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 m x 4.8 m x 1.75 m) at the Institute of Agriculture and Animal Science (IAAS) 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: (1) grass carp only at 0.5 fish/m^2 (control); (2) grass carp at 0.5 fish/m^2 plus tilapia at 0.25 fish/m^2; (3) grass carp at 0.5 fish/m^2 plus tilapia at 0.5 fish/m^2; (4) grass carp at 0.5 fish/m^2 plus tilapia at 1 fish/m^2; and (5) grass carp at 0.5 fish/m^2 plus tilapia at 2 fish/m^2. Grass carp fingerlings (39.3±2.3 – 46.6±0.2 g) were stocked on 26 May 2002, while mixed-sex Nile tilapia fingerlings (9.0±0.1 – 10.0±0.2 g) were stocked 6 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 1) during the twelfth week (81 days) of the experimental period, however, survival of grass carp was not significantly different among the polyculture treatments (treatments 2 through 5) ($P > 0.05$). At harvest, the mean weights and daily weight gains of grass carp in treatment 3 were significantly greater than those in other polyculture treatments ($P < 0.05$). Net and gross fish yields were highest in treatment 3, intermediate in treatments 4 and 5, and lowest in treatment 2 ($P < 0.05$). Survival of Nile tilapia was 100% in all polyculture treatments. Mean weights of Nile tilapia at harvest decreased linearly with increased stocking densities of Nile tilapia, 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. Gut analyses showed that grass carp consumed grass only while Nile tilapia consumed diversified food items including feces of grass carp.

The present study has showed that the optimal ratio of grass carp to Nile tilapia in polyculture fed napier grass is 1:1, i.e., grass carp at 0.5 fish/m^2 plus Nile tilapia at 0.5 fish/m^2. The present study has indicated that the addition of Nile tilapia to the grass carp tanks fed napier grass as the sole nutrient input is a low-cost culture system, which can efficiently utilize available resources, reuse wastes derived from grass carp, augment total fish production.

Introduction

Grass carp (*Ctenopharyngodon idella*), an herbivorous species, is a commonly cultured species 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, whereas 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). The effectiveness is depicted in 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 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 pond water temperature falls between 15 and 20°C during 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 a high yielding perennial tropical grass (Humprey, 1978; Edwards, 1982) that 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 ponds (Woynarovich, 1975).

Recently, Nile tilapia (*Oreochromis niloticus*) was introduced to Nepal and has been cultured in 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 size grass carp can 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. Therefore, the purposes of this study were 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.

Materials and methods

The experiment was conducted in outdoor concrete tanks (4.9 m x 4.8 m x 1.75 m) at the Institute of Agriculture and Animal Science (IAAS), 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: (1) grass carp only at 0.5 fish/m^2 (control); (2) grass carp at 0.5 fish/m^2 plus tilapia at 0.25 fish/m^2; (3) grass carp at 0.5 fish/m^2 plus tilapia at 0.5 fish/m^2; (4) grass carp at 0.5 fish/m^2 plus tilapia at 1 fish/m^2; and (5) grass carp at 0.5 fish/m^2 plus tilapia at 2 fish/m^2. Grass carp fingerlings (39.3±2.3 – 46.6±0.2 g) were stocked on 26 May 2002, while mixed-sex Nile tilapia fingerlings (9.0±0.1 – 10.0±0.2 g) were stocked 6 days later (1 June 2002). The total growing periods were 188 and 182 days for grass carp and Nile tilapia, respectively.

Chopped fresh napier grass leaf was the sole nutrient input and provided *ad libitum* daily in the morning. 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.

Two batches of fresh napier grass, one at the first half and the other at the second half of the experimental period, with three replications in each batch, were analyzed for proximate composition (AOAC, 1980). Similarly, two batches of fresh grass carp feces, one at the middle and the other at the end of the experiment, with three replications in each batch, were analyzed for proximate composition (AOAC, 1980).

Weekly and biweekly measurements of water quality parameters were conducted at 6 am – 8 am starting from 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), chlorophyll *a* (APHA *et al*., 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, 2200, 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 taken randomly at harvest for gut content analysis. Gut was analyzed under compound microscope to find out the composition of feed fed by the fishes.

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 (S.E.).

Results

Mass mortality of grass carp (100%) occurred in all three replications of the monoculture (treatment 1) during the twelfth week (81 days) of the experimental period, however, survival of grass carp was not significantly different among the polyculture treatments (treatments 2 through 5) ($P > 0.05$; Table 1). There were no significant differences in the growth of grass carp among all treatments before the mass mortality occurred ($P > 0.05$; Figure 1). At harvest, the mean weights and daily weight gains of grass carp in treatment 3 were significantly greater than those in other polyculture treatments ($P < 0.05$; Figure 2), among which there were no significant differences ($P > 0.05$; Table 1). Net and gross fish yields were highest in treatment 3, intermediate in treatments 4 and 5, and lowest in treatment 2 ($P < 0.05$; Table 1).

In one of three replications of treatment 2, Nile tilapia growth was found to be much faster than that in other two replications. 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, thus this replication was excluded in all following analyses. Survival of Nile tilapia was 100% in all polyculture treatments. Nile tilapia grew steadily during the entire culture period (Fig. 2). Mean weights at harvest and daily weight gains of Nile tilapia were highest in treatments 2 and 3, intermediate in treatment 4, and lowest in treatment 5 ($P < 0.05$; Table 1). Mean weights of Nile tilapia at harvest decreased linearly with increased stocking densities of

Nile tilapia ($Y = 92.6424 - 26.3333X$, $r = 0.92$, $n = 10$, $P < 0.01$; Fig. 3a), while net fish yields of Nile tilapia increased linearly ($Y = 1.074 + 1.390X$, $r = 0.97$, $n = 10$, $P < 0.01$; Fig. 3b). Mix-sex Nile tilapia reproduced in tanks during the experimental period. The mean number and yields of Nile tilapia recruits were not significantly different among all polyculture treatments ($P > 0.05$), while mean weights of the recruits were significantly greater in treatment 2 than those 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 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 compositions of fresh napier grass and fresh grass carp feces indicated that large amount of grass eaten by grass carp was excreted as nutrient-rich wastes (Table 2). There were no significant differences in feed conversion ratios (FCR) on either dry or fresh weight bases 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 grass only while Nile tilapia consumed diversified food items including feces of grass carp (Table 4).

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.

Item	Treatments				
	T1	T2	T3	T4	T5
Grass Carp					
Initial mean weight (g/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/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/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/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/fish/d)	----	2.27±0.14^{a}	3.14±0.15^{b}	2.37±0.05^{a}	2.16±0.08^{a}
NFY (kg/ha/d)	----	9.00±0.56^{a}	12.60±0.95^{b}	9.78±1.00^{ab}	9.99±1.04^{ab}
GFY (kg/ha/d)	----	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/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/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/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/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/fish/d)	----	0.46±0.02^{a}	0.40±0.02^{a}	0.26±0.01^{b}	0.19±0.01^{c}
NFY (kg/ha/d)	----	1.15±0.06^{a}	2.02±0.10^{b}	2.62±0.07^{c}	3.92±0.20^{d}
GFY (kg/ha/d)	----	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/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/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/d)	----	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/d)	----	10.98±0.65^{a}	14.62±0.99^{a}	12.40±0.98^{a}	13.91±0.96^{a}
GFY(kg/ha/d)	----	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/d)	----	17.49±0.76^{a}	22.71±2.37^{a}	17.90±1.08^{a}	18.66±1.76^{a}
GFY(kg/ha/d)	----	18.82±0.76^{a}	24.19±2.37^{a}	19.65±1.09^{a}	20.94±1.77^{a}

Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

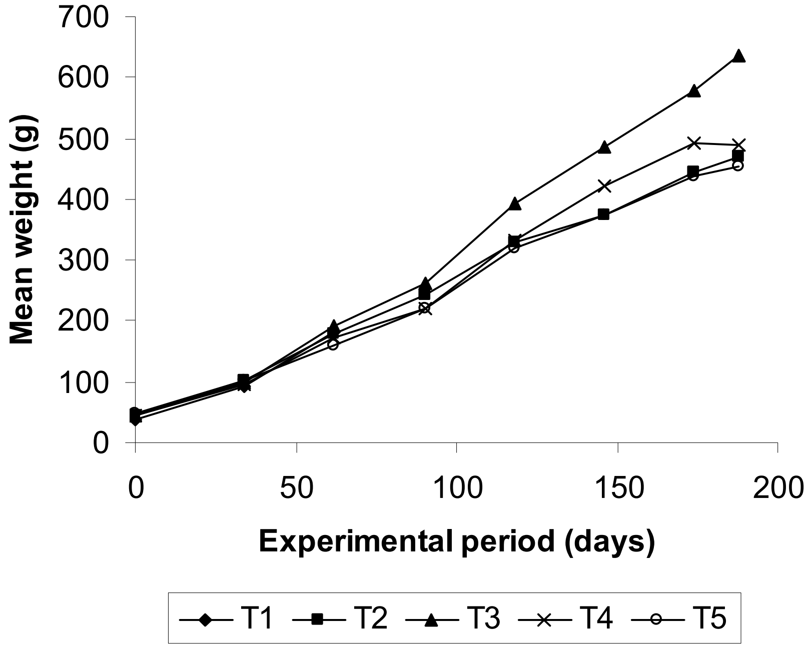

Fig. 1. Growth of grass carp in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

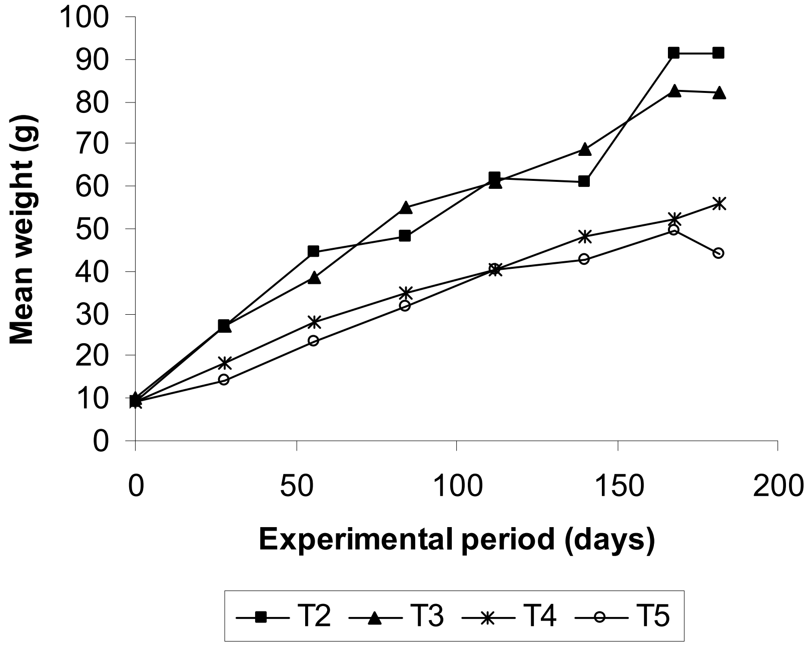

Fig. 2. Growth of mix-sex Nile tilapia in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

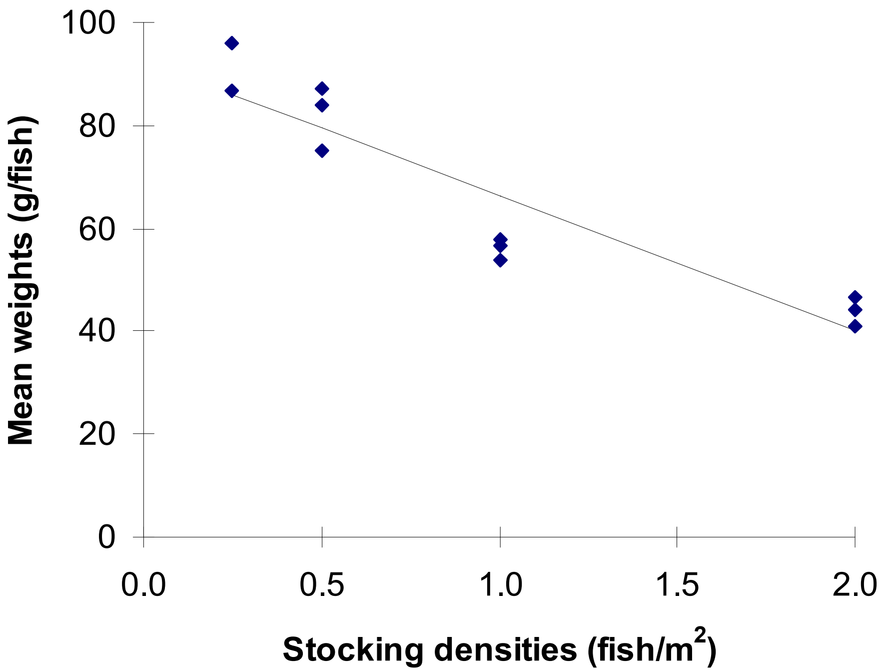

Fig. 3a. Relationship between stocking densities and mean weights of Nile tilapia in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

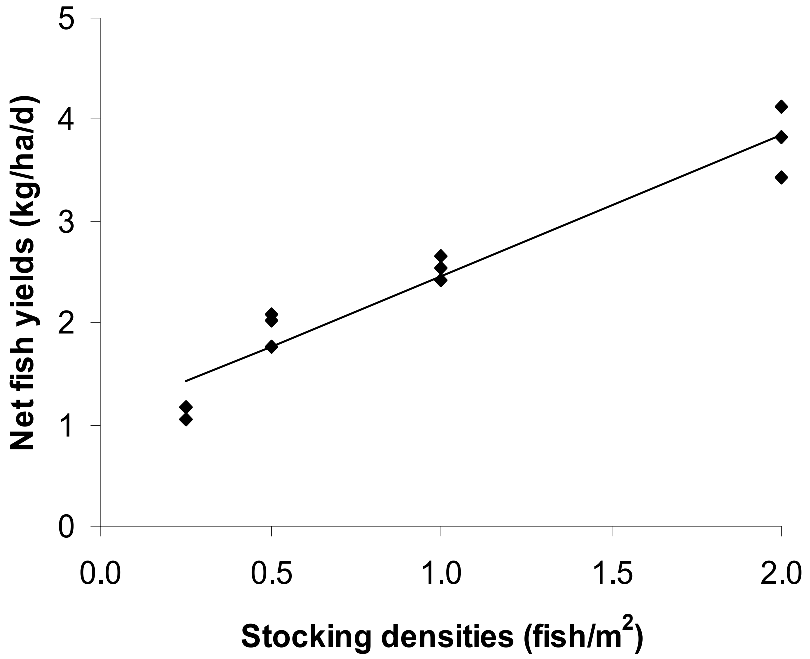

Fig. 3b. Relationship between stocking densities and net yields of Nile tilapia in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

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
Total lipids	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

Table 3. Food conservation 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.

FCR	T2	T3	T4	T5
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 alone.

Species	Gut contents	Frequency*
Grass carp	Napier grass	All
Nile tilapia	*Anabaena; Oscillataria;* Detritus; Grass carp feces	C
	Cosmarium; Euglena; Brachionus	F
	Moina; Daphnia; Cyclops	R

C = commonly observed; F = frequently observed; R = rarely observed.

Repeated ANOVA showed that there were no significant differences of all water quality parameters among all polyculture treatments ($P > 0.05$; Table 5). DO concentrations in most of the tanks were consistently low during week 10 - 12 that coincided with the mass mortality of grass carp in all three replications of the monoculture treatment (Fig. 4). Water temperature decreased continuously from August and reached about 20ºC at the end of the experiment. Secchi disk depths gradually decreased throughout the experimental period (Fig. 5). Total ammonium nitrogen was recorded cyclic high and low values (Fig. 6), while nitrite nitrogen was undetected in most tanks during the initial periods of experiment. Total alkalinity increased gradually throughout the experimental period, from an average of 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 (Fig. 7). This level of alkalinity produced well-buffered water and, as a consequence, fluctuations in pH were small.

Table 5. Mean values and ranges of water quality parameters measured weekly and biweekly during the experimental period. Values in treatment 1 represent the mean values of the measurements until the mass mortality of grass carp. Statistical analyses using repeated ANOVA were conducted among treatments 2 through 5.

Parameters	Treatments				
	T1	T2	T3	T4	T5
Temperature	30.7±0.22	28.1±0.08	28.8±0.03	28.8±0.08	28.8±0.09
(C)	(26.8-32.9)	(19.9-33.2)	(21-33)	(21 - 33.2)	(21.3-33.2)
pH	8.1±0.03	8.2±0.03	8.1±0.04	8.1±0.02	8.1±0.00
	(7.8-8.3)	(7.6-9.2)	(7.3-9.1)	(7.6-9.1)	(7.5-9.3)
DO	6.6±0.1	3.4±0.2	3.7±0.5	3.2±0.1	3.3±0.1
(mg/L)	(0.1-9.9)	(0.1-9.7)	(0.2-9.9)	(0.1-10.4)	(0.1-9.9)
Secchi disk depth	75±6.0	45±4.3	48±1.5	51±0.3	51±0.2
(cm)	(21-120)	(13-120)	(18-112)	(10-115)	(12-115)
Total alkalinity	82±3.1	101±2.8	104±2.5	99±1.4	102±0.1
(mg/Las $CaCO_3$)	(69-97)	(60-133)	(63-143)	(64-133)	(62.2-135)
TAN	0.73±0.06	0.78±0.01	0.73±0.02	0.73±0.04	0.73±0.04
(mg/L)	(0.30-1.50)	(0.14-2.00)	(0.13-1.97)	(0.14-2.07)	(0.15-1.82)
Nitrite-N	0.000±0.000	0.001±0.000	0.001±0.000	0.001±0.000	0.001±0.000
(mg/L)	(0.000)	(0.000-0.002)	(0.000-0.002)	(0.000-0.002)	(0.000-0.002)
SRP	0.02±0.001	0.08±0.004	0.08±0.001	0.08±0.004	0.10±0.007
(mg/L)	(0.01-0.05)	(0.01-0.13)	(0.01-0.13)	(0.01-0.14)	(0.01-0.15)
NPP	3.5±0.34	2.0±0.20	1.6±0.05	1.8±0.03	1.8±0.01
(g C/m^2/12 hrs)	(0.5-3.3)	(0.3-3.3)	(0.2-3.1)	(0.2-3.4)	(0.4-3.4)
GPP	5.3±0.63	4.1±0.5	3.2±0.2	3.5±0.1	3.6±0.02
(g C/m^2/12 hrs)	(1.0-6.6)	(0.5-6.5)	(0.6-6.4)	(0.4-6.9)	(0.6-7.0)
Chlorophyll *a*	79±16.6	144±18.6	149±6.3	137±5.6	139±10.0
(mg/m^3)	(3-209)	(8-393)	(3-380)	(24-329)	(22-353)

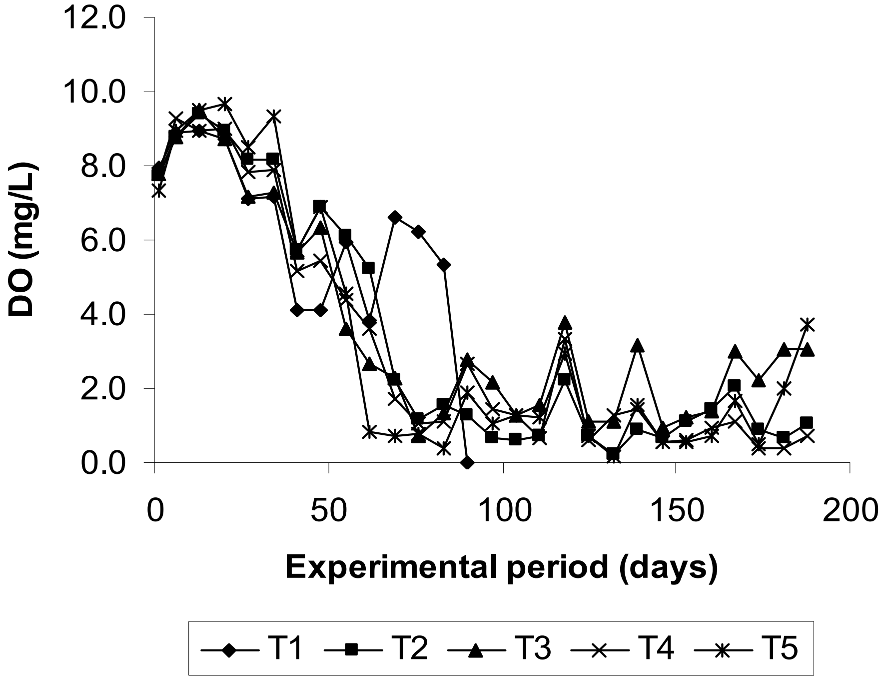

Fig. 4. Fluctuations in DO (at dawn) in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

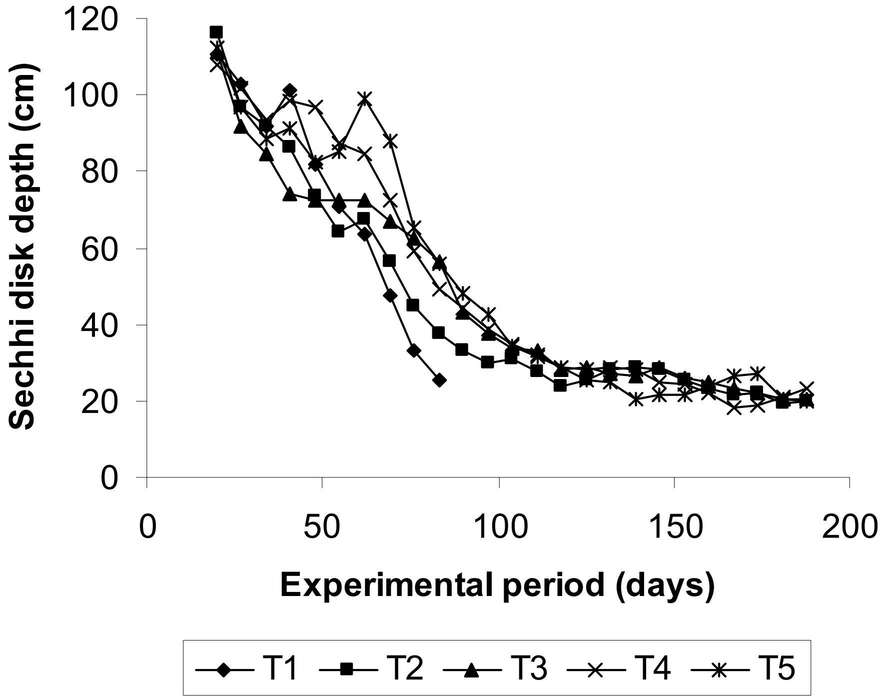

Fig. 5. Changes in Secchi disk depth in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

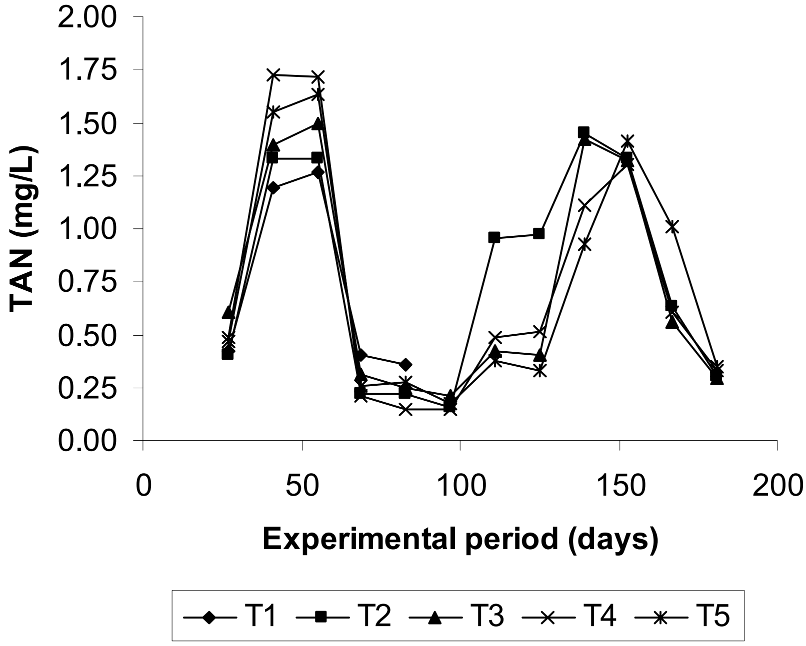

Fig. 6. Fluctuations in TAN in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

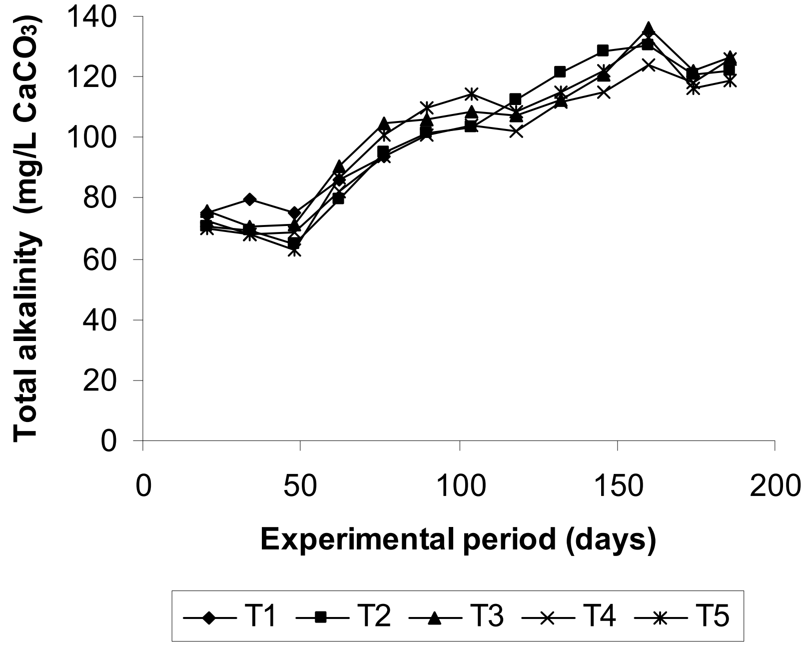

Fig. 7. Changes of total alkalinity in the grass carp – Nile tilapia polyculture tanks fed napier grass over the 188-day experimental period.

Discussion

The modern package of practices for scientific aquaculture provides a high-cost technology, which becomes a major constraint in this type of farming, especially to the small-scale and resource-poor farmers in many developing countries such as Nepal. Though, chopped napier grass contained 9.2% of CP and 28.6% of CF, its perennial nature, hardiness and low cost of production are the major advantages for small resource-poor farmers. In the present study, productions of grass carp in different combinations with Nile tilapia ranged from 9.00 to 12.60 kg $ha^{-1}d^{-1}$. The production of grass carp in the present study was higher than that (8.7 kg ha^{-1} d^{-1}) reported by Venkatesh and Shetty (1978) when grass carps were fed hybrid napier (*P. purpureum* x *P. typhoideum*) and stocked with 0.5 fish m^{-2}. Similar yields of 10.4±0.1 to 12.5±0.5 kg $ha^{-1}d^{-1}$ were reported in grass carp in monoculture and 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 gains of grass carp vary from 1.7 to 14.7 g d^{-1} (Chander and Madan, 1984). The mean daily weight gains recorded in the present study (2.16-3.14 g d^{-1}) are within the above range. However, growth and yields of Nile tilapia in the present study were lower (0.19-0.46 g d^{-1} and 1.15-3.92 kg ha^{-1} d^{-1}, respectively) than those commonly achieved in fertilized/manured ponds (Lin *et al*., 1997). This was obviously caused by the early breeding of mixed-sex Nile tilapia used in the present study and 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 – 72.1 (Hickling, 1960; Venkatesh and Shetty, 1978; Shrestha and Yadav, 1998; Shrestha, 1999). FCRs of grass carp or grass carp plus Nile tilapia in the present study are quite comparable to these results. Examination of grass carp stomachs showed that primarily the given plant material was consumed and no other food materials were found. Similar results was 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 is predacious, even on small fingerling fishes. This observation confirms that when the 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 in their dietary preference. 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 result of present study clearly showed that Nile tilapia consumed napier grass and/or grass carp feces along with other natural foods such as phytoplanktons and zooplanktons and detritus. These results support the suggestion by Chikafumbwa (1996) that napier grass can be used as a low-cost feed or fertilizer inputs for tilapia aquaculture.

Most of the water quality parameters at each sampling dates were found within a suitable range for fish production, however, dissolved oxygen is a crucial factor to affect the culture system in a consistent manner throughout the second half period of the experiment. The greater load of grass carp wastes in ponds caused lower levels of dissolved oxygen, and higher levels of total ammonium nitrogen, due probably to the decomposition of grass carp wastes.

Mass mortality of grass carp in all three replications of the monoculture treatment coincided with the constantly low dissolved oxygen (0.1 mg l^{-1}) for long period (Fig. 4). This suggests that species diversity (plankton feeders) is necessary to maintain balanced ecosystems, e.g., utilization of nutrients and cropping of plankton that otherwise create oxygen depletion due to plankton die off, decomposition and high rate of respiration. Chikafumbwa (1996) suggested that the application of napier grass alone above 50 kg DM $ha^{-1}d^{-1}$ degraded water quality and decreased fish growth and production. Similar results have been reported in grass carp monoculture, fed with napier grass, by Shrestha and Yadav (1998) and Shrestha (1999). Results of the present study showed that, despite higher stocking densities in polyculture systems, water quality was a less problem, compared to the monoculture system. This suggests that monoculture of grass carp fed with large amount of napier grass is risky in stagnant water.

The present study has showed that the optimal ratio of grass carp to Nile tilapia in polyculture fed napier grass is 1:1, i.e., grass carp at 0.5 fish/m^2 plus Nile tilapia at 0.5 fish/m^2. This indicated that the 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, carp–Nile tilapia polyculture fed napier grass is a low-cost alternative aquaculture system for small-scale poor farmers. However, the feeding rate of napier grass and stocking and augment total fish production. The present study has also demonstrated that the grass density of grass carp should be further studied.

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References

APHA, AWWA WPCF. 1985. *Standard Methods for the Examination of Water and Wastewater.* 16th edition, American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC., USA.

AOAC. 1980. Official Methods of Analysis of the Association of Official Analytical Chemists, 13th edition, Association of Official Analytical Chemists. Washington, DC.

Chander, J. and Madan, M.L. 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.

Hall, C.A.S. and Moll, R. 1975. "Methods of assessing aquatic primary productivity." *In*: H. Lieth and R.H. Whittaker (Eds.), *Primary Productivity of the Biosphere.* 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.

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 Mathias, J., (Editors). 1994. *Fresh Water Fish Culture in China: Principles and Practices.* Elsevier, Amsterdam.

Lin, C.K., D. R. Teichert-Coddington, Green, B.W., and Veverica, K.L. 1997. "Fertilization regimes." *In*: H.S. Egna and C.E. Boyd (Eds.), *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 Bhujel R.C. 1999. "A preliminary study in the Nile tilapia (*Oreochromis niloticus*) polyculture with common carp (*Cyprinus carpio*) fed with duckweed (*Spirodella*) in Nepal." *Asian Fisheries Science*, 12: 83-89.

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

Spataru, P. and Hepher, B. 1977. "Common carp predating on tilapia fry in high density polyculture fishpond system." *Bamidgeh,* 29: 25-28.

Steele, R.G.D., Torrie, J.H. 1980. *Principles and Procedures of Statistics*, 2nd edition. McGraw-Hill, New York.

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 Shetty, H.P.C. 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.

Yang, H.Z., Fang Y.X., and Liu Z.Y. 1990. "The biological effects of grass carp (*Ctenopharyngodon idella*) on filter-feeding and omnivorous fish in polyculture". *In*: R. Hirano and I. Hanyu (Eds.), *The Second Asian Fisheries Forum*. Asian Fisheries Society, Manila, Philippines. pp. 197-200.