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Growth and economic performance of Nile tilapia (*Oreochromis niloticus* L.) fed on two formulated diets and two locally available feeds in fertilized ponds

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Abstract

Lack of suitable diets for semi-intensive production of *Oreochromis niloticus* in Kenya has necessitated use of expensive diets designed for intensive production. To address this problem, two isonitrogenous (24% protein) diets were formulated and evaluated for production of *O. niloticus* in fertilized ponds. One diet contained vitamins and minerals premix (CV) while the other had no premix (CW). Growth of fish fed on the formulated feeds was compared with groups of fish fed on commercial pig pellets (PP) and wheat bran (WB). There were significant differences in mean weights, growth rates and feed conversion ratios between the formulated and the other diets. No significant differences in these parameters were observed between CV and CW and also between PP and WB. Fish that fed on the formulated feeds produced significantly lower number of juveniles than those fed on PP and WB. Fish fed on WB gave the best economic returns while those on PP had the least returns. Present results suggest that vitamins and minerals premix may not be necessary in diets for semi-intensive production of *O. niloticus*. Present results showed that the formulated feeds produced higher yields than PP and WB, but WB had the best economic returns among the test diets.

Keywords: *Oreochromis niloticus*, formulated diets, semi-intensive, vitamins

Introduction

Nile tilapia, *Oreochromis niloticus* L. is the most dominant among the group of tilapias farmed in sub-Saharan Africa. This fish has been farmed either for subsistence or commercial purposes and the great majority of the culture practices are semi-intensive. The suitability of *O. niloticus* for semi-intensive culture stems from their ability to utilize feeds from a wide range of materials including plants (Moriarty 1973; Moriarty & Moriarty 1973; Getachew 1987; Getachew & Fernando 1989). Production of *O. niloticus* in fertilized ponds largely depends on natural pond productivity (Diana, Lin & Schneeberger 1991; Knud-Hansen, McNabb & Batterson 1991), but feeds may be added into the ponds to increase fish yields (Green 1992; Diana, Lin & Jaiyen 1994). Yields between 2500 and 4000 kg ha^{-1} of *O. niloticus* have been reported from fertilized ponds (Diana *et al.* 1991; Diana & Lin 1998) while yields between 5000 and 12 000 kg ha^{-1} have been reported from fertilized-fed ponds (Knud-Hansen *et al.* 1991; Diana *et al.* 1994). Feed is among the most costly items in fish production and accounts for over 50% of the total operating costs (Shang 1992). Attempts to search for ways of reducing the cost of feed for the production of *O. niloticus* have led to evaluation of a wide range of plant materials (Wu, Tudor & Brown 1999; Maina, Beames, Higgs, Mbugua, Iwama & Kisia 2002 among others). Semi-intensive culture of *O. niloticus* in Kenya has been based on feeds formulated for intensive production. This practice has led to increased production costs and reduced profits.

Profitable semi-intensive fish farming requires feeds that are designed to supplement natural food in ponds rather than those providing all the necessary nutrients. Previous studies have largely been focused on the development of nutritionally complete diets (Diana *et al.* 1994). However, the suitability of these diets for *O. niloticus* production in semi-intensive ponds is questionable because many of the studies were conducted in recirculating systems (Olvera-Novoa, Campos, Sabido, Martinez & Palacios 1990; Maina *et al.* 2002; Hossain, Focken & Becker 2003; Adebayo, Fagbenro & Jegede 2004) with conditions that do not reflect those in semi-intensive culture ponds. Data from studies focused on feeds formulated for semi-intensive production of *O. niloticus* in fertilized ponds are lacking. The present study was aimed at formulating and evaluating two feed supplements for semi-intensive production of *O. niloticus* in fertilized ponds. The formulated feeds were also compared with two other feeds, commercial pig pellets (PP) and wheat bran (WB), which have previously been used for *O. niloticus* production in Sagana fish farm.

Table 1 Proximate composition (dry weight basis) of the four test diets

	Test diets			
	CV	CW	WB	PP
Composition				
Shrimp meal	12	12	–	–
Cottonseed meal	24	24	–	–
Wheat bran	63.5	64	–	–
Premix	0.5	–	–	–
Total	100	100	–	–
Proximate composition ($g\,100\,g^{-1}$)				
Dry matter	91.5	91.0	91.2	91.7
Crude protein	24.3	24.1	17.6	15.7
Ether extract	7.6	7.5	9.1	7.6
Crude fibre	13.1	12.2	11.4	9.9
Ash	8.5	7.6	5.0	13.7
Nitrogen free extracts	46.5	48.3	60.4	53.6

CV, formulation with vitamins and minerals premix; CW, formulation without vitamins and minerals premix; WB, wheat bran; PP, pig pellets.

Materials and methods

This study was conducted at the Sagana Fish Farm Kenya (0°39′S, 37°12′E), which is located approximately 105 km north-east of Nairobi at an altitude of 1230 m above mean sea level. Two isonitrogenous (24%) diets were formulated from shrimp meal (*Caridinia nilotica*), cottonseed meal (CSM) and WB. The percent inclusion of the ingredients and the proximate composition of the ingredients and diets are shown in Table 1. One of the formulated diets was supplemented with a locally manufactured commercial vitamin and mineral premix at 0.5% inclusion level. The composition of the premix is shown in Table 2. Wheat bran in this diet was included at 63.5% to allow for the premix. Commercial PP were purchased from a local feed manufacturer while WB was purchased from a wheat-processing factory. Twelve 0.08 ha earthen ponds were drained and left to dry for 2 weeks prior to the start of the experiment. The experimental ponds were limed once at the beginning of the experiment at 2.5 tonnes ha^{-1} with agricultural lime.

The ponds were stocked with sex-reversed *O. niloticus* averaging 21 g and *Clarias gariepinus* (Burchell 1822) averaging 2.4 g and at stocking densities of 20 000 and 1000 fish ha^{-1} respectively. *Clarias gariepinus* was included to control juvenile recruitment from the unreversed females of *O. niloticus*. The four diets were fed to the experimental fish in four replicate ponds per dietary treatment. Fish were fed twice a day at 2% body weight for 258 days. Each ration was divided in to two equal parts, one portion was offered at 10:00 hours while the other was offered at 15:00 hours. The experimental ponds were fertilized weekly using urea and diammonium phosphate at rates of 20 kg N ha^{-1} and 8 kg P ha^{-1} to stimulate natural food items. Fish were sampled monthly using a seine net, and each sample contained over 50% of the total pond fish in order to obtain a better estimate of mean weight. Samples of fish were counted and batch weighed to the nearest 0.1 g using a bench scale (DS10) and mean weight was calculated. At harvest, all the experimental ponds were drained and all the fish were harvested, counted, weighed and the mean fish weight for each pond determined.

Table 2 Vitamin and mineral composition of the domestic premix

Vitamin contents		Mineral contents	
Vitamin	Content	Mineral	Content (mg)
A	5 000 000 IU	Copper sulphate	1.5
D3	1 000 000 IU	Manganese sulphate	90
E	1 500 IU	Manganese iodide	300
B1	600 mg	Zinc oxide	70
B2	2500 mg	Nicotinic acid	5500
B6	125 mg	Calcium pantothenate	5000
B12	7.5 mg		
K	1250 mg		
C	200 mg		

Samples for water-quality variables were taken using a 90 cm water column sampler (Boyd & Tucker

1992). Pond water was taken from three different locations (near inlet and outlet, and close to the shore along the pond length) within each pond and pooled to provide an integrated sample; a sub-sample was drawn from the integrated sample for the analyses of water-quality variables. The water-quality analyses included the following variables: ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, orthophosphate-phosphorus, total phosphorus, total nitrogen, alkalinity, hardness and chlorophyll *a*. The analyses were done according to standard methods described in APHA (1989) and Egna, Brown and Leslie (1987). Temperature and dissolved oxygen measurements were obtained using YSI model 57 meters while pH was measured using glass electrode Hi-9024 micro-computer (Hanna Instruments, Mauritius). A 25 cm diameter white disk was used to measure Secchi disc visibility while weather data was gathered from a meteorological station located at Sagana fish farm.

Protein content of the diets was determined using micro-Kjeldhal method, percent fat using ether extraction method, crude fibre by acid–alkali digestion, ash by burning weighed samples at 600 °C in a muffle furnace, and moisture by drying samples to constant weight at 100 °C (AOAC 1990). Carbohydrate, estimated as nitrogen-free extracts, was determined by difference.

Single classification ANOVA was used to test for significance differences and Duncan's multiple range test was used to discriminate which means were significantly different from each other. Where necessary, data were subjected to appropriate transformation to achieve normality (Sokal & Rohlf 1981). Significance was declared at $P = 0.05$.

Results

Fish growth data are presented in Table 3. There were significant differences ($P < 0.05$) in fish growth among the dietary treatments. Fish, that were fed on formulated diets exhibited significantly higher ($P < 0.05$) mean fish weight, growth rate, yields and lower feed conversion ratio (FCR) than those fed on PP and WB. Fish that were fed on the formulated diets had statistically similar ($P > 0.05$) growth performance. The mean weight of fish fed on WB and PP were also statistically similar ($P > 0.05$). Feed conversion ratio did not differ significantly ($P > 0.05$) among the formulated diets but was better than the values recorded for fish fed on PP and WB. Pig pellets and WB had statistically similar ($P > 0.05$) FCR. There was no significant difference ($P > 0.05$) in survival rate among all the dietary treatments.

Table 3 Performance of *Oreochromis niloticus* fed on different dietary treatments

	Dietary treatments				
Variable	CV	CW	PP	WB	SE
Stocking weight (g)	21.0^{a}	21.5^{a}	21.9^{a}	21.5^{a}	0.36
Harvest weight (g)	354.1^{a}	349.1^{a}	303.4^{b}	291.3^{b}	5.02
Gross yield (kg ha^{-1})	5867^{b}	5742^{b}	4865^{a}	4909^{a}	188
Net fish yield (kg ha^{-1})	5433^{b}	5298^{b}	4411^{a}	4469^{a}	189
Annual net production (kg ha year^{-1})	7686^{b}	7494^{b}	6241^{a}	6322^{a}	267
Growth rate (g day^{-1})	1.5^{b}	1.5^{b}	1.3^{a}	1.3^{a}	0.06
FCR	2.6^{a}	2.6^{ab}	2.9^{bc}	3.0^{c}	0.1
Survival (%)	69.7^{a}	69.3^{a}	68.6^{a}	70.1^{a}	2.21
Fingerling recruitment (nos)	29 271^{a}	28 858^{a}	36 856^{b}	46 041^{b}	730

CV, formulation with vitamins and minerals premix; CW, formulation without vitamins and minerals premix; WB, wheat bran; PP, pig pellets; FCR, feed conversion ratio. Values with the same superscript in each row are not significantly different.

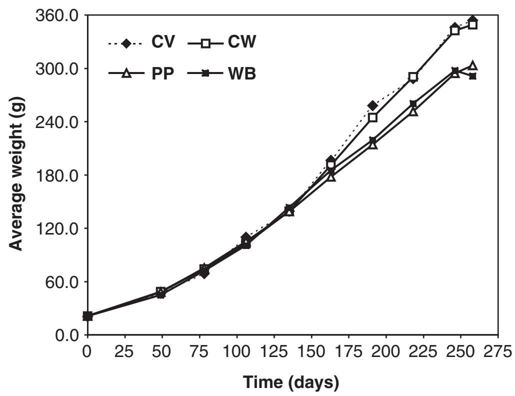

Figure 1 Growth curves for *Oreochromis niloticus* under different dietary treatments (CV, formulation with vitamins and minerals premix; CW, formulation without vitamins and minerals premix; WB, wheat bran; PP, pig pellets).

Figure 1 shows the growth curves for *O. niloticus* during the study period. Growth curves were exponential for the first 140 days of culture where after fish growth assumed more or less linear trends. Differential growth of fish among the dietary treatments appeared between 100 and 150 days of culture when the growth curves of fish fed on the formulated diets separated from those of fish fed on WB and PP. Growth reduction did not appear towards the end of the culture period, although there appeared to be a decline at the harvest time, which could be attributed to bias caused by use of samples instead of total pond harvest to estimate mean weights. At harvest, the growth curves for PP and WB had not separated from each other and so were those for formulated diets.

Juvenile recruitment occurred in the experimental ponds in all the treatments. However, the number of recruits was significantly higher ($P<0.05$) in the treatments receiving WB and PP than in those receiving formulated feeds. There were no significant differences ($P>0.05$) in juvenile production between the groups of fish receiving PP and WB and also between those receiving CV and CW. There were no significant differences ($P>0.05$) in most of the water-quality variables between treatments. However, total ammonia nitrogen and total nitrogen were significantly higher ($P<0.05$) in ponds, which received the diet formulated without premix than in the other dietary treatments. Dissolved oxygen at dawn in all the ponds ranged from 0.6 to 4.5 mg L^{-1} throughout the experimental period and mean values did not significantly ($P>0.05$) differ among the dietary treatments (Table 4).

Data on economic performance are shown in Table 5. All diets indicated positive net returns. Wheat bran demonstrated significantly ($P<0.05$) higher net returns than the other test diets while PP had significantly ($P<0.05$) the least economic performance.

Table 4 Water quality variables in ponds maintained under different dietary treatments

	Dietary treatments			
Variable	CV	CW	PP	WB
Morning temperature (°C)	24.0 ± 0.05[a]	24.1 ± 0.05[a]	24.1 ± 0.05[a]	24.0 ± 0.05a
Afternoon temperature (°C)	26.3 ± 0.12[a]	26.7 ± 0.12[a]	26.3 ± 0.12[a]	26.6 ± 0.12[a]
Dawn DO (mg L^{-1})	1.6 ± 0.16[a]	1.4 ± 0.16[a]	1.4 ± 0.16[a]	1.4 ± 0.16[a]
Afternoon DO (mg L^{-1})	7.3 ± 0.5[a]	7.8 ± 0.5[a]	6.8 ± 0.5[a]	7.9 ± 0.5[a]
Total alkalinity (mg L^{-1} $CaCO_3$)	87.7 ± 9.4[a]	85.1 ± 10.8[a]	87.2 ± 25.3[a]	86.0 ± 6.8[a]
Total hardness (mg L^{-1} $CaCo_3$)	78.8 ± 8.5[a]	81.3 ± 11.8[a]	83.1 ± 24.4[a]	82.7 ± 7.5[a]
pH	8.2 ± 0.2[a]	8.2 ± 0.04[a]	8.2 ± 0.06[a]	8.2 ± 0.1[a]
Dissolved P (mg L^{-1})	0.2 ± 0.2[a]	0.4 ± 0.09[a]	0.3 ± 0.2[a]	0.3 ± 0.2[a]
TAN (mg L^{-1})	1.3 ± 0.06[a]	1.5 ± 0.2[b]	1.3 ± 0.1[a]	1.5 ± 0.1[ab]
NO_2-N (mg L^{-1})	0.05 ± 0.03[a]	0.08 ± 0.03[a]	0.06 ± 0.02[a]	0.03 ± 0.002[a]
NO_3-N (mg L^{-1})	0.03 ± 0.02[a]	0.05 ± 0.02[a]	0.04 ± 0.02[a]	0.03 ± 0.01[a]
Total phosphorus (mg L^{-1})	0.8 ± 0.3[a]	1.3 ± 0.7[a]	1.3 ± 0.6[a]	0.8 ± 0.3[a]
Total nitrogen (mg L^{-1})	3.9 ± 0.2[ab]	4.4 ± 0.6[b]	3.6 ± 0.2[a]	3.7 ± 0.2[a]
TSS (mg L^{-1})	225.5 ± 21.9[a]	228.8 ± 25.8[a]	225.5 ± 18.3[a]	218.0 ± 14.6[a]
TVS (mg L^{-1})	102.9 ± 14.1[a]	103.0 ± 11.8[a]	89.2 ± 6.1[a]	88.5 ± 5.5[a]
Chlorophyll *a* (mg L^{-1})	157.8 ± 29.5[a]	142.0 ± 25[a]	135.4 ± 16.7[a]	118.9 ± 18.3[a]

Values with same superscripts in each row are not significantly different.
DO, dissolved oxygen; NO_3-N, nitrate-nitrogen; NO_2-N, nitrite-nitrogen; TSS, total suspended solids; TVS, total volatile solids; CV, formulation with vitamins and minerals premix; CW, formulation without vitamins and minerals premix; WB, wheat bran; PP, pig pellets.

Table 5 Cost–benefit analysis for the dietary treatments

		Test diets			
Item	Unit	CV	WV	WB	PP
Gross revenue	US$	7620[a]	7457[a]	6375[b]	6318[b]
Variable cost	US$	4810[a]	4446[b]	29 612[c]	4357[b]
Income above variable cost	US$	2809[a]	3012[a]	3413[b]	1981[c]
Fixed cost	US$	571.82[a]	571.8[a]	571.8[a]	571.8[a]
Total cost	US$	5382[a]	5017[a]	3533[b]	4928[a]
Net return	US$	2238[a]	2440[a]	2842[b]	1389[c]
Break-even yields (variable cost)	US$	0.7a	0.6[a]	0.4[b]	0.7[a]
Break-even yields (total cost)	US$	0.9[a]	0.7[a]	0.5[b]	0.9[a]

Values with same superscripts in each row are not significantly different.
CV, formulation with vitamins and minerals premix; CW, formulation without vitamins and minerals premix; WB, wheat bran; PP, pig pellets.

Discussion

Feeding *O. niloticus* on the formulated diets in fertilized ponds resulted in significantly higher mean fish weight than that of fish fed on commercial PP or WB. However, fish that fed on diets formulated with or without vitamins and minerals premix had similar mean weights. In a previous study at the same site, Liti, MacWere and Veverica (2001) fed *O. niloticus* on PP, commercial tilapia feed and rice bran and observed better growth with PP and the commercial tilapia feed than with rice bran. In that study, the growth of fish receiving PP and the commercial tilapia diet was similar. In the present study, the growth of fish fed on PP and WB was similar, suggesting that WB was as effective in the semi-intensive production of *O. niloticus* as the local commercial tilapia feed. In another study at the same site, Liti, Mugo and Muchiri (2002) fed *O. niloticus* on rice bran, maize bran and WB and obtained similar growth rates with wheat and Maize brans. Fish that were fed on rice bran had significantly slower growth than those fed on maize bran and WB. The earlier observations as well as those of the present study indicate that maize bran could be a suitable substitute where WB is not readily or locally available.

The growth curves in the present study demonstrated two phases, an initial exponential growth phase followed by a linear phase. In the exponential growth phase, the treatment growth curves overlapped suggesting that the nutrient supply from the natural food was adequate for fish growth in all the treatments and therefore, during this phase, fish did not require any nutrient supplementation. The rate of fish growth during the first phase also demonstrated steep gradients suggesting an efficient utilization of dietary protein in the natural food. Previous evidence indicates that in fertilized ponds, there is adequate protein from natural food for fish growth until a critical biomass of fish is reached (Hepher 1978; Diana *et al.* 1991). Before this critical biomass, fish growth is independent of the level of protein supplement, but energy supplementation could enhance protein utilization. It is, therefore, possible that during the exponential growth phase, all the diets were utilized as energy supplements, thus sparing of the protein from natural food for growth (De Silva, Gunasekera & Shim 1991). This sparing effect on protein may have led to the high growth rates observed during the exponential phase.

Differentiation of *O. niloticus* growth curves became apparent at fish weights between 140 and 150 g, when the curves for fish fed on the formulated diets separated from those of fish fed on PP and WB. The groups of fish receiving PP (16% protein) and WB (18% protein) demonstrated reduced growth rate compared with the groups fed on the formulated feeds (24% protein). In semi-intensive systems where fish partly rely on natural food, requirement for protein supplementation has been reported to increase with the difference between the standing fish biomass and that of the natural food (De Silva 1992). Based on the present observations, it appears that WB and PP may not provide adequate protein supplementation in semi-intensive production of *O. niloticus* when the fish attains individual weights above 140 g, which corresponded to a standing crop of 1370 kg ha^{-1}.

Supplementation of the formulated diets with vitamins and mineral premix did not significantly improve the growth of *O. niloticus*. This observation suggested that vitamins were not limiting the growth of the fish in fertilized ponds and could be omitted in diets designed for production of *O. niloticus* in fertilized ponds. Natural foods are rich in vitamins and minerals and therefore the natural food items were able to adequately compensate for the inadequacies of micronutrients in the formulated feeds. This observation has a particular relevance to small-scale fish farmers who may wish to formulate simple practical diets for *O. niloticus* production in fertilized ponds. Simple feed formulations could be made without inclusion of vitamins and minerals premix. As the present results indicate, the exclusion of the premix could lead to 20% reduction in feed cost.

The number of juveniles produced by fish that received the formulated feeds was lower than those produced by fish that fed on PP and WB. The formulated diets included an appreciable proportion of CSM. Cottonseed meal contains gossypol, a phenolic chemical compound that is found in the pigment glands of the cotton plant. Gossypol is not only toxic to fish but has also been reported to interfere with physiological processes of reproduction, including inhibition of steroidogenesis in animals (Hadley, Lin & Dym 1981; Coutinho, Segal, Melo & Barbosa 1985; Lin, Dietrick & Rikihisa 1988). Salaro, Pezzato, Barros and Vicentini (1999) observed lowered number of spermatozoa in the testis lumen when *O. niloticus* was fed on diets containing 24% CSM. Most other studies have reported varying levels of gossypol in the blood and gonads of fish fed on CSM (Robinson & Tiersch 1995; Rinchard, Mbahinzireki, Dabrowski, Lee, Abiabo & Ottobre 2002). Although the level of gossypol in formulated diets in the present study was not measured, it is possible that the 24% inclusion of CSM could have levels of gossypol that would reduce the reproductive capacity of *O. niloticus*. These results have a marked implication for *O. niloticus* fingerlings production, especially when CSM-based diets are used to feed the broodstock. Under such conditions, the capacity of the broodstock to produce fingerlings may be reduced.

Although net returns were positive for all the diets, there were significant differences in economic returns among the feeds. Wheat bran was the most profitable compared with the other feeds. Despite the similarity in fish yields in the formulated feeds, the net economic returns were better in the diet without the premix. The lower profits in the feeds containing the premix was because of the increased cost from the premix.

In conclusion, the results of the present study revealed that the formulated feeds were suitable feed supplements in the production of *O. niloticus* at weight above 140 g while PP and WB were suitable supplements below this weight. The study also demonstrated that mineral and vitamins supplementation may not be necessary in intensively fertilized ponds. Inclusion of CSM led to lower juvenile recruitment compared with the other feeds. Wheat bran was the most profitable among the test diets. Since the formulated diets gave better fish growth while WB gave better economic returns, the two could be combined in a feeding strategy that could be cost effective. One such potential strategy would be to undertake a staged feeding schedule similar to that used by Diana, Lin and Yi (1996); starting with WB in fertilized ponds and thereafter changing to the higher protein formulated feeds once the fish attain an average weight of 140 g. This strategy could reduce feed cost and increase profitability by 18%.

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References

Adebayo O.T., Fagbenro O.A & Jegede T. (2004) Evaluation of *Cassia fistula* meal as a replacement of soybean meal in practical diets of *Oreochromis niloticus* fingerlings. *Aquaculture nutrition* **9**, 99–104.

American Public Health Association (APHA) (1989) *Standard Methods for the Examination of Water and Wastewater*, 17th edn. American Public Health Association, Washington, DC, USA.

AOAC (Association of Official Analytical Chemists) (1990) *Official Methods of Analysis*, 15th edn, AOAC, Arlington, VA, USA.

Boyd C.E. & Tucker C.S. (1992) *Water Quality and Pond Soil Analysis for Aquaculture*. Alabama Agric. Exp Station, Auburn University, Auburn, AL, USA, 183 pp.

Coutinho E.M., Segal S.J., Melo J.F. & Barbosa I.C. (1985) Biphasic action of gossypol in men. In: *Gossypol a Potential Contraceptive for Men* (ed. by S.J. Segal), pp. 25–31. Plenum Press, New York, USA.

De Silva S.S. (1992) Supplementary feeding in semi-intensive aquaculture systems. In: *Farm Made Aquafeeds. Proceedings of the FAO/AADCP*, Bangkok, Thailand (ed. by M.B. New, A.G.J. Tacon & I. Csavas), pp. 24–60, 14–18, FAO, Rome, Italy.

De Silva S.S., Gunasekera R.M. & Shim K.F. (1991) Interactions of varying dietary protein and lipid levels in red young tilapia: evidence of protein sparing. *Aquaculture* **95**, 305–318.

Diana J.S. & Lin C.K. (1998) The effects of fertilization and water management on growth and production of Nile tilapia in deep ponds during the dry season. *Journal of the World Aquaculture Society* **29**, 405–413.

Diana J.S., Lin C.K. & Schneeberger P.J. (1991) Relationships among nutrient inputs, water nutrient concentrations, primary production, and yield of *Oreochromis niloticus* in ponds. *Aquaculture* **92**, 323–341.

Diana J.S., Lin C.K. & Jaiyen K. (1994) Supplemental feeding of tilapia in fertilized ponds. *Journal of the World Aquaculture Society* **25**, 497–506.

Diana J.S., Lin C.K. & Yi Y. (1996) Timing of supplemental feeding for tilapia production. *Journal of the World Aquaculture Society* **27**, 410–419.

Egna H.S., Brown N. & Leslie M. (1987) General reference: site description, materials and methods for the global experiments, Pond Dynamics/Aquaculture CRSP Data Reports Vol. 1. Oregon State University, Corvallis, OR, USA.

Getachew T. (1987) A study of an herbivorous fish, *O. niloticus* L., diet and its quality in two Ethiopian Rift valley Lakes, Awasa and Zwai. *Journal of Fish Biology* **30**, 439–449.

Getachew T. & Fernando C.H. (1989) The food habits of an herbivorous fish (*Oreochromis niloticus L.*) in Lake Awasa, Ethiopia. *Hydrobiologia* **174**, 195–200.

Green B.W. (1992) Substitution of organic manure for pelleted feed in tilapia production. *Aquaculture* **101**, 213–222.

Hadley M.A., Lin Y.C. & Dym M. (1981) Effects of gossypol on the reproductive system of male rats. *Journal of Andrology* **2**, 190–199.

Hepher B. (1978) Ecological aspects of warm-water fishpond management. In: *Ecology of Freshwater Fish Production* (ed. by S.D. Gerking), pp. 445–465, 447–468. John Wiley, New York, USA.

Hossain M.A., Focken U. & Becker K. (2003) Antinutrive effects of galactomannan-rich endosperm of sesbania (*Sesbania aculeate*) seeds on growth and feed utilization in tilapia, *Oreochromis nilotica. Aquaculture Research* **9**, 1171–1179.

Knud-Hansen C.F., McNabb C.D. & Batterson T.R. (1991) Application of Limnology for efficient nutrient utilization in tropical pond aquaculture. *Proceedings of the International Association of Theoretical and Applied Limnologists* **24**, 2541–2543.

Lin Y.C., Dietrick T. & Rikihisa Y. (1988) Antifertility effect of gossypol in male Japanese quail. *Life Sciences* **42**, 2283–2292.

Liti D.M., MacWere E. & Veverica K.L. (2001) Growth performance and economic benefits of *Oreochromis niloticus*/*Clarias gariepinus* polyculture fed on three supplementary feeds in fertilized tropical ponds. In: *Nineteenth Annual Technical Report* (ed. by E. McElwee, K. Lewis, M. Nidiffer, P. Buitrago, H.S. Egna, M.M.C. Namaya, J. Bowman & N. Astin), pp. 11–16. Oregon State University, Corvallis, OR, USA.

Liti D.M., Mugo R. & Muchiri M. (2002) *Growth and economic performance of Nile tilapia (oreochromis niloticus) fed on three brans in fertilized ponds*. Aquaculture America, California, USA, 2002, 187pp.

Maina J.G., Beames R.M., Higgs D., Mbugua P.N., Iwama G. & Kisia S.M. (2002) Digestibility and value of same feed ingredients fed to tilapia *Oreochromis niloticus* (L). *Aquaculture Research* **33**, 853–862.

Moriarty C.M. & Moriarty D.J.W. (1973) The assimilation of carbon from phytoplankton by two herbivorous Fishes: *Tilapia nilotica* and *Haplochromis nigripinnis*. *Journal of Zoology London* **171**, 41–55.

Moriarty D.J.W. (1973) The physiology of digestion of blue-green in cichlid fish, *Tilapia nilotica*. *Journal of Zoology London* **171**, 25–39.

Olvera-Novoa M.A., Campos G.S., Sabido G.M. & Martinez Palacios C.A. (1990) The use of alfalfa leaf protein concentrates as a protein source in diets of tilapia (*Oreochromis mossambicus*). *Aquaculture* **90**, 291–302.

Rinchard J., Mbahinzireki G., Dabrowski K., Lee K.J., Abiabo M.A.G. & Ottobre J. (2002) The effects of cottonseed meal protein level on growth, gonad development and plasma sex steroid hormones of Tropical fish Tilapia. *Oreochromis sp. Aquaculture International* **10**, 11–28.

Robinson E.H. & Tiersch T.R. (1995) Effects of long-term feeding of cottonseed meal on growth, testis development, and sperm motility of male Channel catfish, *Ictalurus punctatus* broodfish. *Journal of the World Aquaculture Society* **25**, 271–276.

Salaro A.L., Pezzato L.E., Barros M.M. & Vecentini C.A. (1999) Performance and spermatogenesis of Nile tilapia fingerlings fed with cottonseed meal or cotton seed flour. *Pesquisa Agropecuaria Brasileira* **34**, 499–457.

Shang Y.C. (1992) *The role of aquaculture in the world fisheries*. Presented at the World Fisheries Congress, May 3–8, 1992, Athens, Greece, 30pp.

Sokal R.R. & Rohlf F.J. (1981) *Biometry*. Stony Brook, New York, USA.

Wu Y.V., Tudor K.W. & Brown P.B. (1999) Substitution of plant proteins and bone meal for fishmeal in diets of Nile tilapia. *North American Journal of Aquaculture* **61**, 58–63.

