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Research Article

Effects of farm and commercial inputs on carp polyculture performance: participatory trial in an experimental field station

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ABSTRACT. The carp polyculture production system is the most widely used system by small-scale fish farmers in southern Brazil (States of Paraná, Santa Catarina and Rio Grande do Sul). The aim of this study was to compare biotechnical and economic parameters between a farm system (FS) using farm inputs (chicken manure, maize and grass) and a commercial system (CS) using commercial inputs (triple super phosphate, ammonium nitrate and balanced food) feeding to apparent satiation. The experiment was carried out for 196 days in earthen ponds of 500 m^2, with three replicates per system. The stocking density was 2,000 fish ha^{-1}, consisting of 35% grass carp (*Ctenopharyngodon idella*), 30% of mirror common carp (*Cyprinus carpio* var. *specularis*), 20% of bighead carp (*Aristichthys nobilis*) and 15% silver carp (*Hypophthalmichthys molitrix*). In both systems, a low level of total phosphorus in water (0.06 mg L^{-1}) and in the sediment (4 mg L^{-1}) was observed. Production was significantly increased in the CS (76 kg 500 m^{-2} 196 $days^{-1}$) than in the FS (43 kg 500 m^{-2} 196 $days^{-1}$). Costs and revenues were higher in the CS and profits were similar in the two systems. Similar profits do not mean that CS is necessarily more convenient. Advantages and drawbacks for small-scale farmers considering labor, land and availability of money are discussed.

Keywords: carp, polyculture, feed, water quality, cost-benefit, aquaculture, Brazil.

Efectos de insumos de granja y comerciales en el desempeño del policultivo de carpas: ensayo participativo en una estación experimental en el campo

RESUMEN. El policultivo de carpas es el sistema de producción de peces más utilizado por campesinos en el sur de Brasil (Estados de Paraná, Santa Catarina y Rio Grande do Sul). El objetivo de este trabajo fue comparar parámetros técnico-biológicos y económicos entre un sistema de granja (FS) utilizando insumos de la granja (gallinaza, maíz y pasto) y un sistema comercial (CS) utilizando insumos comerciales (súper fosfato triple, nitrato de amonio y alimento balanceado), alimentando hasta saciedad aparente. El experimento se efectuó en tierra durante 196 días en estanques de 500 m^2, con tres réplicas por sistema. La densidad inicial de los peces fue de 2.000 ind ha^{-1}, compuestos por 35% de carpa herbívora (*Ctenopharyngodon idella*), 30% de carpa común espejo (*Cyprinus carpio* var. *specularis*), 20% de carpa cabezona (*Aristichthys nobilis*) y 15% de carpa plateada (*Hypophthalmichthys molitrix*). En ambos sistemas se obtuvieron bajas concentraciones de fósforo total final en el agua (0,06 mg L^{-1}) y en el sedimento (4 mg L^{-1}). La producción fue significativamente mayor en el CS (76 kg 500 m^{-2} 196 $días^{-1}$) que en el FS (43 kg 500 m^{-2} 196 $días^{-1}$). Los costos e ingresos fueron mayores en el CS y las utilidades fueron similares en ambos sistemas. Utilidades similares no significan que el CS sea necesariamente más conveniente. Se discuten ventajas y desventajas para los campesinos considerando el trabajo, la tierra y la disponibilidad de dinero.

Palabras clave: carpa, policultivo, alimento, calidad de agua, costo-beneficio, acuicultura, Brasil.

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INTRODUCTION

Most of the world's freshwater fish production comes from rural aquaculture via carp polyculture systems. In 2008, 20.4 million ton of carp were produced, representing 72% of the total production. China is the main carp producing country (71%), followed by India (16%) (FAO, 2010). Carp polyculture food inputs used worldwide are whole food items, farm-made aqua foods and commercial balanced food (Tacon & Hasan, 2007). In Europe, the Caucasus, and Central Asia, corn and grass are, among others, frequently used whole food items (supplementary feed) in carp polyculture (Woynarovich *et al.*, 2010). In China, there has been an increase in the use of commercial balanced food in carp polyculture, in order to increase the production of a single target species of greater value (Edwards, 2008).

The Chinese carp polyculture system expanded during the twentieth century to all continents, with local adaptations (Edwards, 2004; Milstein, 2005). This polyculture is the most practiced fish production system by small-scale farmers in southern Brazil (States of Paraná, Santa Catarina and Rio Grande do Sul). In 2005, in the State of Rio Grande do Sul (RS), 21,000 ton of carp were produced (IBAMA, 2006). Studies on carp polyculture in Brazil have been directed towards the introduction of new species such as tilapia (*Oreochromis niloticus*) and native jundia (*Rhamdia quelen*), in their initial (Silva *et al.*, 2006) and final culture periods (Silva *et al.*, 2008). The present study was developed taking into account the importance of carrying out on-farm research to obtain sustainable results under field conditions (Azim *et al.*, 2004; Wahab *et al.*, 2011), and developing appropriate technologies using a participatory approach (Murshed-E-Jahan *et al.*, 2008; Barman & Little, 2011).

Carp polyculture is a complementary rural activity for small-scale family farmers in southern Brazil, some of them grouped in associations, in order to organize production and sales. In the Municipality of Sobradinho, RS, since 1998 to date, they have a fish producers' association named Braspeixe. Every year this community organizes a Fish Festival where different carp dishes are offered to the public. Braspeixe members are of Italian origin and their main economic activity is tobacco production.

In southern Brazil small-scale fish farmers utilize both on-farm and commercial inputs to fertilize and feed carp in polyculture (Hernández & Düpont, 2002). A research request was presented by farmers to the RS-Rural Program from the State Bureau of Agriculture to evaluate the biotechnical and economic advantages and drawbacks of using inputs of different origins. As a result, with the financial support of this Program and from the University of Santa Cruz do Sul (UNISC), an on-farm research station was built to carry out a participatory research trial with Braspeixe.

The objective of this study was to evaluate and compare the effect of supplying on-farm (chicken manure, corn and grass) and commercial (inorganic fertilizers and balanced feed) inputs, on the biotechnical and economic parameters in carp polyculture, when fish are fed to apparent satiation. The biotechnical parameters considered were culture performance, water and soil quality.

MATERIALS AND METHODS

Research station

The fish farm research station is located in Linha Brasileira, Sobradinho, RS, Brazil. The station has ten 500 m^2 earthen ponds (12.5x40 m and 1.5 m depth) and a water reservoir that receives water from springs in a native forest. Each pond has a stopcock for the individual control of the outflow by gravity and an external sedimentation tank.

Soil composition and liming

Soil samples of the empty ponds were taken four and a half months before beginning the growth trial, in order to evaluate its quality and to determine the amount of agricultural lime ($MgCa(CO_3)_2$) necessary to increase water alkalinity to 20 mg L^{-1}. Lime was spread evenly over the soil surface. Soil samples of empty ponds were taken again two and a half months after fish harvesting. Soil sampling and analyses were carried out following agriculture traditional methods (Tedesco *et al.*, 1995). The soil parameters analyzed were clay (densimeter, NaOH solution), pH and pH in buffer solution (glass electrode), total phosphorus (P) (light absorption at 660 nm, Mehlich-1), organic matter (OM) (645 nm, sulphochromic solution), potassium (K) (atomic absorption, Mehlich-1), aluminum (Al), calcium (Ca) and magnesium (Mg) (atomic absorption, KCl). For pH in buffer solution, a method for aquaculture ponds was followed (Stirling & Phillips, 1990). Analyses were performed at the Analytical Center Soil Laboratory-UNISC.

Initial pond soil was acidic, with an average pH of 5.0 containing a low percentage of organic matter, ranging from 0.8 to 2.0%. To determine the required amount of lime, the soil pH and pH in buffer solution values were considered and the table presented by Stirling & Phillips (1990) was used. The agricultural lime available presented 70% purity. In the experimental ponds, the amount required and used ranged from 4,500 to 8,500 kg ha^{-1}.

Experimental design

Two carp polyculture systems named Farm (FS) and Commercial (CS) were tested, using fertilizers and feeds of different origin: on-farm and commercial. The experiment was carried out from November 2004 through May 2005, during the period of high water temperature (21° to 29°C), with two treatments (systems) and three replicates per treatment. Considering that the experimental units presented location differences (different proximity to a rural road and to a drainage channel), a random complete block design was applied. The fish stocking density was 2,000 fish ha^{-1}, composed by 35% of grass carp (*Ctenopharyngodon idella*), 30% of common carp (*Cyprinus carpio* var. *specularis*), 20% of bighead carp (*Aristichthys nobilis*) and 15% of silver carp (*Hypophthalmichthys molitrix*). This initial species percentage composition (35, 30, 20, 15%) was slightly different from that proposed by the rural extension agency in Rio Grande do Sul for carp polyculture in small ponds (35, 35, 15, 15%) (Cotrim, 1995). The ratio of bighead carp to silver carp was increased considering that, in previous studies, a higher final weight of bighead carp was reached compared to silver carp, when these filter feeder species were used in the ratio 1:1 (Hernández & Düpont, 2002).

Fish were provided by a regional fry producer, with an average weight and standard deviation of 22.8 ± 4.3 g for grass carp, 32.7 ± 9.0 g for common carp, 33.6 ± 10.3 g for bighead carp and 3.5 ± 0.9 g for silver carp. Fish were stocked in the ponds in November 2004 and the growth experiment lasted 28 weeks (196 days).

Pond fertilization

Ponds were fertilized only once, four days before starting the experiment. In the FS, 100 kg of dried chicken manure, equivalent to 2.000 kg ha^{-1}, were used as organic fertilizer in each pond. Chicken manure was collected and sun dried by the farmers. In the CS, the amounts of inorganic fertilizers were determined to obtain similar amounts of phosphorus and nitrogen as in the chicken manure, taking into account the theoretical average phosphorus and nitrogen content of dry chicken manure and of the utilized inorganic fertilizers. Therefore, 8.4 kg of triple super phosphate (TSP), equivalent to 168 kg ha^{-1} and 5.3 kg of ammonium nitrate, equivalent to 106 kg ha^{-1}, were applied to each pond. Fertilizers were dissolved in water and evenly distributed across the water surface. The nitrogen and phosphorus contents of the fertilizers were analyzed at the Analytical Center Agriculture Fertilizers Laboratory-UNISC.

The nutrients content of the utilized fertilizers, as measured by the end of the experiment, were 35.5% P in TSP, 28.7% N in the ammonium nitrate and 2.6% P and 0.3% N in the chicken manure. Dry chicken manure moisture was 27.5%.

Feed and feeding

In the FS, broken corn (*Zea maíz*) and elephant grass (*Pennisetum* sp.) were used as feed. Corn was produced by the farmers and elephant grass was planted at one side of the research station, harvested and cut into pieces to be given to the fish. In the CS an extruded balanced fish feed was used (28% crude protein). Fish were fed to apparent satiation from Monday to Friday, at 09:00 and at 16:00 h. Fish were not fed on Saturday and Sunday in order to allow them to feed on residues and to improve the pond water quality. Broken corn was put on a 44x30x6 cm tray, submersed and hung from two floats. The balanced feed pellets and the cut grass were broadcasted over a circular 2 m diameter floating hose, fixed to one corner of the pond.

Water quality

Water temperature was measured during the experimental period from Monday to Friday, at 09:00 and at 15:00 h with a mercury thermometer, at 15 cm depth. The accumulated thermal units (ATU) (ATU = days x °C above 0°C) for the rearing period were calculated. Water transparency was measured weekly from December until the end of the experiment, using a Secchi disk. Water quality was sampled at the beginning (day 2), the middle (day 112) and the end of the experiment (day 196), between 07:00 and 09:00 h, at 15 cm depth. Water temperature, transparency (Secchi), dissolved oxygen (DO, modified Winkler method), pH (electrochemical method with glass electrode), total alkalinity (titration method), total phosphorus (P, 660 nm) and nitrate (NO_3-N, 410 nm) were analyzed following the methods described in APHA (1992). Analyses were performed at the Water Laboratory of the Analytical Center-UNISC.

Fish measurements

Weight and total length of individual fish were measured at the beginning, middle and end of the experiment. In the middle of the experiment, 25% of the total population was caught with a trawl net to assess health conditions and growth. At the end of the experiment ponds were drained and the whole fish population was sampled. The harvesting parameters: survival (%), final weight (g), growth rate (g day^{-1}), condition factor (CF = weight*100/total $length^3$, g cm-^{3}), biomass (kg 500 m^{-2}) and yield (kg 500 m^{-2} 196 $days^{-1}$) were calculated. The feed conversion ratio (FCR) was calculated taking into account the production of the four species and the sum of the feed weight provided to each system (Farm = corn + grass; Commercial = balanced feed), as presented in Abdelghany & Ahmad (2002).

Economic analyses

A simple cost-benefit analysis was carried out, following Abdelghany & Ahmad (2002). Braspeixe associates were visited in 2011 in order to collect the economic data. Semi-intensive carp polyculture continues to be their fish production system, husbandry techniques have not changed and the inputs used in the experiment are still used and available in Sobradinho market. Input costs (fish, agricultural lime, fertilizers and feed) and income obtained from fish sale were considered to calculate each system's profit.

Statistical analyses

Differences between means for water quality data were calculated through a two-way analysis of variance (ANOVA), using Duncan's multiple-comparison test to carry out a post hoc pairwise comparison of means. For this test, systems (Farm and Commercial) and period (initial, middle and final) were used as factors. Significance level was set at $P < 0.05$. Differences between means of the two systems were calculated by a Student's t-test for independent samples. Survival (%) data were normalized using the arcsine of the square root transformation. Fish condition factor and feed conversion ratio (FCR) were transformed to ranks. Before running the ANOVA and Student t-test, the block effect (pond location differences) was included as a factor and discarded because its effect was not significant for any of the studied variables. The analyses were run using the InfoStat v.2008 statistical package.

RESULTS

Soil and liming

The polyculture systems did not present a significant effect on any of the soil variables. However, comparing soil quality before and after the growth experiment, an increase in pH from 5.0 to 5.5, a decrease in aluminum from 2.5 to 0.6 cmolc L^{-1} and a decrease in phosphorus from 9 to 4 mg L^{-1} were observed. Final total soil phosphorus was similar and low in both systems (FS: 4 ± 1 mg L^{-1}; CS: 3 ± 1 mg L^{-1}). As a consequence of the increase in soil pH, lime requirement was reduced by 67%, changing from an average of 329 kg initially to 112 kg afterwards (FS: from 317 ± 101 to 100 ± 89 kg; CS: from 342 ± 72 to 123 ± 50 kg).

Water quality

The average pond water temperature was 24.1°C in the morning and 27.3°C in the afternoon. The calculated ATU for the rearing period was 5037°C. Table 1 presents the two-way ANOVA results for water quality parameters. The models were significant for temperature, transparency, dissolved oxygen, total phosphorus and nitrate, and both system and period were sources of variability. System significantly affected nitrate, showing a higher concentration in the CS.

The period factor significantly affected five water parameters (temperature, transparency, dissolved oxygen, total phosphorus and nitrate). Water temperature varied over time and transparency decreased. Dissolved oxygen (DO) was significantly higher in the initial period and lower in the middle period. In the final period, DO increased significantly compared to the middle period. Total phosphorus and nitrate concentrations were significantly higher in the initial period than later. Final water total phosphorus was low in both systems.

The cross-effect system and period for nitrate (Fig. 1) shows that in the CS the initial concentration of this parameter was much higher than its concentration in the remaining periods (more than an order of magnitude), while in the FS nitrate concentrations were low and showed little change with time.

Culture performance

General average survival was 87% and showed no significant differences between systems (Table 2). Yield was significantly higher in the CS than in the FS. The feed conversion ratio (FCR) in the CS was significantly lower and better than in the FS, where grass consumption by grass carp was rather low (37.7 ± 0.1 kg $pond^{-1}$).

Among the four carp species stocked, common carp showed the highest yield (Fig. 2). The initial number of common carp was 30% of the total population, and its yields were 60% of the total yields in both systems.

The harvesting parameters results for each species are presented in Table 3. Survival did not show significant differences between systems. Final weight and growth rate were significantly higher in the CS for all species. Condition factor (CF), biomass and yield were significantly different between systems for grass and common carp and showed no differences for the filter feeders (bighead and silver carp). In the FS, grass carp CF was significantly lower and common carp CF was significantly higher than in the CS. In the CS, biomass and yield were significantly higher for grass carp and common carp than in the FS.

Economic analysis

The economic analysis was performed using the costs of inputs and income obtained from fish sales in Sobradinho market in 2011 (Table 4). Agricultural lime cost US$0.073 kg^{-1}, 1,000 carp fingerlings US$141.20 (US$0.1412 $unit^{-1}$), TSP US$0.64 kg^{-1}, ammonium nitrate US$0.45 kg^{-1}, corn US$0.28 kg^{-1} and extruded balanced feed (28% CP) US$0.73 kg^{-1}. Whole fish have a market price of US$4.24 kg^{-1} for grass carp and US$3.39 kg^{-1} for the other species. Total costs and

Table 1. Two-way-ANOVA of water quality results. *Post-hoc* pair wise mean comparisons for each water quality variable using Duncan's multiple-comparison test. R^2: coefficient of determination. Sign: significance levels: * = 0.05, ** = 0.01, *** = 0.001. %SS: percentage of total sums of squares. Same letters in each column indicate no significant differences ($P > 0.05$), a > b > c.

Variable	Temp (ºC)	Secchi (cm)	DO (mg L^{-1})	pH	Alkalinity (mg L^{-1})	P-total (mg L^{-1})	NO_3-N (mg L^{-1})	
ANOVA model								
Model significance	***	***	***	ns	ns	*	**	
R^2	0.99	0.84	0.88	0.43	0.21	0.66	0.68	
Variability source	Sign	Sign	Sign	Sign	Sign	Sign	Sign	%SS
System	ns	ns	ns	ns	ns	ns	*	19
Period	***	***	***	ns	ns	*	*	42
System*period	ns	ns	ns	ns	ns	ns	*	39
Mean comparison by system (n = 9)								
Farm	22.1	27	4.5	6.7	28	0.08	0.15 b	
Commercial	22.1	23	5.0	6.8	29	0.36	0.95 a	
Mean multicomparison by period (n = 6)								
Initial	21.3 b	40 a	7.1 a	7.0	27	0.53 a	1.38 a	
Middle	24.9 a	20 b	2.5 c	6.8	33	0.07 b	0.16 b	
Final	20.1 c	15 b	4.7 b	6.5	26	0.06 b	0.11 b	

income in the CS were significantly higher than in the FS, while profit did not differ significantly. Even though production and therefore income were significantly higher in the CS, total costs of inputs were also significantly higher, with balanced feed representing 74% of input costs. In the FS, market corn price was used for analytical purposes, but since corn was produced on-farm using the farmer's labor and land, the actual cost might be lower.

DISCUSSION

Soil and water quality

Lime is an input used in both FS and CS to improve the pond environment and hence fish performance. The amount of lime varied widely between ponds, showing that every pond has a specific lime requirement. The objective of increasing water alkalinity to at least 20 mg L^{-1} through liming was attained in the experimental ponds in both systems and all periods. This shows the practical convenience of analyzing soil pH and pH in buffer solution in order to determine the amount of agricultural lime necessary to increase water total alkalinity, in areas with soft waters and acidic soils. If a fixed amount of lime per hectare is used in ponds without soil analysis, lime can be wasted or be insufficient to increase alkalinity to the desired level. In Chinese carp polyculture ponds in south Brazil, water reached similar total alkalinity values (20 to 40 mg L^{-1}) when 6,000 kg ha^{-1} of agricultural lime was used (Silva *et al.*, 2006).

The pH increase and aluminum reduction in soil quality reflect the effect of liming in the ponds' soil. The increase in soil pH is a favorable condition for the following production cycle because the amount of agricultural lime required in the next season can be reduced by 67%. This has a practical economical advantage for the following production cycle, because lime cost can be reduced.

The amounts of fertilizers supplied in the CS were calculated in order to provide similar levels of P and N to the dry chicken manure of the FS. This was achieved for the P content present in fertilizers. However, the chicken manure utilized presented a very low N content of 0.3%, which may at least partially account for some of the differences found between systems. Nitrogen content reduction might be due to the loss of uric acid from the manure, during the process of collection and drying by the farmers. For future work, better manure processing and prior laboratory analysis of the utilized fertilizers is suggested.

Water temperatures, transparency, DO, pH, alkalinity and P-total did not show significant differences between systems. These parameters were expected to change over time considering climatic conditions and water quality in limed and fertilized carp polyculture ponds at the beginning of the production cycle. High initial nitrate in the CS is related to the use of

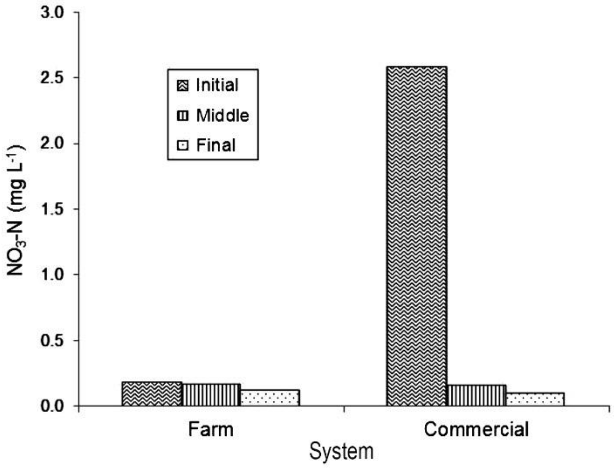

Figure 1. Nitrate water concentration per system and period (n = 3 ponds).

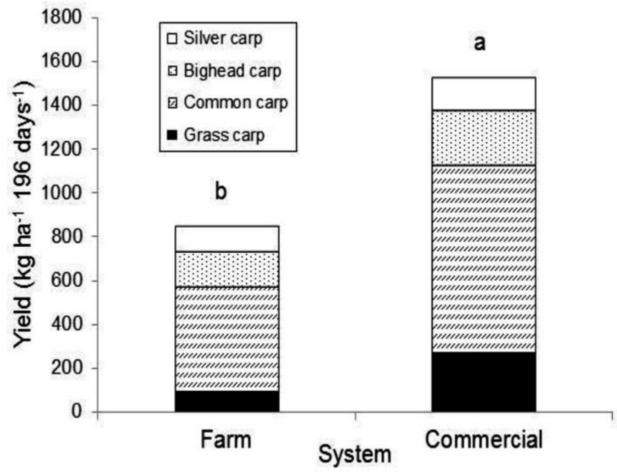

Figure 2. Average total yield per hectare in each system by species. Student t-test means comparison. Different letters indicate significant differences in total yield at the 0.05 level, a > b.

Table 2. Student's t-test for fish survival, yield and FCR. Average ± SD (n = 3). Different letters in each column indicate significant differences, a > b. ‡Student's t-test based on transformed data. Values of means are given untransformed. FCR: Feed conversion ratio.

Variable	Survival‡ (%)	Yield (kg 500 m^{-2} 196 $days^{-1}$)	FCR‡
Significance	ns	0.032	0.021
Farm	89 ± 7	43 ± 6 b	4.8 ± 0.6 a
Commercial	86 ± 10	76 ± 17 a	2.5 ± 0.3 b

ammonium nitrate as fertilizer. An increase in water nitrate with the use of a nitrogen-rich fertilizer in carp polyculture ponds was also observed by Bhakta *et al.* (2004), using urea as a fertilizer. The nitrate decrease in the middle period in the CS is due to the use of this nutrient by phytoplankton and to denitrification in this higher organic loading system.

As an important environmental result, in both systems low total final phosphorus in water and soil were observed. This reflects good recycling of this nutrient in the systems, introduced with the external inputs (fertilizers and feed). Considering that in carp polyculture in Rio Grande do Sul ponds are emptied when fish are harvested and the pond water is released into natural water courses, final low total phosphorus concentration in the system is important to avoid eutrophication problems.

Culture performance

A general average survival of 87% was similar to that obtained in a previous Chinese carp polyculture experiment that began with fish weighing more than 20 g (Hernández & Düpont, 2002). Mortality can be explained by the presence of predators such as herons, kingfishers, North American bullfrogs, long neck turtles and by natural death.

Yield was 77% higher in the CS than in the FS. This can be explained by the low consumption of grass by grass carp in the FS and the better nutritional quality of the balanced feed supplied to the CS compared to the corn and grass supplied to the FS. The difference in nutritional quality is reflected in the lower and better FCR in the CS than in the FS.

The increase in the ratio of bighead carp to silver carp in this experiment (1.33:1) in relation to the recommendation of the rural extension agency (1:1) resulted in a similar final weight of the filter feeders in the Farm and Commercial systems. This might be due to intraspecific competition between both herbivorous carps. Silva *et al.* (2008) found a higher final weight of bighead carp compared to silver carp, using the 15:15% (1:1) ratio under a treatment similar to the FS. A parallel can be drawn with the filter feeders used in the Indian carp polyculture. Filter feeders catla (*Catla catla*) and rohu (*Labeo rohita*) are traditionally used in a 1:1 ratio. When catla density was increased, intraspecific competition led to somewhat smaller fish (Alim *et al.*, 2005). Catla, like bighead carp, feeds mainly on zooplankton.

Differences in condition factor, biomass and yield between the CS and the FS indicate that grass and common carp were affected by the external feed supplied, while in both systems plankton production (phytoplankton and zooplankton) similarly supported filter feeders. In the CS, both common and grass carp showed a better condition factor and a higher yield than in the FS due to the consumption of balanced feed. Common carp attained a higher yield than grass carp,

Table 3. Harvesting parameters results. Student's t-test for comparisons between systems by species. Student's t-test based on transformed data. Significance levels: * = 0.05, ** = 0.01, *** = 0.001. Different letters in each column indicate significant differences, a > b. Values of means are given untransformed.

Variable	Survival[b] (%)	Final weight (g)	Growth rate (g day^{-1})	Condition factor[b] (g cm^{-3})	Biomass (kg 500 m^{-2})	Yield (kg 500 m^{-2} 196 $days^{-1}$)
Grass carp						
Significance	ns	**	**	*	**	**
Farm	81	200 b	0.91 b	1.07 b	5.7 b	4.9 b
Commercial	86	478 a	2.31 a	1.31 a	14.4 a	13.6 a
Common carp						
Significance	ns	*	*	*	*	*
Farm	92	896 b	4.39 b	2.17 a	24.8 b	23.8 b
Commercial	91	1593 a	7.98 a	2.05 b	43.7 a	42.7 a
Bighead carp						
Significance	ns	*	*	ns	ns	ns
Farm	97	449 b	2.12 b	1.15	8.7	8.0
Commercial	85	772 a	3.79 a	1.18	13.0	12.4
Silver carp						
Significance	ns	*	*	ns	ns	ns
Farm	91	430 b	2.18 b	1.06	5.9	5.8
Commercial	76	658 a	3.34 a	1.14	7.6	7.6

Table 4. Economic analysis of costs, income and profit by system. Total cost, income and profit Student's t-test. Dollars (US$ 500 m^{-2}), n = 3. Different letters in each column indicate significant differences, a > b. ns: not significant.

	Input cost				Total cost	Income	Profit	
	Lime	Fish	Fertilizers	Feeds			By pond	By hectare
Significance					0.001	0.028	ns	ns
Farm	23.26	14.12	0.00	47.02	84.40 b	157.71 b	73.31	1467
Commercial	25.10	14.12	7.81	137.00	184.03 a	278.97 a	94.94	1899

maybe as a result of a greater consumption of balanced feed. Even though common carp prefers benthonic macro invertebrates, followed by zoo and phytoplankton, it changes its preference to balanced feed when available (Rahman *et al.*, 2006). In the FS, the low condition factor of grass carp was related to the low quantity of feed consumed (grass and corn). Common carp high and unhealthy CF could be explained by the consumption of corn and as a consequence an increase in body lipids, leading to fat fish. Corn consumption explains most of the yield of common carp. In this system elephant grass consumption and grass carp yield were low. Considering an average FCR of 35 for elephant grass (Tacon & De Silva, 1997), the consumed grass would explain the production of 1 kg of grass carp in each pond. It is likely that grass carp also took advantage of corn a food source, as but to a lesser extent than common carp.

Given that feces produced by common and grass carp in FS and CS should aid to fertilize ponds, its nutrients could be used for plankton production, which favored the growth of bighead and silver carp. This is in accordance with descriptions for Chinese carp polyculture (Milstein, 2005), in which feces produced by the fish feeding on external food fertilize the water, then phytoplankton is produced thus enhancing growth of bighead and silver carp.

Socio-economic considerations

By performing the participatory on-farm research with Braspeixe members, the direct reception, use and diffusion of the results by small-scale farmers was made possible. The two experimental systems showed advantages and drawbacks for farmers, depending on their interests, pond availability, labor and economic family conditions.

The main advantage of the FS is that it uses on-farm resources, which allows farmers to produce fish when they do not have economic resources to buy commercial fertilizers and balanced feed. Furthermore, this system allows them to be self-sufficient and not vulnerable to the unpredictable supply and price of commercial products. A drawback of the FS is the higher labor involved. Labor is associated with the feed used in this system: corn and elephant grass. Corn is normally produced on the farms to feed other farm animals, such as chickens and pigs. Elephant grass is produced to feed cows for milk production and oxen used in agricultural activities. The increase in corn and grass production needs to be analyzed by each family, according to priorities and opportunities of other uses and cultures on their farm.

The main advantage of the CS is the higher fish yield obtained and the lower labor required in feeding the fish, and the main drawback is the higher economic investment. This system might be chosen by a family when there is no space and/or time to increase corn and grass production and there is money available to buy fertilizers and balanced feed.

Similar profits found in the present study in both Farm and Commercial systems mean that the use of balanced feed is not necessarily more convenient for a small-scale farmer under certain financial conditions. As stated by Tacon & Hasan (2007), the choice of the feeding method depends on a variety of different factors (which in turn may vary from region to region and farmer to farmer), including the market value of the cultured species, the financial resources of the farmer and the local market availability of appropriate fertilizers and feeds. Most of the small-scale farmers in sub-Saharan Africa and to a lesser extent in Asia and Latin America do not have the financial resources to purchase feed and/or nutrient inputs for their aquaculture operations.

Taking into account the results obtained, further research on the optimization of the Farm system is suggested. In order to promote grass carp growth, higher initial weight of this species is recommended; hence improved consumption of elephant grass would result in better growth of this species. This would indirectly result in better growth of the other carp species, considering the effect of fertilization by grass carp feces on natural food in the system (plankton and benthos). For common carp, trials including other on-farm products with higher protein content would help to achieve a better energy/protein balance in the diet of this species and therefore a better growth.

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