daily growth rate; and FYkhd= net fish yield expressed in kg/ha/day.



Figure 8

High positive correlations were found between the first axis and organic carbon input (r= 0.84), total alkalinity (r= 0.79) and total water hardness (r= 0.78), net fish production (r= 0.84), fish daily growth rate (r= 0.76), and average fish weight (r= 0.63). In contrast, strong negative correlations existed between DCA ordination axis one and total nitrogen input (r= -0.93), total phosphorus input (r= -0.91), and dissolved oxygen (DO) concentrations in the water (Table 6).

DCA ordination axis 2 correlated positively with total phosphorus (r= 0.70) and chlorophyll \underline{a} (r= 0.67) concentrations in the water, and negatively with total NH_4 -N (r= -0.68), and to a lesser degree, with Secchi disc visibility (r = -0.41). The configurations along DCA axis 2 (Figure 8a and b) illustrated differences between ponds relative to specific water quality variables. Pond D_{11} , which was characterized by a higher concentration in total phosphorus (0.43 mg/l) and chlorophyll <u>a</u> (18.70 mg/m³) and less total ammonia-nitrogen (0.06 mg/l), contrasted with pond C_5 where these variables varied inversely. Higher total nitrogen concentrations were recorded in ponds C_1 (2.80 mg/l) and C_4 (2.50 mg/l), as well as higher algal production measured as chlorophyll <u>a</u> (23.6 and 26.5 mg/m³, respectively). Total phosphorus concentrations were highest in C_4 (0.44 mg/l) and D_{11} (0.42 mg/l).

	Performance Parameters [*]				
Factor	Alka	Hard	Chlor-a	DGR	Net yield
OC input (kg/ha/week)	0.80	0.75	0.55	0.67	0.73
Total-N input (kg/ha/week)	-0.75	-0.71	-0.46	-0.75	-0.75
Total-P input (kg/ha/week)	-0.83	-0.80	-0.40	-0.63	-0.74
Alkalinity (mg/l)	1.00	0.96	0.40	0.83	0.86
Total hardness (mg/l)	0.96	1.00	0.48	0.82	0.88
Temperature (°C)	0.53	0.66	0.22	0.47	0.56
Total-N(mg/l)	0.44	0.53	0.66	0.40	0.45
Total NH ₄ -N (mg/l)	-0.15	-0.11	-0.38	-0.03	0.07
$NO_3 - N (mg/1)$	-0.06	-0.06	-0.01	-0.30	-0.38
Total-P(mg/l)	0.55	0.51	0.68	0.76	0.62
Secchi disc visibility(cm)	0.38	0.54	0.06	0.15	0.34
Chlor-a (mg/m^3)	0.40	0.46	1.00	0.69	0.54

Table 7.	Pearson's correlation coefficients between fish
	performance parameters and particular variables
	of inputs and water quality.

*: Alka= alkalinity;Hard= hardness;Chlor-a= chlorophyll <u>a;</u> DGR= daily specific growth rate.

Table 8. Multiple regression analysis of relationships between chlorophyll <u>a</u>, total phosphorus and total nitrogen concentrations in pond water. (R^2 adjusted for degree of freedom = 0.67). Model: E(Chlor-a) = $b_0 + b_1$ (Tot-P) + b_2 (Tot-N).

Predictor variable	Regression coefficient <u>+</u> SE	Significant level, P-value	r
Intercept	-3.869 <u>+</u> 4.065		
Total-P (mg/l)	41.017 <u>+</u> 13.027	0.0118	0.68
Total-N (mg/l)	5.199 <u>+</u> 1.728	0.0147	0.66

Figure 9. Relationships between daily specific growth rate (DSGR) of \underline{O} . <u>niloticus</u> and pond water temperature (a); net yield of \underline{O} . <u>niloticus</u> and organic carbon input from organic materials (b); net fish yield and chlorophyll <u>a</u> concentrations in pond water (c); and net fish yield and total hardness of the water (d).



Results from DCA analysis were consistent with those from correlation analysis and the stepwise variables selection procedure in multiple regression, performed on the data matrix containing the measured variable levels in order to identify the underlying relationships. The most conspicuous relationships between fish growth and yield relative to pond water quality variables as influenced by the input characteristics were identified (Table 7 and Figure 9).

Fish daily growth rates correlated highly with organic carbon input (r= 0.67), total alkalinity (r= 0.83), total hardness (r= 0.82), total phosphorus (r= 0.76) and chlorophyll <u>a</u> (r= 0.69). The daily growth rates were not closely correlated to water temperature (r= 0.47) and total nitrogen concentrations in the water (r= 0.40).

Temperature was the only variable selected through the stepwise procedure for its effect on fish specific growth rate (Figure 9a). The regression function illustrates the relationship between the two variables: E(DSGR) = -18.92 + 0.96(T), r= 0.68 and P-value= 0.001; where DSGR represents the daily specific growth rate (%g/day) and T is Temperature (°C).

Net fish yields correlated strongly with organic carbon input (r= 0.73), but negatively with total nitrogen (r= -0.75) and total phosphorus (r= -0.74) inputs from organic materials. Multiple regression was used to analyze the relationship between net fish yield and organic carbon input (Figure 9b). The regression function from this analysis was: E(Y) = -5.97 + 0.27(OC), r = 0.73 and P-value= 0.007; where Y represents the net average yield of <u>O.</u> <u>niloticus</u> (kg/ha/day) and OC expresses the amount of organic carbon in the weekly input (kg/ha).

Significant correlations were also found between net fish yield and total hardness (r =0.88), alkalinity (r= 0.86), and total phosphorus concentrations in the water (r= 0.62) (Table 7). Weak correlations were found for net fish yield and temperature (r= 0.56), total nitrogen (r= 0.45), and chlorophyll <u>a</u> (r= 0.54) concentrations in the water. Because of the high correlations between chlorophyll <u>a</u>, total nitrogen and phosphorus concentrations in the water (Table 7), these two variables accounted for 67% of the total variation of chlorophyll <u>a</u> concentrations (Table 8). Chlorophyll <u>a</u> was selected as a variable to be included in the regression model defining the chlorophyll <u>a</u> (mg/m³) relationship to net fish yield (kg/ha/day): E(Y)= 0.94 + 0.13 (Chlorophyll <u>a</u>), r= 0.54 (Figure 9c).

The relationships between water hardness and net fish yield was expressed by the following regression function: E(Y) = -3.39 + 0.11(Hard), r= 0.88 and P-value= 0.0002 (Figure 9d).

DISCUSSION

In general, materials with high OC content and a larger OC:N ratio such as green grass provided less nitrogen and phosphorus. Boyd (1979) reported low nitrogen mineralization rates from decaying aquatic plants with low nitrogen content and large OC:N ratio, and concluded that such conditions lead to the immobilization of some nitrogen from the aquatic environment for microbial growth. Wohlfarth and Hulata (1987) noted that nitrogen immobilization is a temporary phenomenon associated with the transition in trophic levels. Inputs may pass through several pathways of mineralization for the release of nutrients into pond water. The analysis of changes in input composition over time suggested a slow process, especially for the dynamics of nitrogen and phosphorus in materials with high OC:N:P ratios.

Tilapias are very tolerant to low DO levels, and oxygen depletion did not cause noticeable fish mortalities. Balarin (1979) suggested a lower DO limit of 2-3 mg/l for tilapias. Ahmed and Magid (1969) considered 2.5-5 mg/l as critical DO levels for <u>T. nilotica</u>, but Mahdi (1973) and Georges (1975) emphasized the species ability to survive in waters where O_2 content was below critical levels such as tropical waters subjected to marked oxygen deficiencies. Diel increases in DO concentrations resulted from the algal photosynthetic activity indicated by the chlorophyll a concentrations in the pond water which were expanding through time (Figure 5e). Approximately 45% of the total organic input were applied prior to fish stocking, and about 55% were applied biweekly. As the organic materials were broken down, nutrients were more available for algal production. The increase in chlorophyll a levels beginning the second month implied a community succession from heterotrophs to autotrophs in the ponds system and is linked with a release of nutrients from decomposing materials. Diel patterns of oxygen and pH were normal for fish ponds (Boyd, 1979) (Table 4 and Figure 4). The daily photosynthetic activity attained its maximum in the afternoon and resulted in a peak in oxygen production and pH increase (Figure 4a and d). The decreases in diel DO concentrations were caused by diurnal microstratifications that were lost at dusk. The nocturnal respiratory processes resulted in lower DO and pH levels. Low DO levels at the pond bottom (Figure 4b) are consistent with the biochemical processes that take place in the aphotictropholytic zone, where mean maximum temperatures were 5°C lower than those at the surface layer and where oxidizing wastes and dead phytoplankton accumulate.

The total carbon dioxide in the water is not only generated from the diffusion at the air-water interface,

but also within the system from bacterial degradation of organic matter and from respiration of other organisms. At pH 6-7, free CO_2 and HCO_3^- dissolved in the water were in much higher relative proportions than $CO_3^{=}$ (Wetzel, 1983). The correlation between chlorophyll <u>a</u> and input organic carbon was 0.55, indicating a moderate role of decomposing organic material in providing CO_2 in the system for photosynthesis. This is supported by the low correlation between alkalinity and chlorophyll \underline{a} (r= 0.40), alkalinity and total nitrogen (r= 0.44) and alkalinity and total phosphorus (r= 0.55) concentrations in the water. But high correlations were found between chlorophyll a, total nitrogen and phosphorus concentrations in the water. Results from our experiment suggested that nitrogen and phosphorus from the input plant materials were not readily available for algal growth, but organic carbon provided energy to bacterial assemblages which are both fish foods and a processing system for nitrogen and phosphorus containing compounds. These nutrients were made available for algal growth by bacterial degradation. Results from this experiment were also to some extent consistent with studies by McNabb et al. (1988 and 1989). These authors demonstrated that adequate CO₂ supply from ponds with alkalinity as high as 50-60 mg/l resulted in increased algal growth and subsequent increase in phosphorus and

nitrogen uptake from pond water by the phytoplankton biomass. However, Boyd (1979) reported that phytoplankton production tended to increase in fertilized ponds containing only 0-20 mg/l as total alkalinity, while little or no relationships between the magnitude of total alkalinity and algal production was observed in ponds with alkalinity values of 20-120 mg/l. Correlations between alkalinity and algal production were likely related to differences in nitrogen and phosphorus concentrations, which increase along with alkalinity.

The very low correlation between secchi disc visibility and chlorophyll <u>a</u> suggested that sources of turbidity other than biogenic were involved, such as particulate inorganic matter. No important blooms of phytoplankton were observed in ponds during this experiment. Total ammonia-nitrogen levels were low $(\leq 0.20 \text{ mg/l})$, and no correlation was found between total NH_4 -N levels in the water and daily fish growth rate (r= -0.03) and net yield (r= 0.07). According to Boyd (1979), the un-ionized NH_A-N at pH and temperatures values reported in this study may be less than 50% of total ammonia. This indicated that values measured for the experimental ponds were within the normal range of tolerance for tilapias, and did not affect the fish performance. Ammonia toxicity is a major concern in

densely stocked fish ponds, alkaline waters, and at high organic loading rates (Boyd, 1979; and Zur, 1981). Yamada (1986) suggested that even though total dissolved ammonia concentrations of 4 ppm have been reported safe to tilapia, waters should have less than 2 ppm for healthy growth.

The response variability found within ponds in the same treatment group may be attributed to intrinsic differences between pond ecosystems (Boyd, 1979, Stickney et al., 1979 and Habineza, 1986), and to variation in the carry-over effects associated with previous pond fertilization. Previous use of chicken manure and low input of superphosphate (Eqna and Horton, 1988) are possible sources of these variations. Higher mean values recorded especially in ponds C_1 and C_4 for chlorophyll <u>a</u> and total nitrogen, and in ponds C_4 and D_{11} for total phosphorus meet that explanation. High fish performance in pond C₄ might be caused by a higher natural productivity (Hanson and Rwangano, 1986; Habineza, 1986). Differences in pond responses were probably related to differences in soil types and to earlier management of the fish culture site. Rurangwa et al. (1989) and Veverica et al. (1989) have mentioned that some ponds at Rwasave Fish Culture Station have consistently performed better than others receiving the same treatment. Stickney et al. (1979) and others recognized the significant impact of pond history

on experimental results. Although approaches to pond standardization pose specific problems in aquaculture, the following have been suggested (Stickney et al., 1979) and may reduce the variability among culture ponds: utilization of either (1) ponds which have received no prior history of manuring, (2) ponds which have been reworked at the extent that sediments exposed to organic fertilization are removed and replaced, or (3) ponds with like histories of organic fertilization. In general, ponds with low total alkalinity and total hardness, low total nitrogen, phosphorus and chlorophyll a concentrations in the water provided lower fish production. This occurred particularly in ponds loaded with composts, characterized by lower organic carbon and higher nitrogen-phosphorus contents. In contrast, ponds loaded with green grass achieved higher growth rates and fish yield.

On the average, net fish yield was 2 to 6-fold greater than the natural productivity of Rwandan fish ponds (Hanson and Rwangano, 1986; Moehl et al., 1988; Hishamunda, 1988a and b; Rurangwa et al., 1989,). However, the level of production obtained was low compared to yields achieved in intensely manured ponds with high quality inputs and high eutrophication level. Various investigators reported a multifold increase in fish growth and yields, varying from 7 to 40 kg/ha/day, as compared to 0.5 to 2.5 kg/ha/day of natural productivity (Miller, 1976; Hanson and Rwangano, 1986; Matena and Berka, 1987; Moehl et al., 1988 and Hishamunda, 1988a). Hishamunda (1988b) reported that input quality is one of the constraints to enhancing fish pond productivity in Rwanda. Recent trials based on integrated livestock-agriculture-fish farming resulted in productivities ranging from 12-16.5 kg/ha/day. Integrated livestock and aquaculture operations are more productive, but may not be economically possible for many Rwandan farmers. Results from the GG treatment are comparable to those reported from previous studies on O. niloticus carried out at Rwasave Station using chicken manure at the rate of 250 kg/ha/week (Hanson et al., 1988, Egna and Horton, 1988), and in other Rwandan ponds that received 1 m^3 of compost per are while stocked with <u>O.</u> <u>niloticus</u> at a rate of 2 fish/1.5 m^2 . Fish were fed rice bran at a rate of 3% relative to their biomass (Moehl et al., 1988).

Organic fertilization supplied carbon dioxide during decomposition, and CO₂ production increases proportionally with the increasing biomass of bacteria and other organisms that develop in organic-loaded pond systems. Apparently, microbial activity was highest in GG-treated ponds, as indicated by the highest rate of dissolved oxygen consumption in ponds. An abundant supply of dissolved inorganic carbon affects pond ecology by keeping the pH constant and low, and the level of photosynthesis high (Zur, 1981). Along with increasing alkalinity, abundant inorganic C increases phosphorus and nitrogen uptake from the pond water, algal productivity, and fish yield (Egna and Horton, 1988; McNabb et al., 1988 and 1989). Strong relationships between net fish yield and chlorophyll <u>a</u> were reported in studies where <u>O. niloticus</u> feeding regime was discussed (Moriarty, 1973; Moriarty and Moriarty, 1973a; Boyd, 1979; Bowen, 1981 and 1982; Tytler and Calow, 1985; Harwanimbaga, 1987; Harwanimbaga et al., 1988; Coleman and Edwards, 1987; Lowe-McConnell, 1987; Egna and Horton, 1988).

From this study, however, the weak correlation between net fish yield and chlorophyll <u>a</u> concentrations in the water suggested that the fish production in pond systems receiving organic inputs depends partially on algal production, and primarily on other feeding pathways. The primary feeding pathway was probably via the direct consumption of green grass, detritus, bacteria breaking down the plant materials, and other heterotrophic organisms.

Many authors reported that primary productivity is several times greater in fertilized ponds than in unfertilized ponds. Bacterial degradation of organic matter releases CO₂ for phytoplankton growth (Colman and

Edwards, 1987). But it was demonstrated that primary production is not sufficient to account for the increase in fish yields attained in pond systems fertilized with organic materials (Hepher, 1962; Tang, 1970; Schroeder, 1978; Noriega-Curtis, 1979; Colman and Edwards, 1987). Not only the herbivorous O. niloticus may feed directly on green manures in the form of grass or crop leaves (Bardach et al., 1972; Chen, 1976; Balarin, 1979), but fish find energy, protein and other nutrients from the consumption of heterotrophic bacteria, fungi and protozoa flourishing on the organic substrate (Tang, 1970; Schroeder, 1978 and 1980; Noriega-Curtis, 1979; Yamada, 1986; Wohlfarth and Hulata, 1987). Other investigators stated the direct consumption of organic materials by crustaceans or insects eaten by O. niloticus, and also concluded that the fish consume and efficiently use detritus derived from the decomposition of the organic wastes (Moriarty and Moriarty, 1973a; Schroeder, 1978; Bowen, 1982; Colman and Edwards, 1987). According to Schroeder (1978, 1980), the heterotrophic activity is maximum at the pond bottom-water interface where aerobic digestion of organic matter by bacteria converts up to 50% of the available organic C as bacterial cells. The remainder is used for metabolic energy (Doetsch and Cook, 1973, quoted by Schroeder, 1978 and 1980). Microbial assemblages account for a significant

flow of carbon out of the detritus (Schroeder, 1987). The findings of this research work suggested that inputs with high organic carbon concentrations (GG) provided more energy to the pond system to account for higher fish performance.

DCA axis one explained the contrasts between ponds C_4 , C_9 and D_5 as compared to ponds D_2 , D_3 and D_7 . Ponds C_4 , C_9 and D_5 received higher organic carbon inputs, had lower DO concentrations, higher water alkalinity and hardness, and performed better in terms of fish growth and production. Ponds D_2 , D_3 and D_7 were loaded with composted grass characterized by lower OC:N:P ratios, and accounted for higher DO levels, lower total alkalinity and hardness, and produced lower fish growth and net yield.

Water temperature affects fish in many physiological and behavioral ways, including controlling respiration, food consumption and conversion efficiency (Balarin, 1979; Boyd, 1979; Tytler and Calow, 1985; Fast, 1986; Hepher, 1988). The specific growth rate is not only determined by the genetic characteristics of the fish, but also by environmental factors (Chang, 1989). For a given fish species, maximum growth rate exists for specific temperature and feeding rates (Fast, 1986). Water temperatures in May and June 1987 reached 25-28°C at the surface layer, and 19-20°C at the pond bottom, and shifted down to 22-23°C and 17-19°C, respectively, from late August through early October (Figure 5b). These changes in water temperature probably affected fish food consumption and growth. Water temperature accounted only for about 43% of the total variation of the fish daily growth rate, indicating that other factors highly correlated with that performance parameter were of more importance than temperature itself, particularly water quality variables and availability of fish food. Habineza (1986) reported correlations as high as 82%, 71% and 70.5% between the daily growth rate and chlorophyll <u>a</u>, total phosphorus and total nitrogen at Rwasave in a study on <u>O. niloticus</u> in ponds fertilized with chicken manure, and Ngarambe (1986) reported that the daily growth rate was associated with total hardness (r= 0.51).

Total hardness level was moderate but always greater than alkalinity. At a pond water pH of 6-7, this implied that nearly all of the base is present as bicarbonate and that the alkalinity portion is associated with Ca^{2+} and Mg^{2+} (Boyd, 1979 and Wetzel, 1983). Boyd reported that phytoplankton and fish production increase with water alkalinity in natural waters, and hard waters are generally more productive than soft waters. This observation does not necessarily indicate that waters with higher alkalinities have higher concentrations of available

carbon, and therefore, greater phytoplankton productivity. Little or no relationship between the magnitude of total alkalinity values and phytoplankton production has been observed in fertilized ponds, having total alkalinity values of 20-120 mg CaCO₃/l (Boyd, 1979). Results from this investigation showed low correlation between these two variables. However, greater fish production partially resulted from higher alkalinity levels and higher algal production, which increased with levels of phosphorus and nitrogen in the water. The relation of alkalinity and hardness to fish performance resulted from high organic carbon input. In less intensive fish culture, Yamada (1986) reported that phosphorus increases blue-green algae for nitrogen fixation, and stimulates phytoplankton productivity. Phosphorus fertilization appears more important than nitrogen fertilization provided carbohydrate is present. Nitrogen activates the growth of fish food organisms (Yamada, 1986). Fish production increases in response to eutrophication (Opuszynski, 1987; Colman and Edwards, 1987). Eutrophication implies an enrichment with nutrients and a consequent increase in biological productivity, particularly involving an increased standing crop of phytoplankton. Organic manures were extremely beneficial primarily in stimulating heterotrophic activity, but also in enhancing autotrophic production.

CONCLUSIONS AND SUGGESTIONS

The culture of <u>Oreochromis niloticus</u> can be successful in high altitude tropical environments with moderate levels of productivity using fresh and composted plants materials. The addition of green grass to improve fish yields proved to be a beneficial practice that can be used by Rwandan fish farmers. Lacking capital for investment in livestock or supply of foodstuffs and inorganic fertilizers, utilization of green grass in fish culture is an efficient alternative which permits the enhancement of fish yields within the resources available locally. As farmers acquire capital to invest in livestock and fish culture, more intensive methods of aquaculture may develop in a long term approach and become more productive and profitable.

Green grass which provided better fish performances was higher in organic carbon and low in total nitrogen and total phosphorus compared to other treatments. Organic carbon input and water total alkalinity (and hardness) appeared more important factors in determining the growth and net yield of <u>O. niloticus</u>. However, it is important to maintain a suitable C:N:P ratio of input material not only to provide sufficient organic carbon as an energy source for heterotrophs to grow and process organic molecules, and as source of carbon dioxide required for phytosynthetic activity, but also to satisfy the dual demand for N and P

necessary for algal and bacterial production. The strong relationship between chlorophyll <u>a</u>, total nitrogen and total phosphorus concentrations in the water, and the effect of both organic carbon input and algal production on <u>O. niloticus</u> production, suggested that either combination of input materials rich in organic carbon, total nitrogen and phosphorus (e.g. mixtures of green grass and fodder legumes or fresh leaves), or nutrient enrichment of high OC materials (e.g. supply of inorganic N and P) may enhance more efficiently the productivity of the pond system.

For studies in ponds loaded with organic materials, BOD and COD measurements, total dissolved inorganic carbon and primary productivity determination are important parameters to be monitored to understand processes occurring in experimental ponds. Our results suggest that specific studies be conducted to: (1) determine the optimum input level of green grass or other fresh plant materials, using various levels of locally available inputs; (2) study fish performances in organic-treated ponds at various ranges of water temperatures and alkalinities and ; (3) investigate the efficiency of green grass or fresh leaves enriched with appropriate levels of inorganic nutrients, or test the combination of grass with available fodder legumes; (4) study the organic material pathways in pond systems, for example by the analysis of fish stomach contents or by the use of carbon and nitrogen stable isotopes; (5) evaluate the effects of organic treatments on pond soils and analyze the dynamics of nutrients.

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