POLYCULTURE OF GRASS CARP AND NILE TILAPIA WITH NAPIER GRASS AS THE SOLE NUTRIENT INPUT IN THE SUBTROPICAL CLIMATE OF NEPAL

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ABSTRACT

An experiment was conducted in outdoor concrete tanks (4.9 × 4.8 × 1.75 m) at the Institute of Agriculture and Animal Science of Nepal to evaluate the growth of grass carp and Nile tilapia fed with napier grass in polyculture, to evaluate water quality regimes of pond water, to determine the compositions of foods consumed by Nile tilapia, and to determine the optimal ratio of grass carp to Nile tilapia in polyculture.

The experiment was laid out in a completely randomized design with five treatments replicated thrice. Five stocking ratios of grass carp to Nile tilapia were tested: (A) grass carp only at 0.5 fish m^{-2} (control); (B) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 0.25 fish m^{-2}; (C) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 0.5 fish m^{-2}; (D) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 1 fish m^{-2}; (E) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 2 fish m^{-2}. Grass carp fingerlings (39.3 ± 2.3 to 46.6 ± 0.2 g) (mean ± SE) were stocked on 26 May 2002, while mixed-sex Nile tilapia fingerlings (9.0 ± 0.1 to 10.0 ± 0.2 g) were stocked six days later. Chopped fresh napier grass leaf was the sole nutrient input and provided ad libitum daily in the morning.

Mass mortality of grass carp (100%) occurred in all three replications of the monoculture (Treatment A) during the twelfth week (81 days) of the experimental period. Survival of grass carp was not significantly different among the polyculture treatments (Treatments B through E) ($P > 0.05$). At harvest, the mean weights and daily weight gains of grass carp in Treatment C were significantly greater than those in other polyculture treatments ($P < 0.05$). Net and gross fish yields were highest in Treatment C, intermediate in Treatments D and E, and lowest in Treatment B ($P < 0.05$). Survival of Nile tilapia was 100% in all polyculture treatments. Mean weights of Nile tilapia at harvest decreased linearly with increased stocking densities, while net fish yields of Nile tilapia increased linearly ($P < 0.05$). The combined net and gross fish yields of grass carp plus both adult and recruited Nile tilapia were not significantly different among all polyculture treatments ($P > 0.05$). There were no significant differences in all measured water quality parameters ($P > 0.05$). Gut analyses showed that grass carp consumed only grass while Nile tilapia consumed various food items including feces of grass carp.

The optimal density ratio of grass carp to Nile tilapia fed napier grass is 1:1 in the present study, i.e., grass carp at 0.5 fish m^{-2} plus Nile tilapia at 0.5 fish m^{-2}. Addition of Nile tilapia to the grass carp tanks fed napier grass as the sole nutrient input can efficiently utilize available resources, reuse wastes derived from grass carp, and augment total fish production. The present study has also demonstrated that grass carp–Nile tilapia polyculture fed napier grass is a low-cost alternative aquaculture system for small-scale, poor farmers.

INTRODUCTION

Grass carp (Ctenopharyngodon idella), an herbivorous species, is commonly cultured in many parts of the world, especially in east Asia. In China, polyculture of grass carp with other species of different feeding habits is traditionally practiced, where grass carp consume low-value vegetative waste and increase natural food production in the pond by nutrient recycling and fecal production (Yang et al., 1990; Li and Mathias, 1994). This effectiveness is depicted in the Chinese saying "one grass carp raises three silver carps." It is reported that a 5:1 stocking ratio by weight is most suitable for grass carp and filter-feeding species in a polyculture

Table 1. Stocking and harvest size, survival, growth, and net fish yield (NFY) of grass carp and Nile tilapia in monoculture and polyculture tanks fed with fresh chopped napier grass during the 188-day culture period. Mean values with different superscript letters in the same row were significantly different ($P < 0.05$).

Item	Treatments				
	A	*B*	*C*	*D*	*E*
GRASS CARP					
Initial Mean Weight (g per fish)	39.3 ± 2.3	44.2 ± 0.5 ^{a}	44.2 ± 0.1^{a}	45.3 ± 0.3^{ab}	46.6 ± 0.2^{b}
Initial Total Weight (kg per tank)	0.47 ± 0.03	0.53 ± 0.01^{a}	0.53 ± 0.00^{a}	0.54 ± 0.00^{ab}	0.56 ± 0.01^{b}
Final Mean Weight (g per fish)	—	471.0 ± 27.7^{a}	634.9 ± 28.4^{b}	490.0 ± 17.6^{a}	452.9 ± 14.7^{a}
Final Total Weight (kg per tank)	—	4.51 ± 0.25^{a}	6.10 ± 0.42^{b}	4.87 ± 0.44^{ab}	4.98 ± 0.46^{ab}
Survival (%)	0	80.6 ± 7.3^{a}	80.6 ± 7.3^{a}	83.3 ± 9.6^{a}	91.7 ± 8.3^{a}
Daily Weight Gain (g per fish d^{-1})	—	2.27 ± 0.14^{a}	3.14 ± 0.15^{b}	2.37 ± 0.05^{a}	2.16 ± 0.08^{a}
NFY (kg ha^{-1} d^{-1})	—	9.00 ± 0.56^{a}	12.60 ± 0.95^{b}	9.78 ± 1.00^{ab}	9.99 ± 1.04^{ab}
GFY (kg ha^{-1} d^{-1})	—	10.20 ± 0.56^{a}	13.80 ± 0.95^{b}	11.01 ± 1.00^{ab}	11.25 ± 1.04^{ab}
ADULT NILE TILAPIA					
Initial Mean Weight (g per fish)	—	9.4 ± 0.1^{a}	10.0 ± 0.3^{a}	9.3 ± 0.3^{a}	9.0 ± 0.1^{a}
Initial Total Weight (kg per tank)	—	0.06 ± 0.00^{a}	0.12 ± 0.00^{b}	0.22 ± 0.01^{c}	0.43 ± 0.01^{d}
Final Mean Weight (g per fish)	—	91.4 ± 4.5^{a}	82.1 ± 3.6^{a}	56.1 ± 1.2^{b}	44.0 ± 1.7^{c}
Final Total Weight (kg per tank)	—	0.55 ± 0.03^{a}	0.98 ± 0.04^{b}	1.35 ± 0.03^{c}	2.11 ± 0.08^{d}
Survival (%)	—	100 ± 0^{a}	100 ± 0^{a}	100 ± 0^{a}	100 ± 0^{a}
Daily Weight Gain (g per fish d^{-1})	—	0.46 ± 0.02^{a}	0.40 ± 0.02^{a}	0.26 ± 0.01^{b}	0.19 ± 0.01^{c}
NFY (kg ha^{-1} d^{-1})	—	1.15 ± 0.06^{a}	2.02 ± 0.10^{b}	2.62 ± 0.07^{c}	3.92 ± 0.20^{d}
GFY (kg ha^{-1} d^{-1})	—	1.28 ± 0.06^{a}	2.30 ± 0.10^{b}	3.15 ± 0.07^{c}	4.93 ± 0.19^{d}
RECRUIT NILE TILAPIA					
Mean Number	—	248 ± 19^{a}	524 ± 99^{a}	353 ± 70^{a}	332 ± 7^{a}
Mean Weight (g per fish)	—	13.4 ± 1.5^{a}	6.5 ± 0.8^{b}	7.1 ± 1.1^{b}	6.2 ± 1.3^{b}
Mean Total Weight (kg per tank)	—	3.29 ± 0.12^{a}	3.46 ± 0.83^{a}	2.35 ± 0.08^{a}	2.04 ± 0.40^{a}
Fish yield (kg ha^{-1} d^{-1})	—	7.68 ± 0.29^{a}	8.09 ± 1.95^{a}	5.50 ± 0.18^{a}	4.76 ± 0.93^{a}
COMBINED FISH YIELDS (Not Including Nile Tilapia Recruits)					
NFY(kg ha^{-1} d^{-1})	—	10.98 ± 0.65^{a}	14.62 ± 0.99^{a}	12.40 ± 0.98^{a}	13.91 ± 0.96^{a}
GFY(kg ha^{-1} d^{-1})	—	12.31 ± 0.67^{a}	16.10 ± 0.99^{a}	14.15 ± 0.99^{a}	16.18 ± 0.96^{a}
TOTAL FISH YIELDS (Including Nile Tilapia Recruits)					
NFY(kg ha^{-1} d^{-1})	—	17.49 ± 0.76^{a}	22.71 ± 2.37^{a}	17.90 ± 1.08^{a}	18.66 ± 1.76^{a}
GFY(kg ha^{-1} d^{-1})	—	18.82 ± 0.76^{a}	24.19 ± 2.37^{a}	19.65 ± 1.09^{a}	20.94 ± 1.77^{a}

system consisting of silver carp, Hypophthalmichthys molitrix; bighead carp, Aristichthys nobilis; and common carp, Cyprinus carpio (Yang et al., 1990). However, as grass carp are known to feed on a wide variety of plants, the quantity and quality of natural food production derived from recycling of grass carp wastes depend largely on the type and input of forage provided.

In Nepal, pond fish culture is mostly conducted in the southern subtropical region, where water temperature is between 15 and 20°C during the winter period from mid-December to mid-February (Shrestha, 1999). Polyculture of herbivorous carps is the common practice in Nepal. The major constraints for the small-scale resource-poor farmers are fish feeds and chemical fertilizers, which are expensive and unavailable, while livestock manure is traditionally used for land crops (Shrestha and Yadav, 1998; Shrestha, 1999). Exploration of easily available or easily grown plant material that is not used in human food production is a prime need to solve the problems of these fish farmers. Napier grass (Pennisetum purpureum) is high yielding, perennial, and tropical (Humprey, 1978; Edwards, 1982). It is accepted by grass carp and can produce a reasonable yield (Venkatesh and Shetty, 1978; Shrestha and Yadav, 1998; Shrestha, 1999). As in Chinese polyculture systems, a major portion of plant biomass consumed by grass carp returns to the pond as organic manure, which stimulates plankton production for other planktivorous fish in the same pond (Woynarovich, 1975).

Recently, Nile tilapia (Oreochromis niloticus) was introduced to Nepal and has been cultured on an experimental scale (Shrestha and Bhujel, 1999). Nile tilapia is an excellent candidate to be polycultured with grass carp to utilize the natural foods derived from plants fed to grass carp. Polyculture of grass carp and Nile tilapia may have an additional advantage due to the fact that large grass carp could prey to some extent on tilapia fry spawned in the pond (Spataru and Hepher, 1977). To fully utilize available resources, this system should be tested and the ratio of grass carp to Nile tilapia should be evaluated in polyculture ponds.

The objectives of this study were to:

1) Evaluate the growth of grass carp and Nile tilapia fed with napier grass in polyculture;
2) Evaluate water quality regimes of pond water;
3) Determine the composition of foods consumed by Nile tilapia; and
4) Determine the optimal ratio of grass carp to Nile tilapia in polyculture.

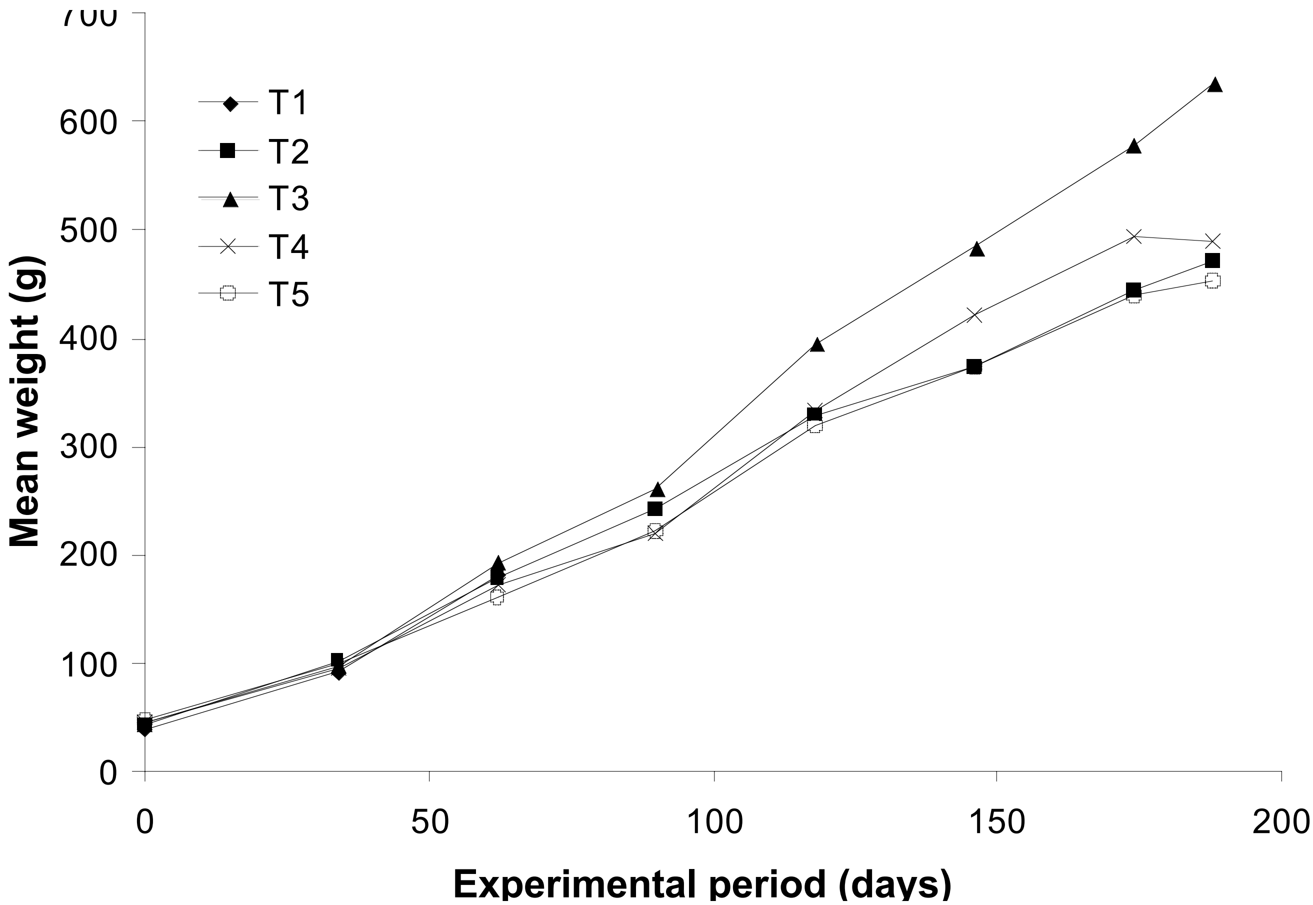


Figure 1. Growth of grass carp fed napier grass in polyculture tanks over the 188-day experimental period.

METHODS AND MATERIALS

The experiment was conducted in outdoor concrete tanks (4.9 × 4.8 × 1.75 m) at the Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal. The tanks were filled with tap water to 1.5 m, and tap water was added weekly to compensate for evaporation losses. The experiment was laid out in a completely randomized design with five treatments replicated thrice. Five stocking ratios of grass carp to Nile tilapia were tested: (A) grass carp only at 0.5 fish m^{-2} (control); (B) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 0.25 fish m^{-2}; (C) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 0.5 fish m^{-2}; (D) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 1 fish m^{-2}; (E) grass carp at 0.5 fish m^{-2} plus Nile tilapia at 2 fish m^{-2}. Grass carp fingerlings approximately 40 g in size were stocked on 26 May 2002. Mixed-sex Nile tilapia fingerlings about 10 g in size were stocked six days later (1 June 2002). The total growing periods were 188 and 182 days for grass carp and Nile tilapia, respectively.

Fresh napier grass leaf was chopped and provided *ad libitum* daily in the morning as the sole nutrient input. The daily grass consumption was calculated by subtracting the leftover grass from the initial weight of grass provided in the previous morning. Calculations were made on dry weight basis by obtaining moisture content of fresh and leftover grass.

Fresh napier grass was analyzed for proximate composition in two batches, one at the first half of the experimental period and the other at the second half (AOAC, 1980). Three replicates were done for each batch. Similarly, two batches with three replicates of fresh grass carp feces were also analyzed for proximate composition (AOAC, 1980).

Weekly and biweekly measurements of water quality parameters were conducted from 0600 to 0800 h starting 27 May 2002. Water temperature, dissolved oxygen (DO), pH, and Secchi disk depths were measured weekly *in situ* using DO meter (YSI meter model 50B), pH meter (ACT pocket meter), and Secchi disk, respectively. Column water samples were taken biweekly from the tanks by plastic column sampler for analyses of total alkalinity, total ammonium nitrogen (TAN), nitrite-nitrogen (nitrite-N), soluble reactive phosphorus (SRP), and chlorophyll *a* (APHA, 1985). Gross primary productivity (GPP) and net primary productivity (NPP) were estimated biweekly by three-point DO curve method (Hall and Moll, 1975). Monthly diurnal fluctuation of temperature and DO was measured by using DO meter (YSI meter model 50B) at five different depths (15, 45, 75, 105, and 145 cm depth) at 0600, 1000, 1400, 1800, and 2200 h, as well as 0200 and 0600 h of the following day.

Monthly growth measurements of grass carp and Nile tilapia were done by randomly sampling and bulk-weighing at least 25% of both grass carp and Nile tilapia. Net fish yield (NFY) was calculated as g m^{-2} d^{-1} by dividing the difference between total initial and final fish biomass per tank by the surface area of the tank (24 m^2) and the experimental grow out period (188 and 182 days for grass carp and Nile tilapia, respectively). Based on the quantity of napier grass fed and

NFY, food conversion ratio (FCR) of grass carp and grass carp and tilapia combined were calculated by dividing the amount of total grass consumed by the NFY. First batches of tilapia recruits were removed and recorded from all the tanks by netting during the end of the thirteenth week of the experiment. At the end of experiment, final total number and weight were recorded.

Three grass carp and seven Nile tilapia of different sizes were randomly selected at harvest for gut content analysis. Gut was analyzed under compound microscope to find out the composition of the diet.

Data were analyzed statistically by ANOVA, repeated measurement ANOVA, ANCOVA, and regression analysis (Steel and Torrie, 1980) using SPSS (version 10.0) statistical software package (SPSS Inc., Chicago). Differences were considered significant at an alpha level of 0.05. All means were given with ± 1 standard error.

Results

Mass mortality of grass carp (100%) occurred in all three replicates of Treatment A (monoculture) during the twelfth week (81 days) of the experimental period. Survival of grass carp was not significantly different among the polyculture treatments (Treatments B through E) ($P > 0.05$; Table 1). There were no significant differences in growth of grass carp among all treatments before mass mortality occurred ($P > 0.05$; Figure 1). At harvest, the mean weights and daily weight gains of grass carp in Treatment C were significantly greater than those in other polyculture treatments ($P < 0.05$), among which there were no significant differences ($P > 0.05$; Table 1). Net and gross fish yields of grass carp were highest in Treatment C, intermediate in Treatments D and E, and lowest in Treatment B ($P < 0.05$; Table 1).

In one replicate of Treatment B, Nile tilapia growth was much faster than that in the other two replicates. Sex examination at the end of the experiment indicated five out of six Nile tilapia were male while the sex ratios in other tanks were nearly 1:1. Therefore, this replication was excluded in all following analyses. Survival of Nile tilapia was 100% in all polyculture treatments (Table 1). Nile tilapia grew steadily during the entire culture period (Figure 2). Mean weights at harvest and daily weight gains of Nile tilapia were highest in Treatments B and C, intermediate in Treatment D, and lowest in Treatment E ($P < 0.05$; Table 1). Mean weights of Nile tilapia at harvest decreased linearly with increased stocking density of Nile tilapia (y = 92.6–26.3x, $r = 0.92$, n = 10, $P < 0.01$; Figure 3), while net yield of Nile tilapia increased linearly (y = 1.07 + 1.39x, $r = 0.97$, n = 10, $P < 0.01$; Figure 3). Mixed-sex Nile tilapia reproduced in tanks during the experimental period. The mean number and yields of Nile tilapia recruits were not significantly different among polyculture treatments ($P > 0.05$), while mean weight of the recruits was significantly greater in Treatment B than in other treatments ($P < 0.05$), among which there were no significant differences ($P > 0.05$; Table 1).

The combined net and gross fish yields of grass carp and adult

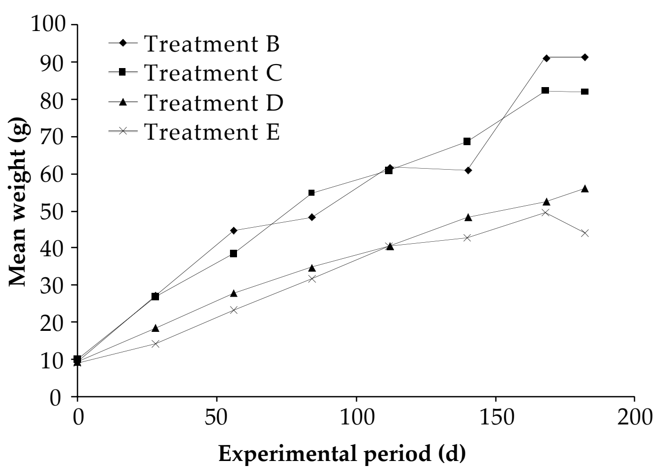


Figure 2. Growth of mixed-sex Nile tilapia in polyculture tanks fed napier grass over the 188-day experimental period.

Table 2. Proximate composition (%) of fresh napier grass and fresh feces of grass carp.

Parameters	Fresh Napier Grass	Fresh Feces of Grass Carp
Dry Matter	18.6 ± 1.5	6.3 ± 0.2
Crude Protein	9.2 ± 0.4	5.2 ± 0.4
Ether Extract	2.0 ± 0.3	1.4 ± 0.4
Crude Fiber	28.6 ± 0.4	36.0 ± 0.6
Ash	10.0 ± 0.2	8.2 ± 0.4
Nitrogen Free Extract	50.2 ± 0.7	49.2 ± 0.4

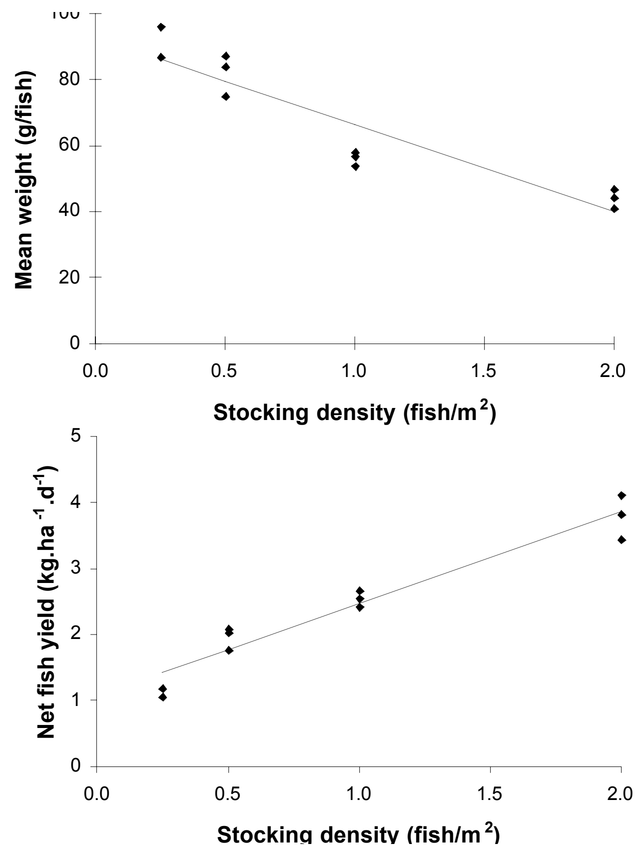
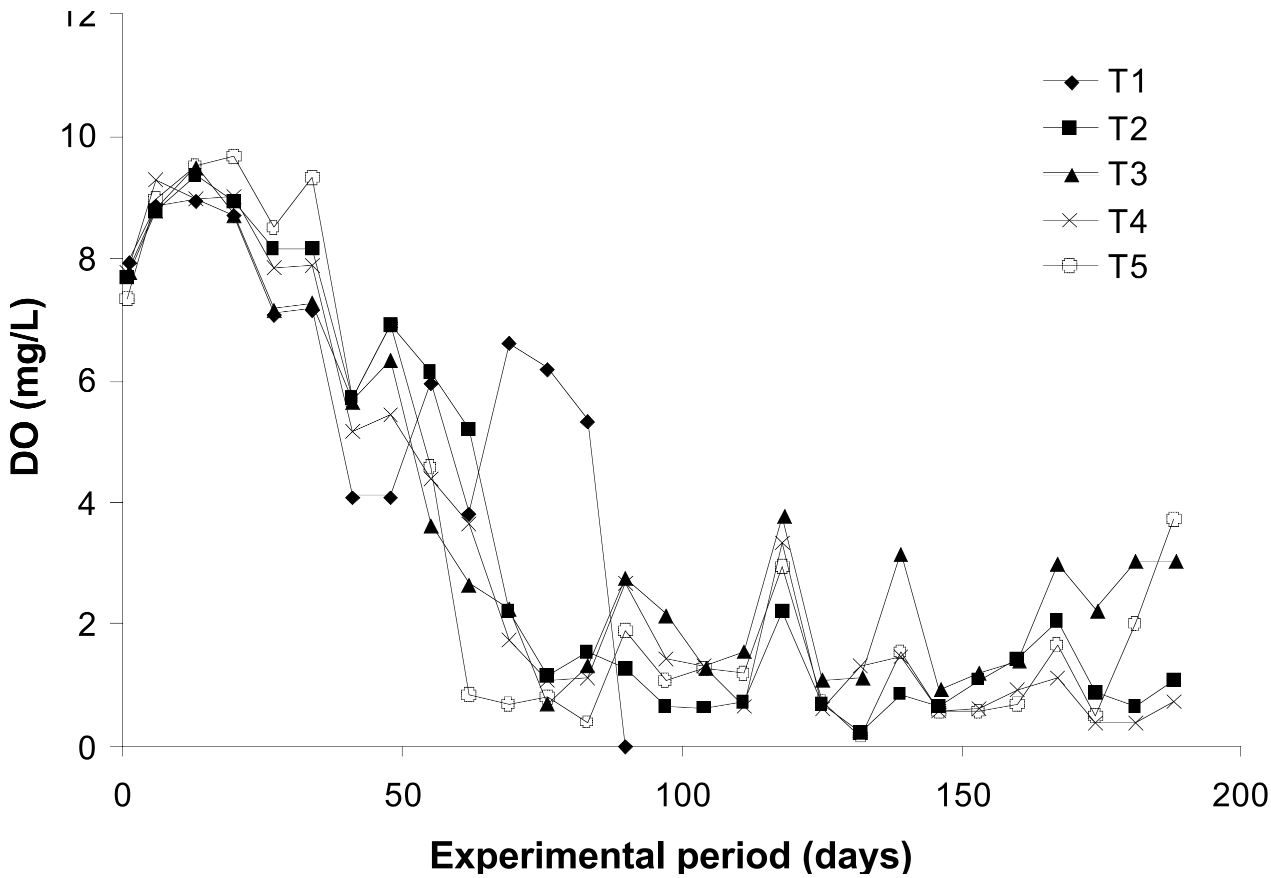


Figure 3. Relationship between stocking density, growth, and net yield of Nile tilapia in polyculture tanks fed napier grass over the 188-day experimental period.

Table 3. Food conversion ratio of napier grass for grass carp, grass carp plus adult Nile tilapia, and grass carp plus both adult and recruited Nile tilapia on fresh weight (FW) and dry weight (DW) bases in polyculture treatments.

Group	**FCR**			
	B	*C*	*D*	*E*
Grass Carp (FW Basis)	37.7 ± 1.8	30.6 ± 1.7	39.1 ± 3.9	35.8 ± 2.3
Grass Carp (DW Basis)	7.2 ± 0.3	5.8 ± 0.3	7.4 ± 0.7	6.8 ± 0.4
Grass Carp + Adult Nile Tilapia (FW Basis)	31.1 ± 2.1	26.4 ± 1.3	30.7 ± 2.3	25.7 ± 0.9
Grass Carp + Adult Nile Tilapia (DW Basis)	5.9 ± 0.4	5.0 ± 0.2	5.9 ± 0.4	4.9 ± 0.2
Grass Carp + Adult and Recruited Nile Tilapia (FW Basis)	19.6 ± 0.6	17.4 ± 1.6	21.4 ± 1.1	19.4 ± 0.9
Grass Carp + Adult and Recruited Nile Tilapia (DW Basis)	3.7 ± 0.1	3.3 ± 0.3	4.1 ± 0.2	3.7 ± 0.2

Table 4. Gut contents of grass carp and Nile tilapia in the culture system fed napier grass. C = commonly observed; F = frequently observed; R = rarely observed.



Nile tilapia were not significantly different among all polyculture treatments ($P > 0.05$; Table 1). When Nile tilapia recruits were included, there were also no significant differences in total net and gross fish yields among all polyculture treatments ($P > 0.05$; Table 1).

Proximate composition of fresh napier grass and fresh grass carp feces indicated that a large amount of grass eaten by grass carp was excreted as nutrient-rich wastes (Table 2). There were no significant differences in FCR on either a dry or fresh weight basis for grass carp, grass carp plus adult Nile tilapia, and grass carp plus both adult and recruited Nile tilapia among all polyculture treatments ($P > 0.05$; Table 3). Gut analyses showed that grass carp consumed only grass while Nile tilapia consumed many food items including feces of grass carp (Table 4).

Repeated ANOVA showed that there were no significant differences in any water quality parameters among polyculture treatments ($P > 0.05$; Table 5). DO concentrations in most of the tanks were consistently low during weeks 10 to 12 when mass mortality occurred for grass carp in all three replicates of the monoculture treatment (Figure 4). Water temperature decreased continuously from August and reached about 20° C at the end of the experiment. Secchi disk depth gradually declined throughout the experimental period (Figure 5). Total ammonium nitrogen had cyclic high and low values (Figure 6), while nitrite-nitrogen was not detected in most tanks during initial periods of experiment. Total alkalinity increased gradually throughout the experimental period, from an average of

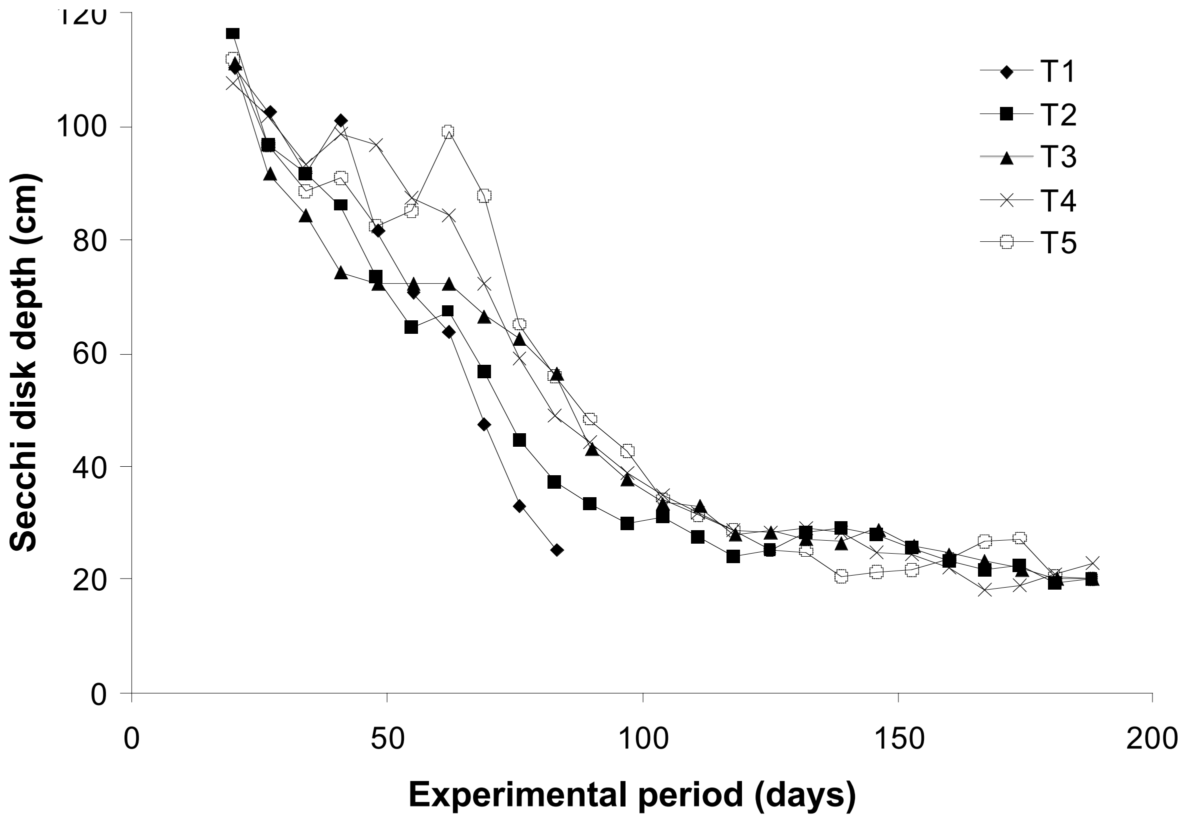


Figure 5. Changes of Secchi disk depth in polyculture tanks fed napier grass over the 188-day experimental period.

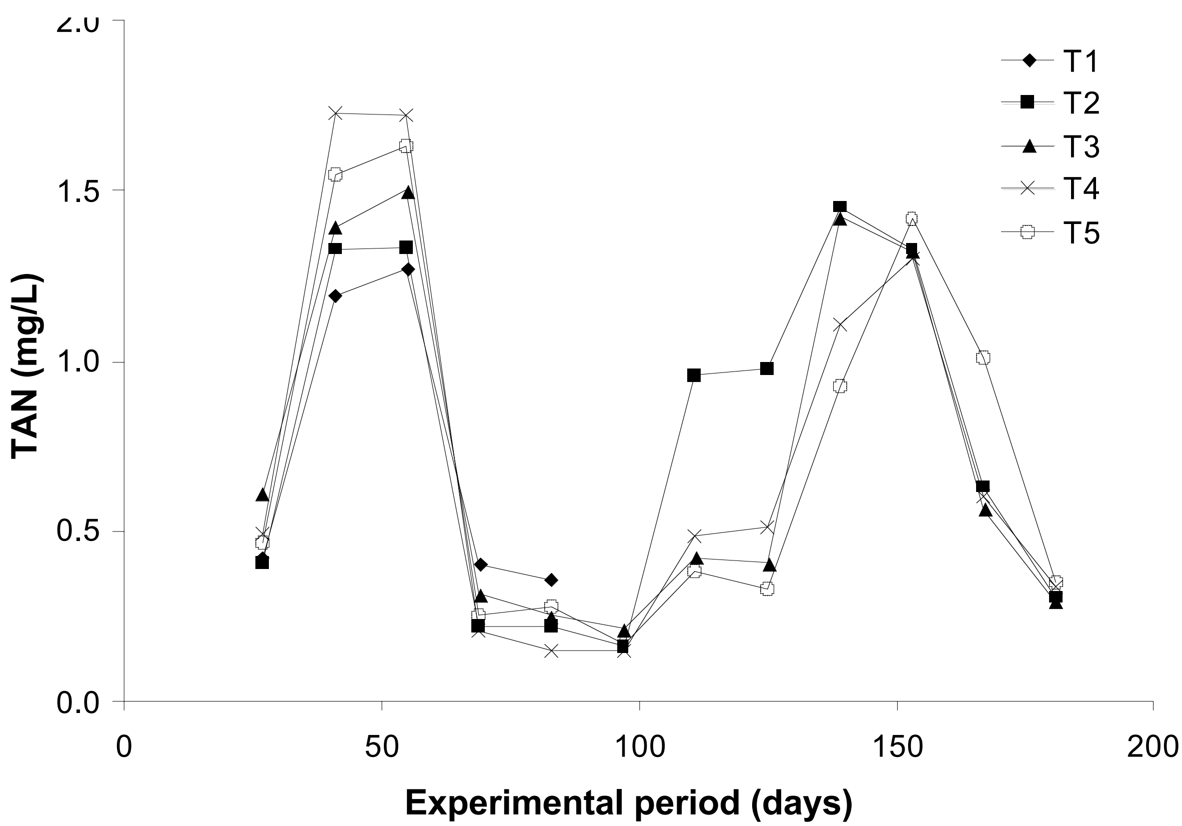


Figure 6. Fluctuations of total ammonium nitrogen (TAN) in polyculture tanks fed napier grass over the 188-day experimental period.

Table 4. Gut contents of grass carp and Nile tilapia in the culture system fed napier grass. C = commonly observed; F = frequently observed; R = rarely observed.

Species	Gut Contents	Frequency
GRASS CARP	Napier Grass	All
NILE TILAPIA	*Anabaena*	C
	Oscillatoria	C
	Detritus	C
	Grass Carp Feces	C
	Cosmarium	F
	Euglena	F
	Brachionus	F
	Moina	R
	Daphnia	R
	Cyclops	R

73 mg l^{-1} as $CaCO_3$ in the third week to 123 mg l^{-1} as $CaCO_3$ in the last week of the experiment (Figure 7). This level of alkalinity produced well-buffered water and, as a consequence, fluctuations in pH were small.

DISCUSSION

The modern package of practices for scientific aquaculture provides high-cost technology, and economic factors become major constraints in this type of farming, especially to small-scale and resource-poor farmers in many developing countries including Nepal. Chopped napier grass contained 9.2% crude protein and 28.6% crude fiber (Table 2), and its perennial nature, hardiness, and low cost of production are the major advantages for small-scale resource-poor farmers. Production (NFY) of grass carp in different combinations with Nile tilapia ranged from 9.00 to 12.60 kg ha^{-1} d^{-1} (Table 1). This production of grass carp was higher than the 8.7 kg ha^{-1} d^{-1} reported by Venkatesh and Shetty (1978) when grass carp were fed hybrid napier (*P. purpureum* × *P. typhoideum*) and stocked at 0.5 fish m^{-2}. Similar yields to this study were reported for grass carp in monoculture and in polyculture fed with napier grass and stocked at 1 fish m^{-2} (Shrestha and Yadav, 1998; Shrestha, 1999). The growth studies carried out in India and other countries have indicated that daily weight gain of grass carp varies from 1.7 to 14.7 g d^{-1} (Chander and Madan, 1984). Mean daily weight gains recorded in the present study (2.16 to 3.14 g d^{-1}) are within the above range (Table 1). However, growth and net yield of Nile tilapia in the present study were lower (0.19 to 0.46 g per fish d^{-1} and 1.15 to 3.92 kg ha^{-1} d^{-1}, respectively) (Table 1) than those commonly achieved in fertilized or manured ponds (Lin et al., 1997). This was obviously caused by the early breeding of mixed-sex Nile tilapia used in the present study, food competition due to recruits, and lower water temperature. The yield ratios of adult to recruited Nile tilapia ranged from 1:1.21 to 1:6.68.

FCR of napier grass for grass carp reported in different studies varies from 17.3 to 72.1 (Hickling, 1960; Venkatesh and Shetty, 1978; Shrestha and Yadav, 1998; Shrestha, 1999). FCR of grass carp or grass carp plus Nile tilapia in the present study are comparable to these results. Examination of grass carp stomachs showed that only napier grass was consumed. Similar results were reported by Lewis (1978) on the examination of gut content of grass carp stocked in the presence of dense populations of fingerling catfish and hybrid sunfish. The author found no evidence that the grass carp was predacious, even on small fingerling fishes. These observations confirm that when the

Table 5. Mean values and ranges of water quality parameters measured weekly and biweekly during the experimental period. Values in Treatment A represent the mean values of the measurements until the mass mortality of grass carp.

Parameter	Treatments				
	A	*B*	*C*	*D*	*E*
Temperature (C)	30.7±0.22 (26.8–32.9)	28.1±0.08 (19.9–33.2)	28.8±0.03 (21–33)	28.8±0.08 (21–33.2)	28.8±0.09 (21.3–33.2)
pH	8.1±0.03 (7.8–8.3)	8.2±0.03 (7.6–9.2)	8.1±0.04 (7.3–9.1)	8.1±0.02 (7.6–9.1)	8.1±0.00 (7.5–9.3)
DO (mg l^{-1})	6.6±0.1 (0.1–9.9)	3.4±0.2 (0.1–9.7)	3.7±0.5 (0.2–9.9)	3.2±0.1 (0.1–10.4)	3.3±0.1 (0.1–9.9)
Secchi Depth (cm)	75±6.0 (21–120)	45±4.3 (13–120)	48±1.5 (18–112)	51±0.3 (10–115)	51±0.2 (12–115)
Alkalinity (mg l^{-1})	82±3.1 (69–97)	101±2.8 (60–133)	104±2.5 (63–143)	99±1.4 (64–133)	102±0.1 (62.2–135)
TAN (mg l^{-1})	0.73±0.06 (0.30–1.50)	0.78±0.01 (0.14–2.00)	0.73±0.02 (0.13–1.97)	0.73±0.04 (0.14–2.07)	0.73±0.04 (0.15–1.82)
Nitrite-N (mg l^{-1})	0.000±0.000 (0.000)	0.001±0.000 (0.000–0.002)	0.001±0.000 (0.000–0.002)	0.001±0.000 (0.000–0.002)	0.001±0.000 (0.000–0.002)
SRP (mg l^{-1})	0.02±0.001 (0.01–0.05)	0.08±0.004 (0.01–0.13)	0.08±0.001 (0.01–0.13)	0.08±0.004 (0.01–0.14)	0.10±0.007 (0.01–0.15)
NPP (g C m^{-2} 12 h^{-1})	3.5±0.34 (0.5–3.3)	2.0±0.20 (0.3–3.3)	1.6±0.05 (0.2–3.1)	1.8±0.03 (0.2–3.4)	1.8±0.01 (0.4–3.4)
GPP (g C m^{-2} 12 h^{-1})	5.3±0.63 (1.0–6.6)	4.1±0.5 (0.5–6.5)	3.2±0.2 (0.6–6.4)	3.5±0.1 (0.4–6.9)	3.6±0.02 (0.6–7.0)
Chlorophyll *a* (mg m^{-3})	79±16.6 (3–209)	144±18.6 (8–393)	149±6.3 (3–380)	137±5.6 (24–329)	139±10.0 (22–353)

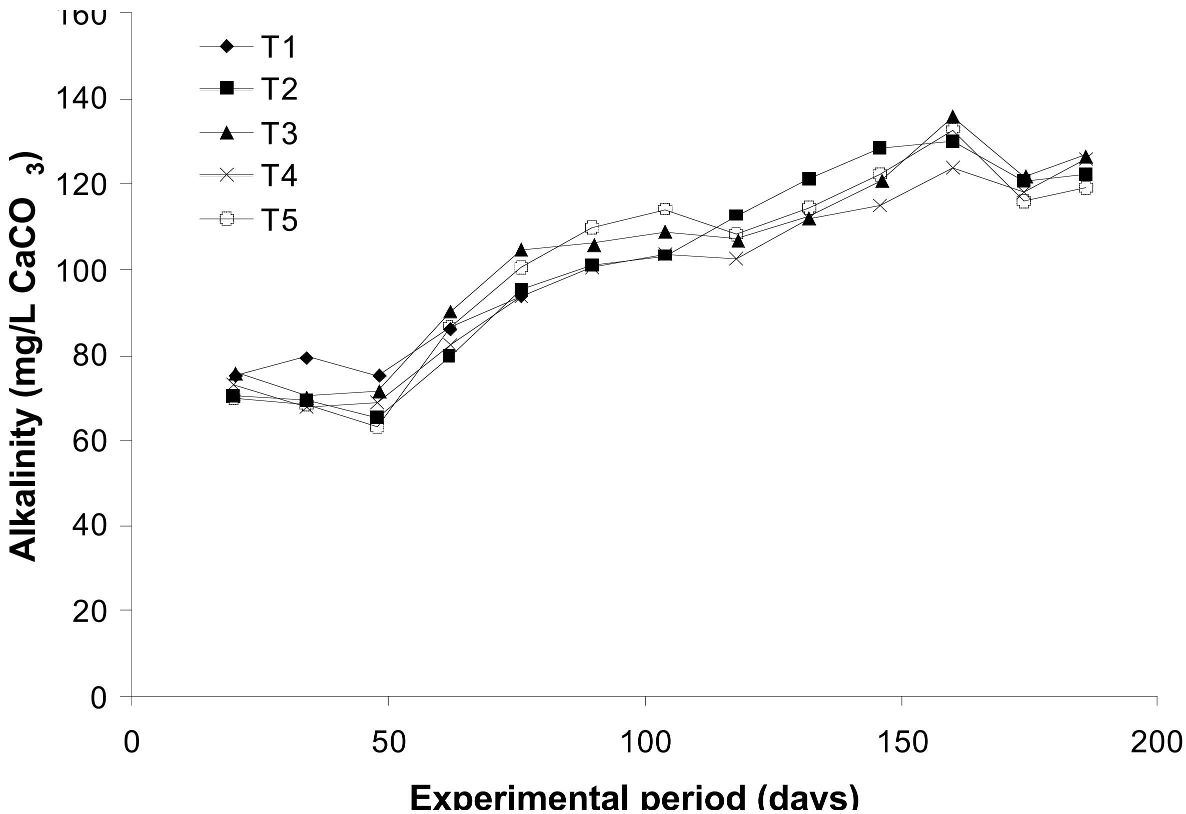


Figure 7. Changes of total alkalinity in polyculture tanks fed napier grass over the 188-day experimental period.

supply of food is sufficient, grass carp do not switch to other natural foods as proposed by Tang (1970). Similarly, the gut contents of Nile tilapia exhibited great plasticity. Presence of large amount of napier grass in the gut of Nile tilapia suggests that Nile tilapia can directly feed on napier grass and/or feces of grass carp. The results of the present study clearly show that Nile tilapia consumed napier grass and/or grass carp feces along with other natural foods such as phytoplankton, zooplankton, and detritus. The results of the present study support the suggestion by Chikafumbwa (1996) that napier grass can be used as a low-cost feed or fertilizer input for tilapia aquaculture.

Most water quality parameters at each sampling date were within a suitable range for fish production. However, DO became low in these ponds and affected the culture system throughout the second half of the experiment. The greater load of grass carp wastes in ponds caused lower levels of DO, and higher levels of TAN, due probably to the decomposition of grass carp wastes. However, presence of tilapia reduced the severity of low oxygen because tilapia consumed detritus and algae, reducing oxygen demand and allowing grass carp to survive.

Mass mortality of grass carp in all three replicates of the monoculture treatment coincided with low DO (0.1 mg l^{-1}) for long periods (Figure 4). This suggests that plankton feeders are necessary to maintain balanced ponds with grass carp. Chikafumbwa (1996) suggested that the application of napier grass alone above 50 kg dry matter ha^{-1} d^{-1} degraded water quality and decreased fish growth and production. Similar results have been reported by Shrestha and Yadav (1998) and Shrestha (1999) in grass carp monoculture fed with napier grass. Results of the present study show that, despite higher stocking densities in polyculture systems, water quality was less of a problem compared to the monoculture system. This suggests that monoculture of grass carp fed with a large amount of napier grass is risky in stagnant water.

The present study showed that the optimal ratio of grass carp to Nile tilapia in polyculture fed napier grass was 1:1 in these pond systems, i.e., grass carp at 0.5 fish m^{-2} plus Nile tilapia at 0.5 fish m^{-2}. Nile tilapia added to grass carp tanks fed napier grass as the sole nutrient input can efficiently utilize available resources, reuse wastes derived from grass carp, and augment total fish production. Grass carp–Nile tilapia polyculture with napier grass is a low-cost alternative aquaculture system for small-scale, poor farmers. However, the feeding rate of napier grass and stocking density of grass carp should be further studied.

ANTICIPATED BENEFITS

Grass carp–Nile tilapia polyculture with napier grass is a low-cost alternative strategy to the culture of grass carp by small-scale farmers. It will not only apply to Nepalese systems but may also benefit fish culturists in many other countries where grass carp and Nile tilapia are commonly cultured.

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Literature Cited

APHA, 1985. Standard Methods for the Examination of Water and Wastewater, Sixteenth Edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC, 1,268 pp.

AOAC, 1980. Official Methods of Analysis of the Association of Official Analytical Chemists International, Thirteenth Edition. Association of Official Analytical Chemists, Washington, DC, 1,018 pp.

Chander, J. and M.L. Madan, 1984. Studies on the growth of grass carp *Ctenopharyngodon idella* (Val.) fed on cattle yard fodder waste under composite fish culture. J. Inland Fish. Soc. India, 16:1–6.

Chikafumbwa, F.J.K., 1996. The use of napier grass *(Pennisetum purpureum)* and maize (*Zea mays*) bran as low-cost tilapia aquaculture inputs. Aquaculture, 146:101–107.

Edwards, P., 1982. Reports of Consultancy at the Regional Lead Centre in China for Integrated Fish Farming. NACA, Bangkok, Thailand, 104 pp.

Hall, C.A.S. and R. Moll, 1975. Methods of assessing aquatic primary productivity. In: H. Lieth and R.H. Whittaker (Editors), Primary Productivity of the Bioshere. Springer-Verlag, New York, pp. 19–53.

Hickling, C.F., 1960. Observation on the growth rate of the Chinese grass carp, *Ctenopharyngodon idellus,* C. and V. Malay. Agric. J., 43(1): 49–53.

Humprey, L.R., 1978. Tropical Pastures and Fodder Crops. Longman Group Limited, Longman House, England, 145 pp.

Lewis, W.M., 1978. Observations on the grass carp in ponds containing fingerling channel catfish and hybrid sunfish. Trans. Am. Fish. Soc., 107(1):146–152.

Li, S.F. and J.A. Mathias (Editors), 1994. Freshwater Fish Culture in China: Principles and Practices. Elsevier, Amsterdam, 445 pp.

Lin, C.K., D.R. Teichert-Coddington, B.W. Green, and K.L. Veverica, 1997. Fertilization regimes. In: H.S. Egna and C.E. Boyd (Editors), Dynamics of Pond Aquaculture. CRC Press, Boca Raton, Florida, pp. 73–107.

Shrestha, M.K., 1999. Summer and winter growth of grass carp (*Ctenopharyngodon idella)* in a polyculture fed with napier grass *(Pennisetum purpureum)* in the subtropical climate of Nepal. J. Aqua. Trop., 14(1):57–64.

Shrestha, M.K. and C.N.R. Yadav, 1998. Feeding of napier *(Pennisetum purpureum*) to grass carp in polyculture: A sustainable fish culture practice for small farmers. Asian Fish. Sci., 11:287–294.

Shrestha, M.K. and R.C. Bhujel, 1999. A preliminary study in the Nile tilapia (*Oreochromis niloticus*) polyculture with common carp (*Cyprinus carpio*) fed with duckweed (*Spirodella*) in Nepal. Asian Fish. Sci., 12:83–89.

Spataru, P. and B. Hepher, 1977. Common carp predating on tilapia fry in high density polyculture fishpond system. Isr. J. Aquacult./ Bamidgeh,, 29:25–28.

Steele, R.G.D. and J.H. Torrie., 1980. Principles and Procedures of Statistics: A Biometrical Approach, Second Edition. McGraw-Hill, New York, 633 pp.

Tang, Y.A, 1970. Evaluation of balance between fishes and available fish foods in multispecies fish culture ponds in Taiwan. Trans. Am. Fish. Soc., 99(4):708–718.

Venkatesh, B. and H.P.C. Shetty, 1978. Studies on the growth rate of the grass carp *Ctenopharyngodon idella* (Valenciennes) fed on two aquatic weeds and a terrestrial grass. Aquaculture, 13:45–53.

Woynarovich, E., 1975. Elementary guide to fish culture in Nepal. Food and Agriculture Organization of the United Nations, Rome, 131 pp.

Yang, H.Z., Y.X. Fang, and Z.Y. Liu, 1990. The biological effects of grass carp (*Ctenopharyngodon idella*) on filter-feeding and omnivorous fish in polyculture. In: R. Hirano and I. Hanyu (Editors), Proceedings of the Second Asian Fisheries Forum, 17–22 April 1989, at Tokyo, Japan. Asian Fish. Soc., Manila, Philippines, pp. 197–200.

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