Suitability of using duckweed as feed and treated sewage as water source in tilapia aquaculture

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ABSTRACT

Use of treated effluent and duckweed biomass from a pilot-scale UASB-duckweed ponds system treating domestic sewage was evaluated in rearing Nile tilapia (*Oreochromis niloticus*). Nutritional value of duckweed as sole feed was compared with wheat bran. Two sources of water were used for each feed trial, treated-sewage and freshwater. The experiment was conducted in parallel with a conventional settled sewage-fed fishpond. Results of growth performance demonstrated that, in case of freshwater ponds specific growth rate (SGR) of tilapia fed on fresh duckweed was significantly ($p < 0.01$) higher than the SGR in wheat bran fed pond. No significant difference ($p > 0.05$) was observed between the two feeding regimes in treated sewage-fed ponds. The SGR of tilapia reared in the treated sewage-wheat bran-fed pond (TWP) was significant higher ($p < 0.01$) than the SGR in the freshwater-wheat bran-fed pond (FWP). On the other hand, due to the early spawning in the treated sewage-duckweed-fed pond (TDP) SGR of tilapia in the latter was significantly lower ($p < 0.05$) than the SGR in the freshwater-duckweed-fed pond (FDP). The results of net fish yield were

11.8, 8.9, 9.6 and 6.4 ton/ha/y in TDP, TWP, FDP and FWP, respectively. Negative net yield (-0.16 ton/ha/y) was observed in the settled sewage-fed pond (SSP) due to high mortality.

Keywords: Fresh duckweed; Domestic sewage; *Oreochromis niloticus*; UASB-duckweed ponds

INTRODUCTION

Production of fish in developing regions is often limited by availability of nutrients in the form of fertilisers or protein-containing fish feeds. Recycling of wasted organic matter in fish aquaculture represents an attractive alternative. Reuse of wastes in fish production could safeguard the environment from pollution and simultaneously generate valuable marketable biomass. One of the major constraints to increase fish production in developing countries is the cost of feed and chemical fertilisers. Integration of fish and livestock production is one option to decrease fish farming cost and to increase productivity of the system (Java and Chakrabarti, 1997; Sadek and Moreau, 1998). Organic fertilisation through application of livestock manure is widely applied in fish farming (Prinsloo and Schoonbee, 1987a; Prinsloo and Schoonbee, 1987b; Zhang *et al*. 1987; Mishra *et al*., 1988; Green *et al*. 1989; Edwards *et al*., 1994). Incorporation of cheaper ingredients, like organic agro-industrial by-products and wild plants in fish feed, are options to reduce the price of fish feed and consequently fish production cost.

Availability of local ingredients for supplementary fish feed is generally limited in Africa including Egypt because of scarce agricultural production or because of strong competition with other livestock production. Egypt has to import two-thirds of its wheat and vegetable oil and currently the annual imported agricultural products amount to about 14.4 million ton. In 1994 the nutrition gap between domestically produced food and national consumption in Egypt, which must be filled by imported food, was estimated at 40% (Abdel Mageed, 1994). Locally available agricultural products by-products and wild vegetation including aquatic plants can be efficiently used as sole feed input or as supplementary feed in the fertilised pond (Rifai, 1980; Cruz and Laundencia, 1980; Prinsloo and Schoonbee, 1987c; Zaher *et al*., 1995).

The competing uses of surface water are largely restricted to irrigation systems and drinking water supply. Though the use of water in aquaculture is often considered as "non-consumptive" there are significant losses due to seepage and evaporation, depending on the soil properties and climatic conditions. In case of limitations of surface water, commercial feed and/or costly chemical fertilisers could be substituted with domestic sewage. The use of domestic sewage as water source and pond fertiliser is practised in a number of countries (Kutty, 1980; Edwards *and* Sinchumpasak, 1981; Wang, 1991) using experimental scale and full-scale ponds. Use of treated sewage in rearing local fish species was conducted in Egypt using laboratory scale models and pilot scale models (Easa *et al*., 1995; El-Gohary *et al*., 1995; Shereif *et al*., 1995; Khalil and Hussein, 1997).

In fact there are two problems related to the consumption of fish raised on human wastes; the social acceptability or consumer behaviour (Mancy *et al*., 2000) and the potential transfer of diseases. There appears to be definite cultural differences concerning the consumption of fish reared on human wastes. The Chinese and Indians appear to have few objections to eat such fish (Edwards, 1980). In the Arab world such suggestion is generally rejected. There will be a big difference in acceptability between fish directly fed on human wastes and fish fed on aquatic plant biomass grown in pre-treated sewage. The main objective of this study is the evaluation of duckweed grown on partially treated sewage as supplementary fish feed compared to wheat bran. The feasibility of using treated sewage from a UASB-Duckweed pond treatment system as replacement of fresh water in fish aquaculture was evaluated as well.

MATERIAL AND METHODS

Fish Species and Husbandry

Nile Tilapia (*Oreochromis niloticus*) weighing about 20 grams average weight and from the same parental stock was obtained from a hatchery two weeks before the start of the experiment. The juveniles were adapted to the experimental conditions in two plastic holding tanks (48 cm deep, area 1 m^2).The tanks were fed with de-chlorinated city tap water. Removal of chlorine was performed by addition of sodium thiosulfate solution (0.025M, 2 ml/litre) and overnight continuous aeration. Tilapia was stocked at 50 fish per tank under continuous aeration and regular removal of faeces. The water flow was 50 litres per day. The fish was fed on a mixture of wheat bran and fresh duckweed to satiation. The experiment was conducted outdoors in five identical plastic holding tanks, each with one square meter surface area and 48 cm depth.

Water Sources and Fish Feed

Three water sources with different qualities were used: (1) de-chlorinated city tap water, (2) treated domestic sewage from a UASB-duckweed pond system and (3) 2 hours settled raw sewage. Daily removal of chlorine from the city tap water was conducted. Two sources of supplementary fish feed were used, fresh duckweed grown on pre-treated sewage and local wheat bran.

Table 1: Operating conditions in fishponds

Item	TDP	TWP	FDP	FWP	SSP
Fish weight (g $fish^{-1}$)	21.41±2.41	20.15±3.57	19.8±3.98	21.7±2.54	20.35±2.69
Feed source	Fresh duckweed	Wheat bran	Fresh duckweed	Wheat bran	-
Feeding rate (g feed/100 g fish)	25	1.34-1.52	25	1.34-1.52	-
Water source	Treated sewage	Treated sewage	Freshwater	Freshwater	Settled sewage
Flow rate (l d^{-1})	42.75	42.75	37.5	37.5	15

<u>Experimental Design and Operating Conditions</u>

The experiment lasted 150 days and was started by filling all tanks with the selected water sources. Pond operating conditions are shown in Table 1. Pond 1 (treated sewage-duckweed-fed pond TDP) and 2 (treated sewage-wheat bran-fed pond TWP) received treated domestic sewage at an average flow rate of 42.75 l d^{-1}. Pond 3 (freshwater-duckweed-fed pond FDP) and 4 (freshwater-wheat bran-fed pond FWP) received de-chlorinated city tap water with daily flow rate of 37.5 litre for each. Pond 5 (settled sewage-fed pond SSP) received 2 hours settled sewage at flow rate of 15 l d^{-1}.

This flow rate was calculated based on the nitrogen content of the settled sewage to provide about 4 kgN/ha/d (Mara *et al*., 1993). The total nitrogen content of each pond was determined before stocking with tilapia. All ponds were stocked with tilapia juveniles at a density of 10 fish per pond. TDP and FDP were fed on fresh duckweed harvested daily from a pilot-scale UASB-duckweed ponds system treating domestic sewage. The feeding rate was established at 25 gram of fresh duckweed per 100 g of live body weight of fish. TWP and FWP were fed on wheat bran at a feeding rate providing the same amount of dry matter as applied to the duckweed-fed ponds. During the experiment fish was weighed twice, after 6o days and at the end of the experiment.

Studied Parameters and Analytical Procedures

Extensive analysis of water quality in the fish tanks was conducted. The measurements included water temperature, pH, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), total ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, TKN, total phosphorus and total suspended solids (TSS). All the analyses were performed using the Standard Method for the Examination of Water and Wastewater, 20th edition (APHA 1998).

The un-ionised ammonia nitrogen (UIA-N) concentrations were calculated using the general equation of bases (Albert, 1973).

$$NH_3 = \frac{[NH_3 + NH_4^+]}{[1 + 10^{(pKa - pH)}]}$$

In fresh water the calculation of pKa is based on the equation developed by Emerson *et al*. (1975).

PKa = 0.09018 + 2729.92/T

Where T = degree Kelvin

Estimation of nitrogen mass balance was performed through the experimental ponds by measuring the total nitrogen input, total nitrogen discharged with the effluent, total nitrogen incorporated in fish and total nitrogen in the sediment.

Water discharge rate was calculated from the influent flow rate and water evaporation rate according to: Water discharge rate (l $tank^{-1}$ d^{-1}) = Influent flow rate (l $tank^{-1}$ d^{-1}) - Water evaporation rate (l $tank^{-1}$ d^{-1}). The water evaporation rate (l $tank^{-1}$ d^{-1}) was measured using plastic buckets. By the end of the experiment, the accumulated sediments in the ponds were analysed for N. Duckweed and wheat bran were analysed for dry matter, nutrients content (N and P) and protein content. Protein content was calculated from the organic nitrogen where protein = N × 6.25 (Rusoff *et al*., 1980). The dry matter content was calculated after drying at 70 ^{o}C overnight. Organic nitrogen was analysed using Kjeldahl method while phosphorus content was determined using vanado-molybdate method following per-sulphate digestion method. The specific growth rates were calculated individually for each treatment based on the following expression:

$$SGR = \frac{(\ln Wf - \ln Wi)}{days} \times 100$$

Where, Wi and Wf are initial and final mean body weight respectively.

The total feed input as dry matter was recorded in each treatment, and feed conversion ratio (FCR) was calculated based on the following expression:

$$FCR = \frac{\text{total feed ingested (dry weight)}}{\text{fish weight gain (wet weight)}}$$

$$\text{Protein efficiency ratio (PER)} = \frac{\text{fish weight gain}}{\text{total protein applied}}$$

By the end of the trial, fish mortalities, total fish yield, net fish yield and nitrogen mass balance were calculated for each treatment.

$$\text{Total fish yield (in ton/ha/year)} = \frac{(\text{Final density in ton / ha})(365)}{\text{Growth period in days}}$$

$$\text{Net fish yield (in ton/ha/year)} = \frac{(\text{Initial density in ton / ha} - \text{Final density in ton / ha})(365)}{\text{Growth period in days}}$$

Statistical Analysis

The parallel treatments were subjected to one-way analysis of variance (one-way ANOVA) to investigate the significance of differences.

Results

Water Quality and Fish Feed

The water quality of treated effluent and settled sewage is presented in Table 2. The protein and phosphorus content of dry matter were 21.1±0.51 and 0.69±0.30 in duckweed and 11±1.3 and 0.43±0.02 in wheat bran. The results of water quality in fishponds are presented in Table 3. No accumulation of ammonia or nitrite occurred in the ponds except for the pond fed with settled sewage.

Table 2: Characteristics of treated and settled sewage

Parameters	Treated sewage	Settled sewage
Temperature (^{o}C)	24-34	25-31
pH	7.2-8.3	6.6–7.5
COD (mg O_2 l^{-1})	49±18	521±136
BOD (mg O_2 l^{-1})	14±5	208±46
TAN* (mg N l^{-1})	0.4±0.9	17.9±3.3
Nitrite(mg N l^{-1})	0.166±0.104	0.01±0.02
Nitrate (mg N l^{-1})	0.697±0.676	0.13± 0.03
TKN (mg N l^{-1})	4.4±1.4	23.2±5.4
TP (mg P l^{-1}l)	1.11±0.41	3.58±0.84
TSS (mg l^{-1})	32±10	161± 74
DO (mg O_2 l^{-1})	6.3±1.2	Nil

* Total ammonia nitrogen

Growth Performance

No significant difference ($p > 0.05$) between the SGR of tilapia stocked in treated effluent and fed on either fresh duckweed or wheat bran was detected (Table 4). On the other hand, when using freshwater, the juvenile tilapia fed on fresh duckweed had significant higher ($p < 0.01$) SGR than those fed on wheat bran. Significantly, lower SGR ($p < 0.05$) was observed for duckweed-fed tilapia when using treated sewage instead of freshwater. When using wheat bran as a feed the opposite effect was observed. SGR in treated sewage-fed pond was significantly ($p < 0.01$) higher compared to the freshwater-fed pond. Due to high mortality in the settled sewage-fed pond, statistical analysis was not performed for this pond and the SGR was calculated based on the average fish weight, initial and final.

Table 3: Water quality parameters in the fishponds

Parameters	TDP	TWP	FDP	FWP	SSP
Temperature ^{o}C	23-35	23-35	23-35	23-35	23-35
PH	8-9.4	8-9.7	8.4-9.9	7.4-9	8.1-10.7
COD (mg O_2 l^{-1})	295 ± 104	257 ± 68	108 ± 46	110 ± 65	256 ± 61
BOD (mg O_2 l^{-1})	34 ± 11	28 ± 8	18 ± 9	19 ± 10	28 ± 5
TAN (mg N l^{-1})*	0.22 ± 0.29^{a}	0.15 ± 0.2^{a}	0.12 ± 0.2^{ab}	0.05 ± 0.08^{b}	0.57 ± 0.89^{c}
UIA-N (mg N/l) *	0.06 ± 0.12^{a}	0.04 ± 0.08^{a}	0.05 ± 0.11^{ab}	0.004 ± 0.01^{b}	0.12 ± 0.22^{c}
Nitrite (mg N l^{-1}) **	0.024 ± 0.012^{a}	0.02 ± 0.016^{a}	0.02 ± 0.01^{a}	0.01 ± 0.005^{a}	0.11 ± 0.15^{b}
Nitrate (mg N l^{-1})	0.181 ± 0.07	0.132 ± 0.06	0.1 ± 0.055	0.09 ± 0.04	0.138 ± 0.055
TKN (mg N l^{-1})	5.95 ± 1.58	4.6 ± 1.02	1.41 ± 0.38	0.4 ± 0.14	5.92 ± 1.45
TP (mg P l^{-1})	1.09 ± 0.43	0.88 ± 0.36	0.56 ± 0.19	0.32 ± 0.11	1.4 ± 0.57
TSS (mg l^{-1})	195 ± 92	164 ± 59	82 ± 48	83 ± 48	135 ± 34
DO (mg O_2 l^{-1})	15.9 ± 4.7	14.9 ± 4.7	15.3 ± 4.1	13.8 ± 4.7	27.3 ± 8.1

*P<0.05 ,**P<0.01

Statistical comparison calculated between values within the same row. Values with the same superscript letters are not significantly different.

Table 4: Growth performance of tilapia (*Oreochromis niloticus*) in fishponds

Parameters	TDP	TWP	FDP	FWP	SSP
Initial standing crop density (g tank^{-1})	214.1	201.5	198	217	203.5
Final standing crop density (g tank^{-1})	481.5	448.9	477.5	432.5	157
Weight gain (g tank^{-1})	267.4	247.4	279.5	215.5	-
Feed input (g tank^{-1})**	589	585	561	526.5	-
SGR*	$0.53 \pm 0.06^{a*}$	$0.53 \pm 0.06^{\underline{a}*}$	$0.59 \pm 0.05^{\underline{b}*}$	$0.46 \pm 0.04^{\underline{c}}$	0.44
FCR	2.2	2.36	2.01	2.44	-
PER	2.1	3.84	2.12	3.72	-

* $p < 0.05$ _ the underscore means that $p < 0.01$ in significantly different treatments (e.g., TDP-FWP $P< 0.05$ and TWP-FWP $P< 0.01$)

** Feed input in dray matter

Total and net fish yield was calculated in all ponds and presented in Figure 1. At the end of the trial, a relatively large part of the total fish biomass consisted of fry fish, especially in TDP. The total net fish yields (fry and adult) were 11.8, 8.9, 9.6, 6.4 and –

0.16 ton/ha/y in the TDP, TWP, FDP, FWP and SSP, respectively. The fry fish contributed to the net yield by 45%, 32%, 29% and 18% in TDP, TWP, FDP and FWP, respectively.

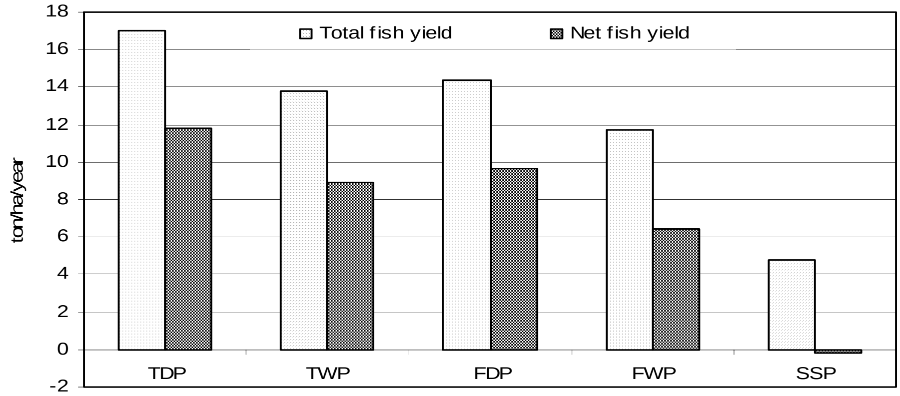

Fig.1: Total and net fish yield in fishponds

Nitrogen Mass Balance

The results shown in Table 5 show that the total nitrogen recovery in fish was 19.6% and 17.9% from the total nitrogen input (feed + treated sewage) in the TDP and TWP, respectively. The values in freshwater fed ponds were 40% and 57.4% in FDP and FWP, respectively. The total nitrogen recovery in SSP was estimated to be 10% including died fish.

Table 5: Nitrogen mass balance in duckweed, wheat bran and settled sewage fishponds

Item	TDP	TWP	FDP	FWP	SSP
$TN_{intput.}$	54.18	44.07	21.05	9.27	52.2
$TN_{reco.}$	10.61 (19.6%)	7.88 (17.9%)	8.4 (40%)	5.32 (57.4%)	5.29 (10%)
$TN_{disc.}$	36.7 (67.7%)	31.57 (71.6%)	7.8 (37%)	2.58 (27.8%)	9.35 (18%)
TN_{sed}.	6.5 (12%)	4.2 (9.5%)	3.8 (18%)	0.6 (6.5%)	11.8 (23%)
TN_{unacc}.	0.37 (0.7%)	0.42 (1%)	1.05 (5%)	0.77 (8.3%)	25.76 (49%)

*TN_{input}. total nitrogen input, $TN_{reco.}$ total nitrogen recovered, $TN_{disc.}$ total nitrogen discharged, TN_{sed}. Total nitrogen in the sediment and TN_{unacc}. Unaccounted nitrogen (all in gram)

* Values between parentheses are % of total nitrogen input.

Discussion

Water Quality and Fish Mortality

Significant higher values of ammonia (p<0.05) and nitrite (p<0.01) were detected in the SSP due to the accumulation of ammonia and low nitrification at the end of the experiment (Autumn). This was mainly due to partial decrease in temperature and decrease in day length. This lead to decreased photosynthetic activity and ammonia uptake capacity of the phytoplankton in SSP. Fish mortality in this pond was 60% in the adult fish and 38% in the fry. This mortality was probably due to chronic ammonia toxicity rather than due to an acute toxicity effect. Acute ammonia toxicity for tilapia may occur at values above 2 mg UIA-N l^{-1} (Render and Stickeny, 1979) while the maximum un-ionised ammonia concentration recorded in SSP was 0.9 mg UIA-N l^{-1} (Fig 3). Person-Le Ruyet *et al.* (1997) demonstrated 50% mortality in trout juvenile after prolonged exposure (chronic toxicity) to 0.73 mg UIA-N l^{-1}. In fresh duckweed-fed tilapia no mortality was recorded after 75 days exposure to 0.43 mg UIA-N l^{-1} (El-Shafai *et al.* 2004). However, Nasr *et al.* (1998) reported skin ulcer, necrosis and mortality in tilapia after 30 days stocking period in treated sewage pond at 0.45 mg UIA-N l^{-1}. Nitrite toxicity also may have played a role in the toxicity either directly (Anuradha and Subburam, 1995; Woo and Chiu, 1995; Schoore *et al.*, 1995) by oxidising haemoglobin into non-functional methaemoglobin and/or indirectly (Bunch and Bijerano, 1997) by increasing susceptibility of tilapia for bacterial infection.

Growth Performance and Fish Yield

In the current experiment, the range of SGR of tilapia was 0.53-0.59 in duckweed-fed ponds and FCR ranged between 2.01-2.2. These results are comparable with the SGR (0.51-0.73) of tilapia weighing about 5 grams and fed on formulated feed with 50% protein, containing blood meal, fish meal, groundnut cake and water hyacinth leaf (Keke *et al.*, 1997). Gaigher *et al.* (1984) reported a SGR of 0.63-0.72 when rearing tilapia with 2.8 grams mean initial body weight and fed on fresh duckweed. By rearing Nile tilapia in static water tanks and fed on fresh duckweed (*Lemna gibba*), Hassan and Edwards (1992) observed SGR of 0.41, 0.8, 1.34 and 1.4 at feeding rates (dry matter bases) of 1%, 2%, 3% and 4%, respectively while the range of FCR was 1.9-3.3. These results support our finding of SGR (0.53-0.59) at 25% feeding rate on fresh duckweed (1.13% dry matter bases). The FCR of 1.9 observed by Hassan and Edwards (1992) at 1% feeding rate is similar to our results (2.01-2.2) in duckweed fed ponds.

SGR in our experiment is lower than reported values (1.8-2.2) of tilapia with 2.5 grams mean body weight and fed on three isonitrogenous fishmeal-based diets containing local ingredients (water hyacinth, duckweed and rice bran) (Zaher *et al.*, 1995). The FCR

(2.2-2.5) of these three diets is similar to our data. The low SGR in our study is mainly attributed to the low feeding rate rather than to the quality of the duckweed. Zaher *et al.* (1995) applied a feeding rate of 3-5% that is 3-4 times higher than in this study.

Our results of FCR and PER are better than the reported values (4.3 and 0.8, respectively) for tilapia (13.5 grams) fed on formulated feed with sun-dried *Spirodela* as substitute for fishmeal (Fasakin *et al.*, 1999), which suggests a better nutritional value of *Lemna gibba* in comparison to *Spirodela*. Our results are comparable with results for FCR (1.2-2) and better than for PER (1.1-1.8) reported by Fontainhas *et al.* (1999) for tilapia fed on fishmeal-based diets with 0%, 33%, 66% and 100% plant ingredients (extruded pea seed meal, defatted soybean meal, full-fat toasted soybean and micronized wheat) as replacement of fishmeal.

Our results showed higher SGR ($p<0.01$) of tilapia in FDP than in FWP. This is probably due to the high nutritional value of duckweed (high protein content) over the wheat bran. The dietary protein is of fundamental importance and generally represents the limiting factor, determining growth performance in fish aquaculture systems. In case of wheat bran-fed ponds, significantly higher SGR was observed in TWP ($p<0.01$) than in the FWP. The nutrients in the treated sewage increased the natural productivity of the pond. The natural productivity of the pond significantly contributes to satisfy the demand for essential compounds such as vitamins, cholesterol, phosphorus and minerals (D' Abramo and Conklin, 1995). Also Cruz and Laudencia (1980) reported that the net fish production and growth performance of fish was significantly higher in fertilised ponds fed on rice bran or copra meal than the yield in non-supplemented ponds. Agustin (1999) investigated the effect of natural productivity and formulated feed addition on the growth of fresh water prawn, *Macrobrachium borelli*. He reported that the natural productivity supported 43% of the prawn growth. In supplemented earthen ponds, the growth of freshwater prawn

(*Macrobrachium rosenbergi*) was significantly higher in organic fertilised ponds than in the non-fertilised ponds (Tidwell *et al*., 1995). The role of natural productivity in enhancing fish yield was also reported in tilapia fertilised ponds (cow manure) fed on formulated feed, in comparison to non-fertilised ponds fed on formulated feed (Victor, 1993).

In addition to the treated sewage nutrients, considerable amount of daphnia and copepods were observed in the treated effluent. The published data show that the protein content of daphnia grown on wastewater is in the range of 55-65% (dry matter) while the energy content is representing 20 KJ g-1 (Proulx and De la Noue, 1985; Kibria *et al*., 1999). The daphnia and copepods contain high amounts of essential and non-essential fatty acids (McEvoy *et al*., 1998; Kibria *et al*., 1999). They represent considerable part of the prey for the omnivorous and carnivorous fish in the natural water and organic fertilised fishponds (Warburton *et al*., 1998; Kibria *et al*., 1999; Lienesch and Gophen, 2001).

Absence of any significant differences between the TDP and TWP and significantly higher SGR in case of FDP than in the TDP is attributed to the early spawning that occurred in the TDP in comparison to the other ponds, Table 6. The new larvae increased the stocking density and negatively affected the SGR and FCR of the adult through competition for feed (Canario *et al*., 1998) and enhancing social interaction due to high density (Breine *et al*., 1996). The spawning itself consumed large amount of energy and so decreased the energy budget of the fish with negative effects on the growth performance. The dietary protein is known to positively affect spawning in fishponds (Siddiqui *et al*., 1998). Accordingly the early spawn in the TDP could be attributed to high protein input either directly from the duckweed, daphnia and copepods or indirectly from the pond fertilisation by the treated sewage.

Table 6: Production of fry in fishponds

Fish ponds / Parameters	TDP		TWP		FDP	FWP	SSP
No of fry (fry tank^{-1})	4	58	73	83	60	28	34
Average weight (g fish^{-1})	10.9	2.99	1.21	0.38	1.93	1.68	1.9
Age (days)	125	50	50	35	50	50	125
No of fry female^{-1}	31		52		20	14	11
No of spawn femal^{-1}	2		2		1	1	1
% of mortality	0		0		0	0	38

The total net fish yields, including adult fish and fry, were 11.8 and 9.6 ton ha^{-1} y^{-1} in the TDP and FDP, respectively. In the parallel treatments of wheat bran the net yields were 8.9 and 6.4 ton ha^{-1} y^{-1} in TWP and FWP respectively. The values for duckweed as well as the values for the treated sewage-fertilised ponds show the advantages of duckweed over the wheat bran and the role of treated sewage in enhancing the fish yield. In organic (cow manure) fertilised ponds supplemented with formulated feed with 27% protein, the net yield of tilapia reached 11.8 ton ha^{-1} y^{-1} (Victor, 1993). This yield is similar to the yield of TDP in our trial, which confirms that the nutritional value of duckweed and treated sewage is similar to that of commercial feed containing 27% protein and cow manure. Production of polyculture carp fed with fresh duckweed and treated sewage ranged between 10-15 ton ha^{-1} y^{-1} (Skillicorn *et al*., 1993) while the maximum attainable yield in ponds fed with fresh duckweed and other supplementary feeds (rice bran and oil cake) was 6.3 ton Ha^{-1} y^{-1} (Wahab *et al*., 2001). The lower yield in sewage-fed ponds supplemented with rice bran and oil cake might be attributed to the higher fibre and lower protein content of rice bran and/or the bad effect of oil cake on the pond water quality. The oil and fat of oil cake disperse in the pond and contribute to the BOD and decrease the gas transfer by forming a fatty layer on the pond surface. The yearly production of tilapia in ponds fertilised with chicken litter was 4.3 $ton.ha^{-1}.y^{-1}$ (Green *et al*., 1989). The results of duckweed-fed ponds and treated sewage-fed ponds is higher than the reported values for the sewage-fed ponds (Shereif *et al*., 1995), buffalo manure-fed ponds (Edwards *et al*., 1994) and swine manure-fed ponds (Berends *et al*., 1980). This indicating the good quality of fresh duckweed as supplemental feed for sewage fed ponds or organic manure fed ponds. This also shows the advantage of producing duckweed on sewage as fish feed and its use with the treated effluent in tilapia farming instead of using the sewage directly as source of pond fertilisation. On the other hand this data is lower than the 20 $ton.ha^{-1}$ yearly production rate of polyculture carp in an integrated duck-fish pond fed with formulated feed in addition to duck faeces (Prinsloo and Schonbee, 1987a). This might be attributed to the use of a carp polyculture, which covers all the trophic levels in the pond and therefore decreases feed loss.

Nitrogen Mass Balance

18% of the total nitrogen input (dietary N + N in the influent) in the treated sewage fed ponds was recovered in fish while the percentage was 40% and 57% in the FDP and FWP, respectively. The values in fertilised ponds supplied with supplementary feed (duckweed or wheat bran) are within the range of 5-25% reported for semi-intensive fishpond culture (Tacon *et al*., 1995). The low value of 10% N-recovery obtained in SSP is still higher than the 3.5% that was reported in polyculture fishponds with high mortality (Liang *et al*., 1999). In the fresh water ponds the range (40-57%) of N recovery is similar to 53% reported by Gaigher *et al*. (1984) for tilapia reared in re-circulating tanks and fed on fresh duckweed. The N retained in the sediment was in the range of 3.8-11.8%, which is similar to the range of 4.3-13.7% reported by Gomes *et al*. (1995) in trout growth trials using plant-based formulated diets. Gaigher *et al*. (1984) reported that 14% of the N from fresh duckweed accumulated in the sediment.

Two primary processes affect ammonia concentration, i.e. fish excretion and sediment diffusion (Hargreaves, 1997). The amount of ammonia excreted by fish depends on average feeding rate and dietary protein content and its biodegradability. In semi-intensive aquaculture systems, nitrogen dynamics in the water column are controlled by ammonia input, its assimilation by phytoplankton or nitrification and loss of nitrogen through sedimentation, volatilisation and discharge. Seawright *et al*. (1998) highly-lighted the role of phytoplankton in nitrogen dynamics in fishponds. This is supported by Lorenzen et al. (1997) who reported that assimilation by phytoplankton and subsequent sedimentation is the principal process of ammonia removal. In the current experiment the unaccounted part of nitrogen, which was probably lost via ammonia volatilisation and/or nitrogen denitrification, was small in treated sewage fed ponds. The major source of ammonia in these ponds was probably ammonia excretion by fish, and this remained below the phytoplankton uptake capacity. The higher value of unaccounted nitrogen in freshwater fed ponds could be attributed to the low density of algae in these ponds. When the inputs of ammonia exceed the phytoplankton assimilation capacity, the remaining high ammonia concentration is subject to volatilisation and de-nitrification. This is what happened in the SSP that received considerable amounts of ammonia nitrogen in the settled sewage, Table 2. The high pH value in the SSP pond, which maximally reached 10.7, enhanced ammonia volatilisation (Gomez *et al*., 1995). Dissolved oxygen produced as by-product from photosynthesis might enhance the nitrification process (Liang *et al*., 1998). The produced nitrate serves as substrate for denitrification during the night. During the night, low dissolved oxygen concentration due to absence of photosynthesis and presence of respiration by algae and fish and presence of high organic matter in SSP may have enhanced the de-nitrification process (Daniels and Boyd, 1989; Diab *et al*., 1993).

Nitrogen Wastes

The total nitrogen waste in the ponds ranged between 12.1- 97.8 Kg N ton fish^{-1} production. The range for the treated sewage-fed ponds was 89.1-97.8 Kg N ton fish^{-1}, which is comparable to the amount of nitrogen released from production of one ton of carp (53-71 kg N) and the nitrogen waste (26-117 Kg N) for one ton of shrimp production (Tacon *et al.*, 1995). In typical Nordic freshwater fish farms the nitrogen release to the environment was estimated to be 132 kg N in 1974 and 55 Kg N in 1995 for each ton of fish production (Enell, 1995) while Gomez *et al*. (1995) reported 61-129 kg N ton fish^{-1} in rainbow trout. The nitrogen waste in our freshwater-fed ponds (12.1-29.4 Kg N ton fish^{-1}) is low, which is mainly attributed to the low amount of nitrogen applied to the ponds. The nitrogen solid waste (faecal N in the sediment) in our experiment ranged between 5-9 Kg N for each ton of fish production. Gomes *et al*. (1995) showed that the solid waste of N released from a rainbow trout farm ranged between 6.3 and 16.1 Kg N ton fish^{-1}.

Conclusions

-The experiments have shown that it is feasible to use treated domestic sewage from UASB-duckweed pond systems as replacement of freshwater in tilapia farming.

-Fresh duckweed (*Lemna gibba*) is superior to wheat bran as supplementary feed in tilapia pond farming. Main advantages of duckweed are the high protein content and its low cost.

-Fertilisation of tilapia ponds with treated sewage from UASB-duckweed pond increases the fish yield significantly. This was valid for both ponds fed with duckweed and wheat bran.

-Since the most important water quality parameters in fishponds are ammonia, nitrite and DO, it is recommended to cultivate duckweed in anaerobically treated sewage followed by use of both treated sewage and duckweed biomass in tilapia farming instead of direct use of settled sewage as a pond fertiliser.

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