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RICE-FISH CULTURE IN THE MEKONG DELTA, VIETNAM: CONSTRAINT ANALYSIS AND ADAPTIVE RESEARCH

Thesis submitted for the award of the degree of Doctor of Science

by

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SUMMARY

Rice is the staple food for the Vietnamese people, and one of the most important export products of the country. More than half of the rice production comes from the Mekong Delta, located in the southern part of the country, where circa 74% of the total agriculture area is used for rice cultivation. Based on the specific hydrological- and soil conditions of a particular area, various rice-based farming systems have developed over the years. However, intensive rice cultivation (two or three crops per year), using improved rice varieties, fertilizers and pesticides is the dominant farming system. Recent studies indicate that continuing intensification of rice cultivation has both technical and economical limits, and may not be sustainable in the long term. Crop diversification and integrated crop-livestock-fish farming systems are considered of particular relevance for the future development of agriculture in the Mekong Delta.

The natural conditions in the Mekong Delta favour aquatic life, and fish is the major source of animal protein in the diet of the Delta’s inhabitants. In view of the importance of rice and fish products and the need for crop diversification, the integrated production of rice and fish seems an appropriate alternative for rice monoculture. Besides, various studies have indicated a synergistic interaction between rice and fish, resulting in improved rice yields from rice-fish fields. The mechanisms explaining this interaction have been related to fish controlling weeds, insect pests and diseases, and to an improved soil fertility as a result of fish activity. However, at present less than 5% of the total rice area in the Mekong Delta is being used for rice-fish culture.

The central issue of the present thesis is the identification of technological and socio-economical constraints of rice-fish culture (“on-farm”) in order to understand the reasons for the low application rate of rice-fish culture, and the investigation of agronomical and aquacultural improvements of rice-fish culture (“on-station”) to make the system more attractive for rice farmers. In chapter 3 and 4, a socio-economical assessment of the present situation of rice-fish with intensive rice cultivation was made, followed by a multiple regression analysis to identify technological constraints. Based on these results, two on-station experiments were conducted in order to test possible improvements of the rice-fish system. The results are presented in chapters 5, 6, and 7. In chapter 8 the practical implications of the research findings are discussed in relation to the socio-economical background of farmers in the Mekong delta, and suggestions are made for further research.

The socio-economical study of farmers practising rice culture with introduced fish, rice culture with indigenous fish, and rice monoculture indicated that household size, labour availability and educational level were not a constraint for the adoption of rice-fish culture (chapter 3). Rice-fish farming systems differed mainly from rice monoculture by a higher fertilizer- and water requirement and less pesticide use. The total farm cash- and net return did not differ among the farming systems. Despite the low fish yields and their rather insignificant contribution to the total farm return above variable costs (2.4%), integration of fish production in the farm was found to be important in terms of environmental sustainability and system biodiversity. A higher degree of farm diversification safeguards the household income against the risks associated with

fluctuations in rice market prices and crop failures, and enhances the food security of the household.

Fish husbandry- and rice culture management factors influencing the yield of introduced fish in rice-fish culture were studied by multiple regression analysis in chapter 4. A significant regression model was computed in which feed input and duration of culture period positively, and ricefield area, rice seeding rate and the year of the survey negatively affected the yield of introduced fish. The results indicated that low fish yields were basically the result of a combined effect of mortality and escape of fingerlings from ricefields, and a high rice seeding rate. High seeding rates probably resulted in a dense stand which suppressed the growth of fish. The year of the survey was found to be a significant factor because of an extreme flood in 1995 resulted in an average yield of introduced fish of 92.5 kg ha^{-1}, as compared to 164.8 kg ha^{-1} in 1994. Options for improvement of fish production are proper ricefield construction, reduced seeding rates, stocking fingerlings early in the dry season and more intensive feeding.

Rice and fish yields in concurrent, direct-seeded rice-fish culture during the dry season, with three different rice seeding rates (100, 200 and 300 kg ha^{-1}), in absence or presence of fish (*Oreochromis niloticus* (all male), *Puntius gonionotus*, and *Cyprinus carpio*) were investigated in chapter 5. Significantly higher paddy and fish yields were obtained at the lowest rice seeding rate. The presence of fish resulted in a significant reduction of the aquatic weed biomass, significant lower dissolved oxygen and PO_4 concentrations, and higher chlorophyll-a levels. Analysis of the results indicated that the effect of rice seeding rate on fish production was most likely related to a "growth effect" resulting from available oxygen and food. Paddy yields at high seeding densities were affected by mutual shading. As such this experiment confirmed that the factor “rice seeding rate”, identified by multiple regression from farmer’s data, is indeed a critical factor affecting the fish yield in rice-fish systems.

Rice production, ricefield environment, and the feeding ecology of fish were studied in chapter 6. In total 6 treatments (3 replicates) were investigated: 4 different polyculture combinations of small sized silver barb, Nile tilapia and common carp, 1 treatment with pre-grown fingerlings, and a control (no fish stocked). Frequent fertilization of the water and a low rice plant biomass during the early vegetative growth phase of the rice stimulated the development of phyto- and zooplankton, but populations declined afterwards due to progressive shading by the rice and a reduced nutrient availability. Temperature and oxygen varied often beyond the tolerance limits for most tropical fish species, and the construction of a refuge area (trench) was considered essential. The total weed biomass was low (maximal 5.3 g dw m^{-2}) and not significantly different among the treatments. A major component of the silver barb diet consisted of rice plants and accessible grains. The introduction of silver barb, however, had only a significant effect on the number of rice tillers in the ratoon crop, but not on the paddy yield. Quantitative differences in the diets of tilapia and common carp were minimal, both species fed mostly on detritus.

The fish production parameters of the 5 polyculture combinations from chapter 6 were analyzed more into detail in chapter 7. The survival rate was not significantly affected by the polyculture combination, but when grouped according to species, the mean survival of silver barb and tilapia was 64.3% and 63.7% respectively, significantly higher than the mean common carp survival rate (33.4%). In general, the growth of silver barb and tilapia was proportionally related to the stocking density, probably because of intraspecific competition. Since low tilapia numbers were associated with high silver barb numbers, a synergistic interaction between silver barb and tilapia could have influenced the growth of tilapia as well. The growth of common carp was not significantly different among the polyculture combinations. The highest net production (474.1 kg ha^{-1}) was obtained in the polyculture combination consisting of 80% small sized silver barb fingerlings, but the fish was not marketable at that time. It was argued that in concurrent rice-fish culture, large silver barb fingerlings are required. Small tilapia can be polycultured with silver barb, provided that a stocking density lower than 1400 ha^{-1} is maintained. Common carp was considered less suitable because of a limited tolerance for the water quality conditions in the ricefield and the large size required for the market.

Throughout the experiments no differences in paddy yield were found between rice-fish and rice monoculture, based on the seeded rice area (chapter 8). However, taken into account the un-planted area of a rice-fish field (11-16% was lost due to trenches and high dikes), the paddy yields were in fact lower than with rice monoculture. Lower paddy yields with rice-fish culture did not affect the total farm profitability because the more diverse rice-fish farms produced a variety of other products (vegetables, fruits, animals and fish). Therefore, some of the beneficial effects of rice-fish farming (system biodiversity, improved family nutrition etc.) are in fact the result of the integration of various agricultural activities within one farm, with fish as a minor component of the system. However, from the present study it became clear that fish itself, and the associated water management in rice-fish culture, diminish the need for herbicides and pesticides. Farmers are probably motivated to spray less frequently in rice-fish culture because of economic reasons (i.e. the risk of fish mortality). Both considerations support the view that rice-fish culture is complementary to Integrated Pest Management strategies.

For a further adoption of rice-fish culture, the economical incentive of the integration of fish in the farm should be improved. This can be achieved by reducing the fish operational costs (lower stocking density, appropriate feeding strategy), minimizing the trench area, and improving the fish yield through a reduction of the rice seeding rate, stocking fish early in the dry season and harvesting before October, and proper field construction. Within the context of the present thesis, it was argued that the most suitable fish species for concurrent rice-fish culture with intensive rice cultivation, are silver barb and Nile tilapia. It was hypothesized that nursing of silver barb fingerlings during the dry season rice crop, followed by a polyculture with small Nile tilapia fingerlings during the wet season rice crop and subsequent ratoon crop could result in a final production of 375 kg marketable silver barb ha^{-1} and 60 kg marketable tilapia ha^{-1}. In this situation the total farm return above variable costs would be circa 57% higher in comparison with rice monoculture.

SAMENVATTING

Rijst is het belangrijkste voedsel- en handelsgewas van Vietnam. Circa 52% van de totale Vietnamese rijst productie wordt gerealiseerd in the Mekong Delta, gelegen in het uiterste zuiden van Vietnam. Afhankelijk van de hydrologie en bodemvruchtbaarheid van een gebied vindt de rijstverbouw op meer of minder intensieve wijze plaats. Echter, intensieve teelt (twee of drie oogsten per jaar), welke gebruik maakt van kunstmest en bestrijdingsmiddelen tegen onkruiden, plagen en ziektes, is de belangrijkste teelt vorm. Recente studies tonen echter aan dat intensieve rijstteelt niet duurzaam is op de lange termijn. Gemengde bedrijfsvormen waarbij verschillende gewassen, dieren en vissen geïntegreerd worden gekweekt zouden een beter alternatief voor de verdere ontwikkeling van de landbouw in de Mekong Delta zijn.

Naast rijst is ook vis van groot belang voor de bewoners van de Mekong Delta. Gezien de betekenis van rijst en vis, en de noodzaak af te stappen van rijst monocultuur, kan men stellen dat een geïn tegreerde produktie van rijst en vis (rijst-visteelt) een goed alternatief voor rijst monocultuur is. Bovendien wijzen verschillende studies op een positieve interaktie van vis met rijst, hetgeen zou resulteren in hogere rijst opbrengsten. Uit onderzoek zou blijken dat vis bepaalde onkruiden, insecten en rijst ziekten kan bestrijden, en dat vis de bodemvruchtbaarheid verbetert. Toch is er van het totale rijst areaal in de Mekong Delta minder dan 5% geïntegreerd met vis.

Het centrale thema van deze thesis is het identificeren van de technologische en socio-economische beperkingen van rijst-visteelt, en het ontwikkelen van landbouwkundige en visteelt-technische verbeteringen van het systeem. In hoofdstuk 3 worden de resultaten van een socio-economische onderzoek van rijst-visteelt in de Mekong Delta besproken, gevolgd door een multiple-regressie analyse van dezelfde data set in hoofdstuk 4. Gebaseerd op de resultaten van dit onderzoek werden twee experimenten op een rijst-vis onderzoekstation gedaan, welke resultaten vermeld worden in hoofdstuk 5, 6, en 7. In het laatste hoofdstuk worden de bevindingen besproken in relatie tot de (socio)economische en praktische aspecten van rijst-visteelt, en worden aanbevelingen gedaan voor verder onderzoek.

Een vergelijking tussen rijst-visteelt met geïntroduceerde vis, rijst -visteelt met wilde vis, en rijst monocultuur liet zien dat de grootte van het huishouden (aantal personen), de beschikbaarheid van arbeidskrachten, en het opleidingsniveau geen obstakel vormden voor het uitoefenen van rijst-visteelt (hoofdstuk 3). Rijst-visteelt verschilde voornamelijk van rijst monocultuur middels een hoger verbruik van water en kunstmest, en een geringer verbruik van bestrijdingsmiddelen. De totale netto bedrijfsopbrengst was niet verschillend tussen de onderzochte bedrijfsvormen. Ondanks de lage vis oogst, en de geringe bijdrage van vis aan het totale bedrijfsresultaat, was de integratie van vis belangrijk vanwege gunstige milieu effecten en een grotere biodiversiteit welke de voedsel voorziening van het huishouden verbetert, en de economische risico's van rijst misoogsten afzwakt.

In hoofdstuk 4 kon een significant regressiemodel berekend worden voor de oogst van geïntroduceerde vis, met de voedsel gift en lengte van de groeiperiode als positieve factoren, en het oppervlakte van het rijstveld, rijst zaaidichtheid, en het jaar van onderzoek als negatieve factoren. Hieruit kon afgeleid worden dat lage vis oogsten voornamelijk het gevolg waren van een gecombineerd effect van sterfte en ontsnappen van vis. Daarnaast leidt een hoge rijst zaaidichtheid waarschijnlijk tot een dicht gewas welke resulteert in een slechte groei van de vis. Het jaar van onderzoek was ook een significante factor omdat een extreme overstroming in 1995 resulteerde in een gemiddelde vis oogst van 92.5 kg ha^{-1}, terwijl dit in 1994 164.8 kg ha^{-1} was. Mogelijkheden voor boeren om de vis produktie te verhogen zijn een goede aanleg van het rijst-vis veld, een lage zaaidichtheid, het uitzetten van vis vroeg in het droge seizoen, en meer bijvoeren.

In hoofdstuk 5 werd het effect van 3 zaaidichtheden (100, 200, en 300 kg ha^{-1}) in af- of aanwezigheid van vis (Nijl tilapia *Oreochromis niloticus* (monosex), zilver barbeel *Puntius gonionotus*, en karper *Cyprinus carpio*) op de rijst- en vis produktie tijdens het droge seizoen onderzocht. Significant hogere rijst en vis oogsten werden behaald bij de laagste zaaidichtheid. De aanwezigheid van vis resulteerde in een significante vermindering van onkruiden, en significant lagere zuurstof en PO_4 concentraties, en significant hogere chlorophyll-a gehaltes in het water. Analyse van deze gegevens liet zien dat het effect van de rijst zaaidichtheid op de vis produktie waarschijnlijk zijn oorzaak vindt in een groei afname tengevolge van een verminderende beschikbaarheid van zuurstof en voedsel. Hoge zaaidichtheden verminderden de rijst oogst ten gevolge van “zelf beschaduwing” door de rijst planten. Als zodanig bevestigde dit experiment deels de uitkomst van de studie uit hoofdstuk 4.

De relatie tussen de rijst oogst, het rijstveld milieu, en de voedsel ecologie van de vissen werd onderzocht in hoofdstuk 6. Zes behandelingen werden onderzocht (in drievoud): 4 verschillende polycultuur combinaties van zilver barbeel, Nijl tilapia en karper, 1 behandeling met voorgestrekte vis, en een controle waarbij geen vis uitgezet werd. Fyto- en zooplankton waren vooral in het begin, tijdens de vegetatieve rijst groei, in hoge concentraties aanwezig, maar namen daarna sterk af tengevolge van beschaduwing door rijst planten en een verminderd nutriënten aanbod. De temperatuur en het zuurstof gehalte in het rijstveld vertoonden grote schommelingen, welke de tolerantie grens van de meeste tropische vissoorten overschreed. De constructie van een diepe greppel rond het rijstveld is daarom essentieel voor de vis om deze periode te overleven. De totale onkruid biomassa was laag (maximaal 5.3 g droge stof m^{-2}), en niet significant verschillend tussen de behandelingen. Het voedsel van de zilver barbeel bestond voornamelijk uit rijst plant materiaal en rijst korrels, maar dit had geen significante daling van de rijst oogst tot gevolg. Tilapia en karper voeden zich voornamelijk met detritus.

De vis produktie parameters van de vissen uit hoofdstuk 6 werden in detail geanalyseerd in hoofdstuk 7. De overleving van de vissen werd niet beïnvloed door de behandeling, maar als de resultaten per soort bekeken werden dan bleek dat de gemiddelde overleving van zilver barbeel en tilapia (64.3% en 63.7% respectievelijk) significant hoger was dan die van karper (33.4%). De groei van zilver barbeel en tilapia was proportioneel aan de bezettingsdichtheid, waarschijnlijk vanwege intraspecifieke competitie. Doordat lage tilapia dichtheden geassocieerd werden met hoge zilver barbeel dichtheden kon een synergistische interaktie tussen tilapia en zilver barbeel niet uitgesloten worden. De groei van karper werd niet beïnvloed door de behandeling. De hoogste netto vis produktie (474.1 kg ha^{-1}) werd bereikt in de combinatie bestaande uit 80% kleine zilver barbeel, maar de vis was niet marktwaardig aan het einde van het experiment. In de praktijk van rijst-visteelt is voorstrekken van zilver barbeel noodzakelijk. Dit is niet noodzakelijk voor tilapia, maar de bezettingsdichtheid zou lager dan 1400 ha^{-1} moeten zijn. Karper is waarschijnlijk minder geschikt voor rijst-visteelt vanwege zijn mindere tolerantie voor de slechte water kwaliteit in het rijstveld, en zijn hoge marktgewicht.

Uit de resultaten van deze studie werd geen effect van vis op de rijst oogst gevonden (hoofdstuk 8). Gebaseerd op de beplante rijst oppervlakte waren de opbrengsten niet significant verschillend tussen rijst-vis en rijst monocultuur. Echter, de beplantbare oppervlakte van een rijst-vis veld is lager in vergelijking met een rijst monocultuur veld vanwege de perifere greppel en hogere dijken. Hierdoor is de uiteindelijke rijst oogst per totale bedrijfs oppervlakte lager. Dat dit niet resulteerde in een lager economisch bedrijfsresultaat is te wijten aan de meeropbrengst van andere produkten dan rijst, zoals groenten, fruit, dieren (pluimvee, varkens) en vis. In feite zijn sommige voordelen van rijst-vis (biodiversiteit, verbeterde voedselvoorziening) het gevolg van de integratie van verschillende landbouwkundige aktiviteiten in één bedrijf, waarvan vis niet de belangrijkste vormt. Echter, uit de huidige studie is wel duidelijk naar voren gekomen dat vis, en het daarmee samenhangende water management, de noodzaak tot pesticide gebruik aanzienlijk vermindert. Ook boeren spuiten minder frequent pesticiden, maar waarschijnlijk vooral vanwege de economische noodzaak (het risico van vis sterfte). In beide gevallen kan geconcludeerd worden dat rijst-visteelt zeer goed aansluit op IPM (Integrated Pest Management).

Voor een verdere uitbreiding van rijst-visteelt moet de winstgevendheid van de vis component verbeterd worden. Dit is mogelijk indien de kosten verlaagd worden (lagere bezettingsdichtheid, juiste voeder strategie), de oppervlakte van de greppel tot een minimum beperkt wordt, en de opbrengst van de vis verhoogt wordt door een lagere zaaidichtheid te gebruiken, de vis uit te zetten aan het begin van de droge periode en te oogsten voor oktober, en een goede aanleg van het veld. De meest geschikte vissoorten voor integratie met intensieve rijstteelt in de Mekong Delta zijn zilver barbeel en Nijl tilapia. Indien zilver barbeel voorgestrekt wordt tijdens het droge seizoen, en vervolgens tezamen met klein tilapia broed in het natte seizoen opgekweekt wordt tot het marktgewicht, is de verwachte oogst circa 375 kg zilver barbeel en 60 kg tilapia ha^{-1}. Dit betekent dat de totale bedrijfsopbrengst na aftrek van operationele kosten circa 57% hoger zal zijn in vergelijking met rijst monocultuur.

CURRICULUM VITAE

Arjo (Arie Johannes) Rothuis was born in Mill (the Netherlands), on 22 June 1959. In 1977 he graduated from the “Wagenings Lyceum”, and started his study at the Wageningen Agricultural University. In 1984 he obtained his M.Sc. degree, with majors in Aquaculture and Aquatic Ecology. Hereafter he worked circa one year as a research assistant at the Department of Fish Culture and Fisheries of the Wageningen Agricultural University.

However, during his practical period in Egypt he developed a strong interest in tropical aquaculture, and when the opportunity came he left for Vietnam at the end of 1985. Based in Can Tho, he worked as an aquaculture specialist for the ”Artemia Project”, and contributed to the start of successful commercial Artemia cyst production in the coastal zone of the Mekong Delta.

From 1987 to 1991 he joined the Food and Agricultural Organization (FAO), and worked as an associate expert in Zambia (integrated freshwater fish culture) and Madagascar (marine shrimp culture).

The acquired experience in tropical aquaculture and project management gave him the opportunity to work as a consultant. He carried out several missions for the Dutch Committee for Science and Technology for Vietnam, the EC and for DGIS, in Vietnam and Zambia.

In 1992 he worked again for the Department of Fish Culture and Fisheries of the Wageningen Agricultural University, as expert for the “Fish Farming at Village Level Project” in Nigeria. Unfortunately, the project did not come beyond the preparatory phase. Instead, Arjo prepared a course on shrimp aquaculture, and participated in technical consultations for FAO and the EC.

Between 1993 and 1995 he worked for a private company where his main responsibility was to provide technical support for aquaculture enterprises in the Middle- and Far East, the marketing of aquatic feeds in that region, and market research.

Nevertheless, aquatic resources management in tropical countries continued to be his primary interest, and therefore he (and his family) left once more the Netherlands in 1995 for a contract in Vietnam. Until October 1997, Arjo worked as project manager for the “Rice-Fish Farming Project” on behalf of the University of Leuven. Afterwards, he started working on this thesis. It is his wish to continue working in Development Co-operation projects in the near future.

CHAPTER 1

GENERAL INTRODUCTION

1.1. VIETNAM

Vietnam is located in Southeast Asia, between latitude 8°30' N and 23°22' N, and has a north to south extension of approximately 1650 km. The total land area is about 330,000 km^2, basically consisting of mountainous areas (circa 80%) and plains of which the red River Delta in the north and the Mekong River Delta in the south are the most important ones (fig.3.1, chapter 3).

Vietnam has an agricultural economy. Rice is the traditional food crop, and the 1995 production was estimated to be approximately 25 million ton (Anon. 1996), making Vietnam one of the largest rice exporting countries in the world.

The total fish production in 1992 was 1,086,800 metric ton, of which aquaculture contributed circa 30% (Thuoc 1995). In general, aquacultural production systems in Vietnam can be categorized as: 1) Coastal aquaculture in lagoons, ponds, and cages; 2) Inland aquaculture in large water bodies such as lakes and reservoirs; 3) Inland aquaculture in small water bodies and fish ponds; 4) Cage culture in inland waters and sheltered coastal areas; 5) Aquaculture in ricefields. With the exception of cage culture, most aquacultural systems are extensive or semi-intensive of nature, and based on fertilization and supplementary feeding with agro-by products.

1.2. THE VIETNAMESE MEKONG DELTA

1.2.1. Background

With a length of 4425 km, the Mekong is the tenth largest river of the world. From the source in Tibet, the river flows through parts of China, Myanmar, Thailand, Laos, Cambodia, and Vietnam where the river discharges in the South China sea through a dense network of streams and canals.

The Vietnamese Mekong Delta covers an area of 39,000 km^2. With a population of circa 16 million people it contributes significantly to national exports (circa 30% to the national Gross Domestic Product in 1990), particularly through rice and fish products (Nedeco 1993). Paddy (rough unprocessed rice) production in the Mekong Delta amounted to circa 13 million tons in 1995, 52% of the total Vietnamese production (Anon. 1996). The Mekong Delta fisheries production amounted to approximately 480,000 t in 1991, of which 35% originated from aquaculture (Nedeco 1993)

Fish is a major source of animal protein in the diet of the Delta's inhabitants, estimated to contribute circa 60% of their total animal protein intake. The average yearly consumption of fresh fish products was estimated at 21 kg capita^{-1}, which is high as compared to neighbouring areas (Cambodia 16.5 kg in 1990, Northeast Thailand 12.5 kg) and to Vietnam as a whole (12 kg capita^{-1} year^{-1}), but substantially lower than recommended by the National Institute of Nutrition (Nedeco 1993).

1.2.2. Agro-ecosystems[1]

The Vietnamese Mekong Delta is a flat plain with elevation 0-1.5 m above mean sea level. The two main physical factors influencing land use are hydrology and soil type.

Hydrology is determined by rainfall, upstream discharge and tidal fluctuations. Rainfall in the Lower Mekong basin -consisting of 77% of the total catchment area- is concentrated between May and November. Combined with upstream discharge, large parts of the Mekong Delta become flooded every year between August and October. The inundation level depends on the drainage capacity of a particular area, but in general three zones can be differentiated: a deep water zone (circa 1.5-3.0 m), a semi-deep water zone (circa 0.6-1.5 m), and a shallow water zone (<0.6 m) (fig.3.1 in chapter 3). Although flooding can cause severe damage to the infrastructure, most farmers have adapted their cultivation practises accordingly so that direct agricultural damage only occurs during extreme weather conditions. A positive effect of flooding is the deposition of sediments in the flood plain which contributes to the soil fertility.

In the dry season water discharge from the Mekong river is low, and large parts of the coastal zone become affected by salt water intrusion (fig. 1.1).

Basic soil types in the Mekong Delta are: alluvial soils along the river banks

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[1] After Nedeco (1993)

(31% of the total area), saline soils in the coastal plain (19%), and acid sulphate soils (41%). Alluvial soils have a high natural fertility and are suitable for agriculture. Temporary saline soils can be used for rice cultivation during the wet season only. Severe acid soils have little agricultural possibilities, but under good management moderate acid soils can be used for agriculture.

Circa 74% of the total agricultural area of the Mekong Delta is used for rice cultivation. This is the result of appropriate physical conditions, but also from tradition and policy. The intensity of rice cultivation (number of crops per year, traditional or improved varieties, input use etc.) and possible cultivation of other (upland) crops differs according to the specific hydrological and soil conditions of a particular area (fig. 1.2). Intensive rice cultivation (two or three crops per year) takes place on 54% of the total rice area. The area under triple rice cropping is rapidly increasing at a rate of circa 10,000 ha per year.

1.2.3. Problems in rice cultivation

Continuing intensification of rice cultivation has both technical and economical limits, and may not be sustainable on the long term because of environmental degradation (Nedeco 1993). A year round rice monoculture (triple rice) may harm soil fertility and increase the risk of outbursts of plant diseases due to growing resistance for pesticides. Brown plant hopper infestation in the Mekong Delta has been related to misuse of pesticides. Noda, Loc & Du (1997) reported that farmers applied 5-20 sprayings of broad spectrum insecticides per rice crop. These authors also discussed the benefits of Integrated Pest Management (IPM) strategies. The increased reliance on large quantities of fertilizers and pesticides has also negatively affected the economic profitability of intensive rice monoculture (Duong 1994). Crop diversification and integrated crop-livestock-fish farming systems (a.o. rice-fish culture), in combination with IPM techniques, is of particular relevance for the future development of agriculture in the Mekong Delta.

1.3. RICE-FISH CULTURE

1.3.1. History of rice-fish culture

Rice culture has been practised in Asia for 5000-6000 years, and the harvesting of wild fish from ricefields can be considered as a prelude to fish culture (Fernando 1993). The earliest records of fish culture in ricefields originate from China, circa 2000 years ago (Li 1988), followed by India, 1500 years ago (Tamura 1961). Other countries with a recorded history of rice-fish culture are Indonesia, Malaysia, Thailand, Japan, Madagascar, Italy and Russia (after Halwart, 1994). Also in northern Vietnam and Lao PDR rice-fish culture is a traditional farming system (Chevey & Lemasson 1937, cited in Edwards, Little & Yakupitiyage 1997).

In the Mekong Delta, the collection of indigenous fish from ricefields probably dates back to the 15th century when the first people settled in the lowland area (Chiem 1994). Aquaculture in ricefields is a more recent activity.

1.3.2. Present rice-fish systems in the Mekong Delta

1.3.2.1. Rice-fish with single rice cultivation

Cultivation of a single rainfed rice crop takes place mostly in the coastal area of the Mekong Delta and the Ca Mau peninsula. Brackish water intrusion during the dry season permits the cultivation of a second rice crop. Rice varieties are mostly traditional. At the onset of the wet season the fields are flushed with rain water, and when the soil salinity has decreased sufficiently, rice is planted. The cultivation period is approximately 150-180 days. Fertilizers and pesticides are used at limited quantities. Rice yields are in the order of 2-3 ton ha^{-1} (Can 1994).

Concurrent rice-fish systems are based mostly on indigenous fish. Snakeskin gourami, *Trichogaster pectoralis* (Regan) broodstock are collected from natural sources and released into the ricefield at the onset of the wet season, where they reproduce and are left to grow for 6-8 months. Deliberately collected or from natural influx, other indigenous fish such as snakehead, *Channa striata* (Bloch), climbing perch, *Anabas testudineus* (Bloch), *Notopterus notopterus* (Pallas), and *Clarias* spp. enter the ricefield as well. No supplementary feeds are provided. Fish yields are in the order of 100-500 kg ha^{-1} (Can 1994; Duong & Rothuis 1997).

A traditional rotation of rice and shrimp is also practised in this area. With the rise in salinity at the onset of the dry season, ricefields are flushed again to allow brackish water fish and shrimp to enter the fields. However, due to a decline in wild seed and low market prices of small sized shrimp, this system has been replaced by the stocking of hatchery produced shrimp juveniles (mostly *Penaeus monodon* Fab.). With supplementary feeding yields are in the order of 200 kg ha^{-1}, and profits a factor 10 higher as compared to the traditional system (Ut, Quang, Nghia, Bosteels & Rothuis 1995). The success of this system encouraged many farmers to convert their ricefields into permanent shrimp ponds. However, the uncontrolled expansion of shrimp culture without the facilitating hydrological infrastructure and legislation, combined with poor pond management brought about a collapse of this system in 1995.

1.3.2.2. Rice-fish with intensive rice cultivation

Intensive rice cultivation (2 or 3 crops a year) takes place mostly in the central area of the Mekong Delta. Soils are primarily of alluvial origin, flood levels are in the order of 0.6-1.5 m, and the area is not affected by salt water intrusion. The rice varieties are mostly high yielding, short duration (100-120 days), require fertilizers, and pesticides for the control of weeds, insect pests and diseases. The first rice crop is established directly after the flood recedes, usually in November and harvested in January or February. Irrigation water is provided by pumping (or by gravity) from the numerous canals and streams. After a short fallow period, one or two more crops can be produced in the wet season. Typical yields are 6, 4 and 3 ton ha^{-1} respectively for the first, second and third rice crop.

Although the harvest of indigenous fish from ricefields is still practised in this area, most rice-fish farmers stock hatchery-produced fingerlings in response to declining yields of wild fish. It is believed that this decline is caused by an intensification of the rice cultivation which has made the ricefield environment less suitable for fish production. The fields are levelled, water is shallow and present for a short period only. Fertilizer and pesticides are used at high quantities (Interim Committee for Coordination of Investigations of the Lower Mekong Basin 1992). Furthermore, the yield of wild fish from ricefields is also affected by a growing fishing effort in rivers and irrigation canals.

Commonly stocked fish species are species silver barb *Puntius gonionotus* (Bleeker), common carp *Cyprinus carpio* (L.), Nile tilapia *Oreochromis niloticus* (L.), and silver carp *Hypophthalmichthys molitrix* (Val.). To increase the natural productivity of the ricefield, supplementary feeds such as rice bran, water spinach (*Ipomea aquatica* Forskal) and sweet potato are provided. Fish yields are in the order of 100-700 kg ha^{-1} (Duong 1994).

Wild juveniles of fresh water prawn (*Macrobrachium rosenbergii* DeMan) are also stocked in ricefields in this area. Yields range from circa 100-350 kg ha^{-1} for one annual crop (Sanh, Phu, Villanueva & Dalsgaard 1993; Duong 1994). Although the income from prawns is much higher than from fish, the major constraints of this system are the scarcity of prawn juveniles and associated high seed costs, risks of poaching, and disease problems related to water pollution.

1.3.3. Synergisms in rice-fish culture

The integration of rice and fish has a beneficial effect on the rice yield. Ruddle (1982) reported a 15% increase in rice yield when fish are stocked. In an analysis of 18 rice-fish studies Lightfoot, van Dam & Costa-Pierce (1992) found a similar trend, which could be explained in part by the specific rice-fish agronomy, and in part by direct positive effects of fish.

The high water levels and the precise water control required for the fish reduce weed emergence and growth, which has a positive impact on the rice yield (Bhagat, Bhuiyan & Moody, 1996). Direct control of weeds in ricefields is possible by herbivorous fish such as grass carp (*Ctenopharyngodon idella* Val.), Tilapias (*zillii* Gervais, *rendalii* Boul.) and silver barb (*Puntius gonionotus* Bleeker). Bottom feeding fish such as common carp (*Cyprinus carpio* L.) can uproot submerged and emergent weeds, and through soil perturbation increase water turbidity which supresses the development of (especially) submerged weeds (Ruddle 1982; Cagauan 1995).

Other direct beneficial effects of fish on the rice yield are related to pest control, improved soil fertility, and a reduction of nitrogen losses through volatilization. Fish can control insect pests which pass a part of their life cycle in the water or at the base of the rice plant, or insects which fall into the water (Cagauan 1995). This has been reported a.o. for leafhoppers, planthoppers, leaffolders stemborers (Cagauan 1995; Xiao Fan 1995), and caseworm (Vromant, Rothuis, Cuc & Ollevier 1998). Control by fish of rice diseases was observed for sheath blight (Xiao 1992, cited in Cagauan 1995), narrow brown leaf spot, and bacterial leaf blight (MacKay 1986, cited in Cagauan 1995). In general, the pest organisms are consumed directly by the fish.

Lightfoot et al. (1992) discussed the various mechanisms by which fish contribute to soil fertility. Decomposition of fish excrement increases nitrogen accumulation at the soil surface. Furthermore, reduction of the algal biomass from fish grazing decreases the photosynthetic intensity and keeps the pH of the water near neutral, which in turn reduces NH_3 losses via volatilization. Nitrogen volatilization is further reduced by bottom feeding fish through oxydation of the top soil which slows the denitrification process.

1.3.4. Prospects for rice-fish culture in the Mekong Delta

Despite the large rice area in the Mekong Delta, the importance of fish products and the favourable conditions for fish production, the need for development of sustainable integrated farming systems, and the proclaimed benefits of rice-fish culture, the integrated production of rice and fish is not popular among farmers. At present, less than 5% of the total rice area is being used for rice-fish culture. In other countries in the Southeast Asian region this figure is even lower: China 3%, Indonesia 1%, the Philippines and Korea less than 0.05% (Choudhury, 1995). Therefore, an analysis of the causes for the low application rate of rice-fish culture by farmers is important. Hence, a collaborative research project was initiated by the Mekong Delta Farming Systems Research & Development (Can Tho University) and the Katholieke Universiteit Leuven (Laboratory of Ecology & Aquaculture, and Laboratory of Soil Fertility & Soil Biology). The project, “Impact analysis and improvement of rice-fish farming systems in the semi-deep water area of the Mekong Delta, Vietnam”, was supported by the Flemish Interuniversity Council (Vl.I.R.) through funds provided by the Belgian Development Co-operation (BADC).

1.4. OBJECTIVES OF THE STUDY

The overall objective of the project was to contribute to improvement of the living conditions of small scale rice farmers in the Mekong Delta of Vietnam, through the integration of fish culture in their farming system. In the present thesis a part of the project research findings from May 1995 to September 1997 are presented. The central issue of the thesis is the identification of technical and socio-economical constraints of rice-fish culture with intensive rice cultivation (“on-farm”), and the investigation of possible agronomical and aquacultural improvements of rice-fish culture (“on-station”), with respect to practical aspects of rice-fish culture and the socio-economical background of the farmers. More specific objectives are:

1). Investigation of the effect of rice seeding rate on fish production, and determination of interactions between rice seeding rate, weed abundance, rice yield and the aquatic environment (water quality, plankton and benthos).

2). Investigation of the interaction between fish species combination, rice production and the ricefield environment, in relation to the feeding ecology of the fish

3). Investigation of the performance of silver barb, Nile tilapia and common carp at different polyculture combinations.

4). Investigation of the possibility to raise fish in ricefields to a marketable size by stocking pre-grown fingerlings

Other aspects of rice-fish culture, derived from above specific objectives, discussed in the present thesis are: the relationship between the developing rice plants and the aquatic environment (phyto- and zooplankton, periphyton, oxygen, temperature, pH and nutrients), and the ability of fish to control weeds in ricefields.

The general approach of the on-station research carried out under the framework of the collaborative research project has been to study the entire rice-fish ecosystem (i.e. rice, fish, soil, water, insects etc.). The present thesis does not present a comprehensive analysis of all these aspects, and as such can not be regarded as a final project report. Only after project closure in March 1999, such an analysis could be undertaken.

1.5 GENERAL CONCEPT OF THE THESIS

According to the formulated objectives, the thesis is presented into three sections.

A socio-economical assessment of the present situation of rice-fish with intensive rice cultivation was made, followed by a multiple regression analysis to identify technological constraints (chapters 3 and 4).

Based on these results, two on-station experiments were conducted in order to test possible improvements of the rice-fish system (chapters 5, 6, and 7).

The practical implications of the research findings are discussed in relation to the socio-economical background of farmers in the Mekong delta, and suggestions are made for further research (chapter 8).

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CHAPTER 2

DESCRIPTION OF THE STUDY AREA AND EXPERIMENTAL STATION

2.1 THE CO DO CO-OPERATIVE FARMING AREA

The Co Do (“red flag”) Co-operative covers an area of circa 6000 ha. It is located in the so called “West Bassac” region, circa 50 km NW of Can Tho city, on the border of Can Tho and Kien Giang Provinces (fig. 3.1 chapter 3). Average annual rainfall is in the order of 1500 mm, average air temperature 26-27 ^{o}C. Basic soil types are alluvial and slightly acidic. Flood levels vary between 0.5-1.0 m (semi-deep). Dominant land use is double, and since 1995, triple rice cropping (table 2.1). Total rice (paddy) production in 1994 was 42,000 ton. As such, the area is representative for the intensive rice-fish system.

Table 2.1. Distribution of land use in Co Do, 1995

Land use	Area (ha)	Distribution (%)
Double rice	4318	81
Triple rice	1014	19
Fish ponds	7	0.1
Total Agriculture	5339	

Under the colonial regime, the area was managed by a French landlord as a large-scale rice plantation. After 1954 the ownership changed to successive governmental officials. In 1967 the land was sold to individual farmers. Under the land reformation in 1973, the land was re-distributed, with a maximum area of 3 ha per farmer. After the unification of North and South Vietnam in 1975, the area was managed by the army. In 1977 it was converted into a state farm and all farming activities were planned by the government (Ministry of Agriculture). In 1989 the management of the state farm changed to the Provincial Department of Agriculture. Since 1990, farmers have a 20 year lease contract for the land they cultivate. Decisions regarding land use, cropping pattern and marketing are made by the farmer himself.

Nowadays, the former state farm functions as a kind of co-operative. Farmers can obtain loans to purchase farm inputs (fertilizer, pesticides etc.) or can get these in kind. Repayment is done either in cash or in rice. Farmers can sell their products to the co-operative, or on the market. Prices at the co-operative are more stable and usually slightly higher than market prices. Furthermore, the co-operative provides technical assistance, health care services, and elementary education. Although Co Do functions as a co-operative, it is owned by the state. The farmers are not shareholders.

Circa 2400 households are living in the Co Do co-operative, of which about 5 % belongs to an ethnic minority (mostly Khmer).

Integrated rice-fish culture in Co Do first started in the early 1990’s.

2.2 THE CO DO EXPERIMENTAL STATION

The experimental rice-fish station is located within the territory of the Co Do Co-operative Farm, and was constructed in 1995. The total area is approximately 2 ha, consisting of 18 experimental rice-fish fields of each 650 m^2, 3 fish ponds (total 2800 m^2), separate irrigation and drainage canals, and a field laboratory annex staff accommodation (fig. 2.1). Besides the experimental facilities, a rice-fish demonstration field of 2000 m^2 is situated on the same station. The soil consists of heavy clay (Typic Tropaquepts) of alluvial origin (Nhan pers.inf.). The water originates from the main irrigation canal of the Co Do co-operative farming area, which also supplies water to neighbouring rice farms.

Since the experimental rice-fish fields are spread out over a large area, a possible effect of the location of a particular field on the rice- or fish yield could not be excluded. Therefore, the first experiment (chapter 6 and 7) was laid out as a randomized complete block design in which 6 apparently related experimental fields were grouped into one block, in order to minimize the variability within each block. However, after analyzing the results, no significant block effect was found for rice and fish yield. Subsequently, the next experiment was carried out in a complete randomized design (chapter 5).

CHAPTER 3

RICE WITH FISH CULTURE IN THE SEMI-DEEP WATERS OF THE MEKONG DELTA, VIETNAM: A SOCIO-ECONOMICAL SURVEY

ABSTRACT

The results of a socio-economical survey of farming systems practicing rice culture with introduced fish, rice culture with indigenous fish and rice monoculture in the semi-deep waters of the Mekong Delta, Vietnam, are presented. Rice and fish yields, inputs and cost-benefits were computed to evaluate the agricultural effects of rice with fish culture. Household size, labour availability and educational level were not significantly different among the three farming systems. Rice-fish farming systems differed mainly from rice monoculture by a higher fertilizer/water requirement and less pesticide use. The total farm cash- and net return did not differ among the farming systems. The main beneficial effects of rice-fish culture are thought to be related to environmental sustainability, system biodiversity, farm diversification and household nutrition.

3.1. INTRODUCTION

A flooded rice field is a productive ecosystem that can sustain a variety of aquatic organisms including fish (Fernando 1993). Fish itself are generally presumed to have a beneficial effect on the rice production (Ruddle 1982; Lightfoot, van Dam & Costa-Pierce 1992a). The integration of rice and fish production is recognized as an efficient means for agricultural land use (Khoo & Tan 1980), and offers great potential in terms of animal protein supply and income generation for small-scale rice farmers (Mukherjee 1995). Despite these proclaimed benefits, rice-fish culture has not been widely adopted by Asian rice farmers. Fish is usually regarded as a secondary crop. The rice production is being intensified by growing fast maturing, short stem varieties which require fertilizer and pesticides. These factors restrict fish production in the ricefield (Koesoemandinata 1980), and therefore require modification of certain agronomic practices, such as selective pesticide use (Cagauan & Arce 1992) and the construction of fish refuges. These activities in turn influence the economic profitability of rice production (Grover 1979).

In the Vietnamese Mekong Delta, collection of indigenous fish from rice fields probably dates back to the 15th century when the first people settled in the lowland area (Chiem 1994). Nowadays, rice cultivation is the major land use type, and areas under irrigation control are increasing year by year. In response to declining yields of indigenous fish, farmers stock ricefields with hatchery-produced fingerlings. To sustain domestic fish consumption and export earnings in the near future, the fish production from ricefields is considered to increase substantially (Nedeco 1993). However, presently only circa 2% of the total rice area is used for rice-fish culture (Interim Committee Lower Mekong Basin 1992).

In this paper the results of a socio-economical survey of farming systems practicing rice culture with introduced fish (**R-Intro.F**), rice culture with indigenous fish (**R-Ind.F**), and rice monoculture (**RM**) in the semi-deep water area of the Vietnamese Mekong Delta are presented. Rice/fish yields, inputs and costs-benefits are computed to evaluate possible beneficial effects of rice with fish culture.

3.2. MATERIALS AND METHODS

3.2.1. The study area

In the Mekong Delta rainfall is concentrated between May and November. Combined with upstream discharge, large parts of the Delta become flooded every year between August and December. The inundation level depends on the drainage capacity of a particular area, but in general three zones are differentiated: a deep water zone (circa 1.5-3.0 m), a semi-deep water zone (circa 0.6-1.5 m), and a shallow water zone (<0.6 m). The present study was undertaken within the vicinity of the cooperative farm at Co Do, which encompasses an area of approximately 6000 ha, situated in the semi-deep water zone (Fig.3.1). In Co Do the dominant farming system is double cropped, irrigated rice, using high yielding varieties.

3.2.2. Methodology

The survey covered the period between March 1994 and February 1995. R-Intro.F and R-Ind.F farming systems were marked on a topographical map of the study area. Subsequently, 48 and 11 farms of each system respectively were sampled ad random, and completed with 37 RM farms. For the interviews a combination of a structurized, pre-tested questionnaire and a pictorial modeling method was used (Lightfoot & Noble 1993). Since most farmers buy inputs and sell products through the cooperative, data on input use and production could be cross checked.

Fig.3.2 Resource systems transect of the rice and fish systems in the Co Do area.

For analysis of the rice enterprise of R-Intro.F and R-Ind.F systems, data on rice production, input use and economics were based on the rice-fish field only. If rice-fish farmers cultivated a second ricefield as rice monoculture, these data were included in the analysis of the whole farm profitability. Total costs (**TC**) consisted of costs not related to the crop (fixed costs, **FC**) and costs specific for a crop (variable costs, **VC**). In the present study fixed costs consisted of land tax, and depreciation of the construction costs of the trench and dike over 10 years (only for rice-fish farming systems). Of the variable costs, family labour was valued at opportunity costs at a particular season as indicated by the interviewed farmer. Family labour for the different farming activities were only calculated for very specific works, and valued at opportunity costs for that specific activity. Works that could not be specified clearly (e.g. feeding of fish) were excluded from the cost calculation. Hired labour included the costs for hiring machinery. Interest costs were not specified since the majority of the farmers cover operational costs through credits in kind supplied by the cooperative. Repayment is done with paddy rice, the quantity of which is based on the market price and added interest. Therefore, interest costs are part of the variable costs. The gross return (**GR**) (value of total output) was based on the farm-gate prices. The following profitability indicators were calculated[2]:

return above variable costs (**RAVC**) = GR - VC
cash return (**CR**) = GR in cash - TC in cash
net return (**NR**) = GR - TC
profit-cost ratio (**PCR**) = total farm net return / total farm TC.

Variations in farm- and household characteristics, rice and fish production, input use, and profitability were analyzed using ANOVA or the non-parametric Kruskal-Wallis test, factors being R-Intro.F, R-Ind.F, and RM. In case an effect was significant, means were compared with the Least Significant Difference test, or the Mann-Whitney-U test (Sokal & Rohlf 1981). All significance testing was done at the 0.05 level. The coefficient of variation (**CV** %) was calculated as: CV = standard deviation / mean * 100.

3.3. RESULTS

3.3.1. Farming systems and household characteristics

Four resource systems could be differentiated in the farms: the homestead, fishpond, ricefield and dike (Fig. 3.2). Usually, the homestead is build on an elevation made by excavated soil. The resulting depression is used as fishpond. The major characteristics of a rice-fish field (both for R-Intro.F and R-Ind.F) are the heightened dike (to confine the fish at times of high flood levels) and the trench at the periphery of the ricefield as fish refuge. The fishpond is often connected to the ricefield to increase the fish refuge area. In double-cropped rice, the first crop is grown in the dry season between November and February, the second in the wet season from April to July. In R-Intro.F fish is usually stocked during the establishment of the wet season rice crop and harvested 9 months later, after the harvest of the dry season rice crop. At this time fish from the R-Ind.F system is also harvested. Vegetables and fruits are cultivated at the homestead, and -in the case of rice-fish culture- at the heightened dike. Most farmers raised poultry at the homestead, and 50% of the interviewed farmers kept at least one pig. Circa 40% of the rice-fish farmers also practiced rice monoculture.

The total farm area ranged from 2.79 ha for R-Ind.F to 2.22 ha for RM, the latter being significantly smaller than the 2.64 ha of R-Intro.F (Table 3.1). In rice-fish farms the dike and trench occupied 11-16 % of the former ricefield area and this explains the significant higher total ricefield/total farm ratio in rice monoculture as compared to those of rice with fish culture.

Household size, labour availability and educational level were not significantly different among the three farming systems (Table 3.2).

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[2] 11,000 Vietnamese Dong was valued at one US Dollar

Table 3.1. Physical characteristics of the different farming systems (means; standard deviation in parenthesis).

Item	R-Intro.F.	R-Ind.F.	RM
Homestead (m^2)	676 (440)	518 (343)	446 (188)
Fish pond (m^2)	281 (134)	213 (180)	224 (240)
Dike (m^2)	1906 $(951)^a$	1559 $(1549)^a$	173 $(575)^b$
Ricefield for rice-fish (ha)	1.69 (0.96)	1.90 (1.74)	-
Trench (m^2)	1599 (866)	1128 (660)	-
Total fish refuge (m^2)	1822 (875)	1288 (730)	-
Refuge/ricefield (%)	14.4 (10.1)	9.7 (6.2)	-
Ricefield for rice monoculture (ha)	0.50 $(0.84)^a$	0.55 $(0.79)^a$	2.14 $(0.69)^b$
Total farm area (ha)	2.64 $(0.87)^a$	2.79 $(1.62)^{a,b}$	2.22 $(0.67)^b$
Total ricefield/total farm (%)	82.5 $(7.05)^a$	87.2 $(4.53)^b$	96.0 $(3.90)^c$

Farming system effect: indices with the same superscript are not significant different at the 0.05 level.

Table 3.2. Household size (total number of on-farm and off-farm members), labour availability (number of on-farm members with age between 17 and 60 years) and educational level of the farm members of the different (means; standard deviation in parenthesis)

	R.Intro.F.	R.Ind.F.	RM
Household size	6.0 (2.6)	5.3 (1.8)	5.9 (2.2)
Labour availability$^{1)}$	3.0 (1.5)	3.0 (1.6)	2.9 (1.2)
Education (%)			
Elementary	48.9 (31.2)	48.2 (19.2)	59.7 (25.4)
Secondary	27.6 (25.0)	31.9 (16.6)	21.4 (20.6)
Higher	11.7 (22.8)	4.8 (8.8)	6.5 (14.4)

3.3.2. Rice production and inputs

Rice seeding rates as well as rice yields were not different among the three farming systems, for both the dry- and wet season crop (Table 3.3). The N and P_2O_5 input for the dry season rice crop was significantly higher for R-Intro.F than for RM. Pesticide application in the dry season did not differ among the three farming systems. In the wet season fertilizer use did not differ, but significantly less pesticide sprays were applied in the R-Intro.F farming system.

Table 3.3. Rice production and inputs of the different farming systems (means; standard deviation in parenthesis).

	R-Intro.F.	R-Ind.F.	RM
RICE YIELD (TON/HA)			
Dry season crop	5.6 (0.9)	5.5 (0.9)	5.9 (0.7)
Wet season crop	3.7 (0.9)	3.8 (0.7)	4.0 (0.6)
INPUTS DRY SEASON			
Rice seed (kg/ha)	251 (42)	263 (22)	239 (25)
Fertilizer:			
Total kg N/ha	119 (26)^{a}	108 (18)^{a,b}	105 (16)^{b}
Total kg P_2O_5/ha	57 (13)^{a}	48 (10)^{a,b}	50 (14)^{b}
Total kg K/ha	8.9 (6.4)	6.4 (3.1)	7.4 (4.1)a
Pesticides:			
(Number of sprays/farmer)			
Insecticides	1.4 (1.2)	0.8 (1.3)	1.7 (1.5)
Fungicides	1.2 (0.9)	1.4 (0.9)	1.1 (1.0)
Herbicides	1.5 (0.8)	1.7 (0.6)	1.4 (0.8)
Total	4.0 (1.9)	3.9 (1.8)	4.2 (1.8)
INPUTS WET SEASON			
Rice seed (kg/ha)	242 (41)	262 (23)	239 (28)
Fertilizer:			
Total kg N/ha	118 (23)	103 (16)	109 (20)
Total kg P_2O_5/ha	54 (15)	49 (18)	52 (15)
Total kg K/ha	10 (7.3)	6.9 (2.6)	8.3 (6.1)
Pesticides:			
(Number of sprays/farmer)			
Insecticides	1.5 (1.3)	1.5 (1.2)	2.2 (1.4)
Fungicides	1.0 (0.8)	1.6 (1.0)	1.2 (1.0)
Herbicides	1.6 (0.9)	2.2 (0.8)	1.8 (0.8)
Total	4.1 (2.0)^{a}	5.4 (1.4)^{b}	5.3 (1.4)^{b}

Farming system effect: indices with the same superscript are not significant different at the 0.05 level.

3.3.3. Production of introduced and indigenous fish

The major cultured species were silver barb, *Puntius gonionotus* (Bleeker), common carp, *Cyprinus carpio* (L.), Nile tilapia, *Oreochromis niloticus* (L.), and silver carp, *Hypophthalmichthys molitrix* (Val.). The yield of indigenous fish was dominated by snakehead, *Channa striata* (Bloch), and to a lesser extend by *Clarias* spp. and climbing perch, *Anabas testudineus* (Bloch).

The total fish production differed significantly among the three farming systems, the average being 155, 73 and 11 kg/ha for R-Intro.F, R-Ind.F, and RM respectively (Table 3.4). The yield of indigenous fish was not different between R-Intro.F and R-Ind.F, but both systems produced more indigenous fish than RM.

Table 3.4. Production (kg/ha) of introduced and indigenous fish (means; standard deviation in parenthesis).

	Rice-introduced fish	Rice-indigenous fish	Rice monoculture
Introduced fish	99 (104)	0	0
Indigenous fish	56 (35)^a	73 (37)^a	11 (17)^b
Total	155 (116)^a	73 (37)^b	11 (17)^c

Farming system effect: indices with the same superscript are not significant different at the 0.05 level.

3.3.4. Cost-benefit analysis and household consumption

For the dry season rice crop, costs for fertilizer and labour for rice cultivation and harvest were significantly higher for R-Intro.F than for RM, resulting in higher total variable costs for R-Intro.F (Table 3.5). For the wet season rice crop, labour costs for land preparation were significantly lower, but labour costs for rice cultivation and harvest were higher for the R-Intro.F system as compared to RM. The costs for irrigation in the two rice-fish systems were significantly higher than for RM, while fertilizer costs for R-Intro.F were higher than for R-Ind.F and RM. The total variable costs for the wet season rice crop did not differ among the three farming systems.

The costs for fingerlings, feed, miscellaneous materials, labour, and the total variable costs in R-Intro.F were significantly higher than for the R-Ind.F system (Table 3.6).

The costs and benefits of the three farming systems are listed in Table 3.7. The significantly lower rice GR of R-Intro.F and R-Ind.F as compared to RM resulted in a significant lower total rice RAVC for R-Intro.F, despite the lower total rice variable costs for the two rice-fish systems. Although the fish GR from the rice-fish field for the R-Intro.F system was significantly higher than for the R-Ind.F system, the variable costs were also much higher. This resulted in a significantly lower fish RAVC for the R-Intro.F system as compared to that of the R-Ind.F system. The GR from the homestead was significantly higher for R-Intro.F than for R-Ind.F and RM. This in combination with lower variable costs, resulted in a significantly higher homestead RAVC of R-Intro.F than for the RM system. Although the average RAVC of dike produce was much higher for the two rice-fish systems than for RM, the difference was not significant. The total farm fixed costs were significantly different among the three farming systems, the highest being for the R-Intro.F system. The total farm CR, NR and PCR did not differ among the three farming systems.

The quantity and value of on-farm fish, and the quantity of on-farm vegetables and fruits, consumed by the farming household was significantly higher for the two rice-fish systems than for RM.

Table 3.5. Variable costs (Dong/ha of ricefield area) for rice cultivation (means; standard deviation in parentheses).

Input	R-Intro.F.	R-Ind.F.	RM
DRY SEASON CROP			
Land preparation			
Family labour	55,181 (65,361)	43,263 (30,173)	46,605 (38,227)
Hired labour	230,531 (110,514)^{a}	252,741 (44,858)^{a}	277,588 (9,464)^{b}
Total	285,712 (115,649)	296,004 (65,224)	324,193 (36,701)
Irrigation	413,154 (130,387)	403,121 (192,211)	398,005 (97,822)
Rice seed	439,952 (119,691)	407,244 (139,910)	402,261 (129,049)
Fertilizer	1,266,078 (275,307)^{a}	1,072,647 (280,615)^{b}	1,103,689 (249,892)^{b}
Insecticides	67,554 (90,923)	27,064 (53,533)	53,202 (59,764)
Fungicides	65,301 (61,391)	70,497 (47,129)	54,544 (48,863)
Herbicides	62,388 (58,282)	46,677 (23,503)	51,090 (61,342)
Rice cultivation and harvest			
Family labour	469,211 (227,199)	459,169 (311,642)	363,323 (183,978)
Hired labour	662,331 (192,978)	578,245 (151,867)	608,638 (220,976)
Total	1,131,542 (312,097)^{a}	1,037,414 (250,006)^{a}	971,961 (248,478)^{b}
Miscellaneous costs	31,701 (21,245)	61,794 (71,687)	27,341 (20,149)
Total variable costs	3,763,381 (614,874)^{a}	3,422,461 (634,053)^{a,b}	3,386,287 (478,398)^{b}
WET SEASON RICE CROP			
Land preparation			
Family labour	62,125 (65,375)	51,318 (65,802)	49,688 (40,583)
Hired labour	289,304 (136,096)^{a}	351,223 (63,467)^{a,b}	382,374 (42,970)^{b}
Total	351,429 (133,516)^{a}	402,541 (54,273)^{a,b}	432,062 (57,332)^{b}
Irrigation	281,684 (68,671)^{a}	274,783 (48,692)^{a}	230,531 (36,251)^{b}
Rice seed	362,740 (101,973)	346,685 (78,424)	330,629 (65,021)
Fertilizer	961,150 (165,359)^{a}	818,217 (140,642)^{b}	891,196 (137,925)^{b}
Insecticides	46,569 (52,627)	39,044 (38,451)	76,904 (70,237)
Fungicides	62,550 (53,088)	64,807 (43,792)	55,722 (47,851)
Herbicides	59,610 (55,850)	63,615 (54,608)	57,245 (54,536)
Rice cultivation and harvest			
Family labour	541,693 (314,771)	568,607 (297,685)	399,110 (162,739)
Hired labour	774,422 (229,222)	617,974 (212,795)	746,734 (287,964)
Total	1,316,115 (375,710)^{a}	1,186,581 (298,016)^{a,b}	1,145,844 (262,220)^{b}
Miscellaneous costs	28,320 (20,679)	44,943 (50,348)	25,088 (13,940)
Total variable costs	3,470,168 (586,975)	3,241,217 (388,902)	3,245,222 (386,573)

Farming system effect: indices with the same superscript are not significant different at the 0.05 level.

Table 3.6. Variable costs (Dong/ha of ricefield and trench area) for fish culture in rice-fish systems (means; standard deviation in parentheses).

Item	R-Intro.F	R-Ind.F.
Maintenance of pond and trench		
Family labour	13,947 (56,834)	27,373 (59,916)
Fingerlings	502,217 (328,925)^{a}	843 (2666)^{b}
Feed	262,551 (287,307)^{a}	3,730 (9252)^{b}
Inputs for pond preparation1)	27,874 (60,168)	8,429 (23,875)
Miscellaneous materials2)	81,878 (108,623)^{a}	2,178 (6,887)^{b}
Fish cultivation and harvest		
Family labour	148,072 (62,655)^{a}	80,469 (53,723)^{b}
Hired labour	51,030 (42,995)^{a}	28,304 (42,306)^{b}
Total	199,102 (76,166)^{a}	108,774 (68,944)^{b}
Total variable costs	1,087,542 (625,486)^{a}	151,327 (100,467)^{b}

1) Lime, Derris root, fertilizer
2) Nets, bamboo screen etc.
Farming system effect: indices with the same superscript are not significant different at the 0.05 level.

3.4. DISCUSSION

Little, Surintaraseree & Innes-Taylor (1996) reported that the adoption of rice-fish culture in rainfed ricefields of Northeast Thailand was strongly biased towards farmers with more land and labour resources. In the present study, rice-fish culture was practiced on larger farms, and labour availability and educational level were not a constraint for the adoption of rice-fish culture. At larger farms a part of the holding could be allocated to rice-fish culture and another part to rice monoculture, reducing possible financial risks of rice-fish culture.

In an analysis of eighteen rice-fish studies Lightfoot *et al.* (1992a) reported an average increase of the rice yield by 15%. This was explained in part by the specific rice-fish agronomy, and in part as a direct effect of the fish. The high water levels required for fish reduced weed occurrence and as such increase rice yields (Moody 1992). Direct beneficial effects of fish on rice production are related to weed-, pest- and disease control by fish, and increased nutrient availability through soil perturbation and decomposition of fish excrement (Ruddle 1982; Cagauan 1995). Rice yields were not affected by the presence of fish in our study. Most farmers favoured high rice plant densities to reduce weed occurrence, a major problem in direct seeded rice. High plant density restricts the access of fish into the ricefield (Halwart, Borlinghaus & Kaule 1996), and could restrain a possible beneficial effect of fish on the rice yield.

Table 3.7. Costs and benefit of rice-fish (r-f) culture and rice-monoculture (r-m) means; standard deviation in parentheses (figures in 1000 Dong/one-ha farm1)).

Item	R-Intro.F.	R-Ind.F.	RM
Gross return			
Rice r-f field	7,535 (3,495)	7,324 (3,699)	0
Rice r-m field	2,238 (3,542)^{a}	2,250 (3,095)^{a}	11,662 (2,024)^{b}
Total gross rice return	9,773 (2,045)^{a}	9,574 (1,576)^{a}	11,662 (2,024)^{b}
Fish r-f field	750 (600)^{a}	402 (307)^{b}	0
Fish pond	229 (482)	312 (461)	71 (152)
Homestead	1,642 (1,637)^{a}	1,060 (1,674)^{b}	1,287 (3,489)^{b}
Dike	284 (440)^{a}	278 (479)^{a,b}	26 (59)^{b}
Total farm	12,678 (2,730)	11,626 (2,914)	13,046 (3,946)
Variable costs			
Rice r-f field	4,677 (1,924)	4,209 (1,904)	0
Rice r-m field	1,312 (2,098)^{a}	1,623 (2,197)^{a}	6,598 (796)^{b}
Total rice variable costs	5,989 (822)^{a}	5,831 (709)^{a}	6,598 (796)^{b}
Fish r-f field	631 (310)^{a}	92 (96)^{b}	0
Fish pond	96 (214)	93 (132)	31 (86)
Homestead	956 (1,245)^{a}	675 (1,559)^{b}	989 (3,353)^{b}
Dike	123 (256)^{a}	107 (151)^{a}	9 (28)^{b}
Total farm	7,793 (1,828)	6,800 (1,406)	7,628 (3,595)
Fixed costs			
Rice r-f field	1,452 (580)	1,274 (580)	0
Rice r-m field	333 (526)^{a}	399 (537)^{a}	1,722 (234)^{b}
Total rice fixed costs	1,785 (176)	1,673 (83)	1,722 (234)
Depreciation	156 (74)^{a}	94 (46)^{b}	0
Total farm	1,940 (195)^{a}	1,767 (114)^{b}	1,722 (234)^{c}
Return above variable costs (RAVC)			
Rice r-f field	2,858 (2,173)	3,115 (2,178)	0
Rice in r-m field	926 (1,490)^{a}	627 (1,385)^{a}	5,063 (2,156)^{b}
Total rice RAVC	3,785 (1,938)^{a}	3,743 (2,174)^{a,b}	5,063 (2,156)^{b}
Fish in r-f field	119 (530)^{a}	309 (244)^{b}	0
Fish pond	134 (308)	218 (338)	40 (103)
Homestead	686 (619)^{a}	385 (226)^{a,b}	298 (506)^{b}
Dike	161 (357)	171 (337)	16 (54)
Total farm	4,884 (2,300)	4,826 (2,296)	5,418 (2,246)
Total farm cash return	3,243 (2,042)	3,180 (1,823)	3,914 (2,830)
Total farm net return	2,944 (2,281)	3,059 (2,291)	3,696 (2,122)
Profit-cost ratio	0.32 (0.25)	0.36 (0.26)	0.43 (0.25)

1). Based on a double rice crop, one fish crop, and one year cultivation at the homestead and dike.
Farming system effect: indices with the same superscript are not significant different at the 0.05 level.

The reduced use of pesticides on the wet season rice crop in R-Intro.F is the direct result of the farmers awareness of the risk of fish mortality after pesticide application. The stocking of expensive fingerlings shifts the economic threshold level of the pesticide application to a much higher level (Waibel 1992). This finding confirms the compatibility of rice-fish culture with the adoption of Integrated Pest Management strategies (Horstkotte, Lightfoot, Waibel & Kenmore 1992; Kamp & Gregory 1994). The general perception among farmers that big fish are less vulnerable to pesticides probably explains the observation that pesticide use for the dry season crop was not significantly different.

Fish yields from concurrent rice-introduced fish systems are usually in the order of 300 kg/ha (Lightfoot, Costa-Pierce, Bimbao & Dela Cruz 1992b). The yield of indigenous fish has been reported as 88-175 kg/ha from irrigated rice (Ali 1990), and 209 kg/ha from rainfed rice (Middendorp 1992). The yield of introduced fish in the present study was much lower, despite the long cultivation period. This is basically related to a combined effect of fish mortality and escape (Rothuis, Nhan, Richter & Ollevier, in prep.). Fish production in ricefields can be considered as an uncertain operation. The variation coefficient of the fish yield data was 75% and 50% for introduced- and indigenous fish respectively, while the average variation coefficient of rice yield was only 17%.

In general, fertilizer requirement in rice-fish culture is higher than in rice monoculture (Singh, Early & Wickham 1980). In our study fertilizer use and costs were higher for R-Intro.F than for R-Ind.F and RM. Besides for stimulation of the production of fish food organisms, the additional fertilizer was required for maximizing the growth of the young rice plants. In this way fish could be released early into the ricefield with minimal risk of plant damage by the fish.

The higher irrigation costs in rice-fish culture are a result of the additional water requirement for fish. Optimal water levels in rice-fish fields are 2-3 times higher as for rice alone (Singh *et al*. 1980). The irrigation costs in the dry season were not different because the fields were mainly irrigated by gravity, while in the wet season pumps had to be employed.

Labour costs for R-Intro.F were high, both for rice cultivation and harvest (as compared to RM), and for fish cultivation and harvest (as compared to R-Ind.F). It means that further development of R-Intro.F will depend partly on labour availability, which could become critical if more people migrate to urban areas.

Middendorp & Verreth (1986) and Bimbao, Cruz & Smith (1990) reported an increase in farm profitability when fish production was integrated with rice cultivation, while Sollows & Tongpan (1986) reported that the one-year profit from rice-fish was less than for rice monoculture. In our study, the gross return from rice in R-Intro.F and R-Ind.F was circa 20% lower, mainly because of the conversion of riceland into trenches and dikes. However, this production loss was compensated by an additional production of the homestead, and to a lesser extend by fish production, and vegetables and fruits from the dike. As a result, total farm profitability was not affected by the introduction of rice-fish culture. In the Philippines, harvested fish from irrigated rice accounted for 25-30% of the total gross return (Tagarino 1985). In our study, the contribution of fish to the total gross return in the two rice-fish farming systems was only 6% and 3% respectively.

Improvement of the nutritional status of the farming household through rice-fish culture has been reported by Middendorp (1992) and Little *et al*. (1996). Although the present study did not investigate the entire household consumption pattern, more on-farm produced fish, vegetables and fruits were consumed by rice-fish households than by RM households. In the common situation of limited cash availability it is likely that the on-farm availability of fish, vegetables and fruits improves the nutritional status of rice-fish farming households.

Farms can be considered as agroecosystems, and their performance can also be analyzed from an ecological perspective (Conway 1985). Lightfoot and Pullin (1995) extended this principle into their assessment of farm sustainability through the use of kite diagrams. In a four-way diagram, species diversity (number of species on the farm) was plotted against bioresource recycling (number of bioresource flows within the farm), natural resource type capacity (total biomass output), and farm economic efficiency (profit-cost ratio). The rationale behind this approach is that an increase in diversity results in a more stable farming system. We have made with our data a similar performance kite for rice-fish systems of the Mekong Delta in Vietnam (Fig.3.3). Based on the whole farm enterprise (Table 3.7) the rice-introduced fish system has the widest kite, but it's economic efficiency is lower as compared to the other two farming systems.

The main beneficial effects of the integration of rice and fish, in the semi-deep water area of the Vietnamese Mekong Delta, are probably in the field of environmental sustainability and system biodiversity. Despite the low fish yields, and their rather insignificant contribution to the total farm profit, the inclusion of fish in the farm is important in terms of a decreased use of pesticides. Moreover, a higher degree of farm diversification safeguards the household income against the risks associated with fluctuations in rice market prices and crop failures. In this way introduction of fish in ricefields has also an economical benefit. Finally, farm diversification enhances the food security of the household.

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CHAPTER 4

RICE WITH FISH CULTURE IN THE SEMI-DEEP WATERS OF THE MEKONG DELTA, VIETNAM: INTERACTION OF RICE CULTURE AND FISH HUSBANDRY MANAGEMENT ON FISH PRODUCTION

ABSTRACT

Fish husbandry- and rice culture management factors influencing the yield of introduced fish in ricefields of the Vietnamese Mekong Delta were studied by multiple regression analysis. A significant ($p<0.001$) regression model was computed in which feed input and duration of culture period positively, and ricefield area, rice seeding rate and the year of the survey negatively affected the yield of introduced- as well as indigenous fish. The negative impact of larger ricefields is probably the result of escape of fish. This is also likely the reason for the year of survey since the average yield of introduced fish was 92.5 kg/ha in 1995 (due to an extreme flood) as compared to 164.8 kg/ha in 1994. A high seeding rate of rice results in a dense stand which suppresses the growth of fish. Options for improvement of fish production are proper ricefield construction, reduced seeding rates, stocking fingerlings early in the dry season and more intensive feeding.

4.1. INTRODUCTION

In rice-fish culture management, input use (fertilizers and pesticides) are primarily aimed at maximizing the rice production. Moderate quantities of fertilizers stimulate fish growth through the autotrophic food web while high doses of ammonia fertilizers can result in short-term exposure to toxic NH_3 levels (Middendorp 1985). Pesticides can affect fish production directly or through effects on fish food organisms. Pesticide application in ricefields changes the structure of the aquatic community (Roger & Kurihara 1991) and detrimental effects on cladocerans have been reported by Ali (1990). The impacts of pesticides on fish and their food web depend on the persistence, chemical formulation, manner and time of application (Cagauan & Arce 1992). Not all pesticides are equally toxic, herbicides are generally less toxic to fish than insecticides.

In the semi-deep waters of the Vietnamese Mekong Delta, rice-fish farming with hatchery-produced (introduced) fingerlings differed mainly from rice monoculture by a higher fertilizer and water requirement and less pesticide use. Rice yields were not affected by the presence of fish, and the contribution of fish to the total farm profitability was low (Rothuis, Nhan, Richter & Ollevier, in prep.). As a first step towards the optimization of fish yields, the interaction of rice culture- and fish husbandry management on fish production was studied by multiple regression analysis.

4.2. MATERIALS AND METHODS

4.2.1. Study area and data sets

The study was within the vicinity of the cooperative farm at Co Do which encompasses an area of approximately 6000 ha, situated in the semi-deep water zone of the Mekong Delta, Vietnam. In a previous paper (Rothuis et al. 1998) the socio-economical data of farming systems practicing rice culture with introduced fish (**R-Intro.F**), rice culture with indigenous fish (**R-Ind.F**) and rice monoculture (**RM**) in this study area (data of 1995) were presented. The data set on rice culture and fish husbandry management of the present study concerning R-Intro.F was derived from the socio-economical survey and supplemented by a similar (unpublished) data set obtained in the same area in 1994.

Table 4.1. Fish species introduced into ricefields

Fish species	Stocked by farmers (%)
Silver barb (*Puntius goniotus*) (Bleeker)	93
Common carp (*Cyprinus carpio*) (L.)	91
Tilapia (*Oreochromis niloticus*) (L.)	27
Silver carp (*Hypophthalmicthys molitrix*) (Val.)	23
Indian carps (*Labeo rohita* (Hamilton), *Cirrhinus mrigala* (Hamilton)	19
Others*	15

*) Including *Oxyeleotrix marmorata* (Bleeker), *Trichogaster pectoralis* (Regan), and hybrid of *Clarias macrocephalus* (Gunther) * *Clarias gariepinus* (Burchell).

4.2.2. Fish husbandry management and rice culture

Small fingerlings (circa 1 gram) were usually stocked between March and June during the wet season rice crop, and harvested circa 9 months later during or after the dry season rice crop (December-February). Between August and October the land was left fallow because of high water levels. The fish were reared in polyculture predominantly consisting of silver barb, *Puntius gonionotus* (Bleeker), and common carp, *Cyprinus carpio* (L.) (Table 4.1). The stocking density was calculated as the total number of all fish introduced per m^2. Usually, fish were first confined to the trench for about 3 weeks in order to prevent damage of the young rice plants by the fish. Particularly during this period and during the wet season rice crop, farmers used a variety of fresh and dry feeds to supplement the natural productivity of the water, the most common being rice bran (Table 4.2). Since energy is usually the first nutritional factor limiting fish growth in systems dependent on natural food (Hepner & Pruginin 1981), the total input of supplementary feeds was calculated as kcal gross energy per m^2 rice-fish field. The approximate composition of the feeds was calculated using the tables from New (1987), and FAO (1972), and converted into gross energy according to New (1987).

Of the rice inputs, fertilizer applications (Urea, NPK and Di-Ammonium-Phosphate) were converted into total nitrogen and phosphate (P_2O_5) and expressed in kg ha^{-1}. Pesticides were expressed both in quantity of active ingredients (a.i.) and as the number of sprayings. As not all farmers stocked fish at the same time, only those rice inputs applied during the time that the fish were actually present in the field were used in the analysis. The rice seeding rate was calculated as the average seeding rate of the rice crops cultivated during the presence of the fish.

For fish nursery, animal manure input, inorganic fertilizer use (apart from the fertilizer used for rice cultivation), and Derris root application (to eradicate unwanted fish), only the presence or absence of such a treatment was indicated (dummy variables). The year of the survey was also included in the regression analysis as a dummy variable.

Farmers introducing hatchery produced fingerlings made no attempt to prevent the entrance of indigenous fish. Often these were deliberately attracted into the ricefield by putting feed and branches at the water gate. Consequently, the harvest consisted of both stocked and wild fish. The latter were predominantly snakehead (*Channa striata* Bloch), climbing perch (*Anabas testudineus* Bloch), and *Clarias* spp.

Table 4.2. Percentage of total number of farmers using different supplementary feeds and average quantity of feed type per farmer.

Feed type	% of farmers	quantity (kg/ha)
Rice bran	96	292.5
Fish meal	28	28.9
Rice$^{1)}$	30	163.3
Water spinach (*Ipomea aquatica* Forskal)	25	475.7
Sweet potato$^{2)}$	9	607.2
Cassava$^{2)}$	8	89.3
Crabs, snails	6	67.0

1) Paddy rice, broken rice and milled rice
2) Tubers

4.2.3. Statistical analysis

The following model of variables affecting the yield of introduced fish in ricefields was hypothesized:

$$Y = a + b_1X_1 + b_2X_2 + ... + b_{22}X_{22} + u$$

where

Y = Yield of introduced fish (kg ha^{-1}); X_1 = Ricefield area, excluding fish refuge (ha); X_2 = Ratio of fish refuge to rice field area (%); X_3 = Period of stocking fish into the ricefield (month code); X_4 = Duration of fish rearing period (months); X_5 = Fry nursery in fish pond (dummy); X_6 = Fish species composition (% of silver barb); X_7 = Total stocking density (No.m^{-2}); X_8 = Feed input (kcal. m^{-2}); X_9 = Use of animal manure (dummy); X_{10} = Use of inorganic fertilizer (dummy); X_{11} = Use of Derris root (dummy); X_{12} = Total nitrogen input on the rice crop (kg ha^{-1}); X_{13} = Total phosphorous input on the rice crop (kg ha^{-1}); X_{14} = Total insecticide applied on the rice crop (kg a.i. ha^{-1}); X_{15} = Total fungicide applied on the rice crop (kg a.i. ha^{-1}); X_{16} = Total herbicide applied on the rice crop (kg a.i. ha^{-1}); X_{17} = Total number of insecticide sprayings; X_{18} = Total number of fungicide sprayings; X_{19} = Total number of herbicide sprayings; X_{20} = Rice seeding rate (kg ha^{-1}); X_{21} = Year of the survey (dummy); X_{22} = Yield of indigenous fish (kg ha^{-1}); a = constant (intercept); u = residual.

The frequency distribution of the dependent variable (yield of introduced fish) differed significantly ($p>0.05$) from normal, and was transformed to logarithmic (base 10) values. Extreme cases, out of range 3 * standard deviation, were eliminated. The final database consisted of 99 cases with 23 variables.

The regression model was calculated after the procedure by van Dam (1990). First, a correlation matrix was calculated to determine relationships between independent variables, followed by the actual construction of the regression model. An independent variable would be retained in the model only if its partial regression coefficient was significantly different from zero at the 0.05 level. Pairs of independent variables with high correlation coefficients were not jointly included into the model. Logarithmic (base 10) transformation of independent variables would be incorporated if this contributed to the overall significance of the model. Residuals were analyzed for linearity and systematic patterns to verify the assumptions of linear regression (Hair, Anderson & Tatham 1990). The possible existence of autocorrelation was verified by calculation of the Durbin-Watson statistic, and compared with significance points (Neter, Wasserman & Kutner 1990). Standardized partial regression coefficients were calculated to compare the relative importance of independent variables.

4.3. RESULTS AND DISCUSSION

4.3.1. Correlation and regression analysis

The fish husbandry and rice culture characteristics (untransformed data) are summarized in Table 4.3. The mean fish yield was 186.4 kg ha^{-1}, consisting of 130.5 kg ha^{-1} introduced fish and 55.9 kg ha^{-1} indigenous fish. Stocking period and duration of the fish culture period, stocking density and feed input, total nitrogen and total phosphate, and the quantity and number of insecticide applications were highly correlated (Table 4.4).

Table 4.3. Mean, standard deviation (s.dev.), minimum (min.), and maximum (max.) of the untransformed variables (99 cases).

Variable	Dimensions	Mean	S.dev.	Min.	Max.
Fish husbandry					
Ricefield area	ha.	1.73	0.93	0.22	4.50
Refuge/field ratio	%	13.16	8.41	1.10	48.50
Fish management					
Stocking period	month code	6.36	2.12	2.1	11.3
Duration fish cultivation	months	8.69	2.06	4	15
Fry nursery	dummy	0.87	0.34	0	1
Fish species composition	% silver barb	52.17	26.25	0	100
Total stocking density	no./m^2	2.01	1.56	0.04	9.70
Fish inputs					
Feed	kcal./m^2	115.62	131.81	0	773.3
Animal manure	dummy	0.37	0.49	0	1
Inorganic fertilizer	dummy	0.75	0.44	0	1
Derris root application	dummy	0.37	0.49	0	1
Rice inputs					
Total nitrogen	kg./ha.	180.98	67.53	70.5	363.3
Total phosphorous	kg./ha.	84.97	32.96	25.0	159.5
Total insecticide	kg.a.i./ha.	0.44	0.62	0	3.2
Total fungicide	kg.a.i./ha.	0.19	0.37	0	2.2
Total herbicide	kg.a.i./ha.	0.47	0.45	0	3.0
Insecticide applications	no. sprayings	1.56	1.95	0	8
Fungicide applications	no. sprayings	1.15	1.26	0	6
Herbicide applications	no. sprayings	2.02	1.57	0	7
Rice seed rate	kg./ha.	257.19	46.28	128.2	384.6
Miscellaneous					
Year of survey	dummy	0.47	0.50	0	1
Yield indigenous fish	kg./ha.	55.91	40.02	5.13	205.5
Dependent variable					
Yield introduced fish	kg./ha.	130.47	184.86	3.08	1281.3

A significant ($p<0.001$) regression model was computed with five independent variables (Table 4.5). Feed input and duration of the culture period had a positive effect on the yield of introduced fish, while the year of the survey, ricefield area, and rice seed rate negatively affected fish yield. Highest standardized partial regression coefficients (beta) were found for year of the survey and feed input. Residual analysis did not indicate violation of assumptions for multiple regression. The Durbin-Watson statistic was higher than the critical value of d_u at 1%, indicating the absence of autocorrelation among the independent variables.

Higher fish yields were obtained when the duration of the rearing period was extended. This suggests that feed nor fish metabolites limited fish production. Fish yields from concurrent rice-fish systems stocked with hatchery-produced fingerlings using no or little supplementary feeding are usually in the order of 300 kg/ha (Lightfoot, Costa-Pierce, Bimbao & Dela Cruz 1992). In the present study the total fish biomass (indigenous and introduced species) did not reach this level, suggesting further scope for growth. The duration of the fish rearing period was highly negatively correlated to the month of stocking ($R^2=-0.72$, $p<0.001$; Table 4.4). This implies that stocking fingerlings early, between January and March (dry season), results in higher fish yields. Probably the weather conditions favour natural food resources through an increased activity of the photosynthetic aquatic biomass in this season. Besides, this could also be an effect of an improved survival rate since predatory fish are more abundant in the wet season (Duong 1994). The negative impact of larger ricefields on fish production is probably the result of a lower recovery rate (escape). Larger fields require more investment capital and are often less well constructed and managed. Consequently larger fields are prone to fish loss. Escape of fish is probably the reason for the negative effect of the year of the survey on fish yield. The average yield of introduced fish in 1995 was only 92.5 kg ha^{-1}, as compared to 164.8 kg ha^{-1} in 1994. The main difference between these two years was the extreme flood in 1995, which inundated large parts of the study area. Chapman (1992) reported that the size of fingerlings determines their survival in the ricefield. The positive effect of supplementary feeds on fish yield in our study is probably the result of an increased survival rate of the bigger fingerlings, since feeding was carried out primarily during the early phase of the fish rearing period.

The rice seeding rate had a negative impact on the fish yield. A high seeding rate quickly results in a dense stand which suppresses the growth of weeds (a major problem in direct seeded rice (Moody 1992)) and phytoplankton due to a reduced availability of nutrients and increased shading as the rice canopy closes (Simpson, Roger, Oficial & Grant 1994). At lower seeding rates, emerging weeds (Cagauan 1995) and newly formed (soft) rice tillers can be consumed by herbivorous fish (silver barb) so that the final rice plant density remains low. This will facilitate the access of fish into the ricefield, and increase the feed resources available to fish. According to De Datta & Nantasomsaran (1991) 100 kg pre-germinated rice seed ha^{-1} results in good stand establishment and weed control, while the average seeding rate in our study was 257 kg ha^{-1}.

Table 4.4. Correlation matrix of variables used for the regression analysis (marked correlations are significant at p<0.01);No. of cases = 99).

Var.	rfar	rf%	stp	culp	nurs	spec	std	feed	man	fert	root	year	wfis	N	P	ins	fung	herb	ispr	fspr	hspr	seed	fish
rfar	1.00																						
rf%	-.61*	1.00																					
stp	.08	-.10	1.00																				
culp	-.01	.05	-.72*	1.00																			
nurs	.23	-.16	.18	-0.21	1.00																		
spec	-.02	-.01	.15	-.19	.22	1.00																	
std	-.45*	.36*	-.03	.05	.05	.11	1.00																
feed	-.46*	.42*	-.09	.14	.03	.02	.71*	1.00															
man	-.02	-.05	-.10	.10	.18	.12	.25	.10	1.00														
fert	.06	.02	-.02	-.06	-.02	.14	.09	.08	.02	1.00													
root	.09	-.01	-.04	.09	.05	.12	.07	.08	.27*	.06	1.00												
year	-.02	.15	-.48*	.34*	.01	-.08	-.09	-.04	.06	-.10	-.02	1.00											
wfis	-.42*	.28*	-.29*	.26	-.19	-.15	.45*	.45*	.12	-.12	.05	-.01	1.00										
N	.00	.07	-.54*	.60*	-.10	-.14	-.07	-.02	.13	.06	-.17	.34*	.10	1.00									
P	.02	.04	-.55*	.54*	-.18	-.23	-.13	-.02	.00	.10	-.12	.31*	.09	.72*	1.00								
ins	.17	-.13	-.11	.20	.01	.01	-.12	-.14	.09	-.04	.04	.36*	-.03	.40*	.37*	1.00							
fung	.07	-.07	-.11	.01	-.21	.03	-.14	-.13	-.06	.13	-.17	.28*	-.11	.07	-.02	.18	1.00						
herb	.09	-.08	-.28*	.25	-.03	-.06	-.03	.01	.07	-.04	.10	.27*	.08	.29*	.33*	.32*	.20	1.00					
ispr	.26*	-.17	-.28*	.37*	.08	.00	-.17	-.12	.09	-.07	.03	.48*	-.01	.40*	.35*	.75*	.14	.37*	1.00				
fspr	.10	-.03	-.34*	.16	-.05	.19	-.13	-.17	.06	.00	-.09	.52*	-.13	.32*	.21	.36*	.54*	.33*	.37*	1.00			
hspr	.30*	-.17	-.38*	.31*	.08	-.16	-.12	-.13	.02	.14	-.06	.40*	-.08	.42*	.38*	.34*	.28*	.59*	.53*	.48*	1.00		
seed	.15	-.15	.30*	-.23	.27*	.19	.05	.02	.23	-.05	.17	-.22	-.25	-.14	-.13	-.05	-.22	.01	-.09	-.16	-.06	1.00	
fish	-.32*	.25	-.20	.20	-.08	.07	.43*	.53*	.16	-.02	.00	-.20	.57*	.02	-.01	-.08	-.06	-.10	-.10	-.08	-.17	-.16	1.00

(rfar = ricefield area; rf% = refuge/field ratio; stp = stocking period; culp = duration fish cultivation; nurs = fry nursery; spec = fish species composition; std = stocking density; man = animal manure; fert = inorganic fertilizer; root = Derris root; wfish = yield indigenous fish; N = total nitrogen; P = total phosphorous; ins = total insecticide; fung = total fungicide; herb = total herbicide; ispr = insecticide sprays; fspr = fungicide sprays; hspr = herbicide sprays; seed = rice seed rate; fish = log (yield introduced fish)).

Not all variables identified a priori were significant in the constructed regression model. Information was lost by using dummy variables (nursery management), other independent variables were

correlated (ricefield area with refuge-field ratio, duration of the fish cultivation period with stocking period). Rice fertilizer and pesticide input did not affect the fish yield, contrary to van Dam (1990) who found a positive effect of nitrogen and negative effects of phosphorous and pesticides.

In his model for gross fish yield, van Dam (1990) found a coefficient of determination (R^2) of 0.6571 with a F-value of 52.013. In the present study the constructed regression model explained only 40% of the total variance in fish production. However, van Dam analyzed the results of purposely designed on-station experiments, while our data originate from interviews with farmers. In this situation errors in the variables are likely to be higher.

Table 4.5. Results of multiple regression analysis.

Independent variable	b	Std.Error	beta
Feed	0.0013	0.0004	0.310^{**}
Duration fish cultivation	0.067	0.0236	0.247^{**}
Year of survey	-0.34	0.096	-0.312^{***}
Log ricefield area	-0.42	0.194	-0.216^{*}
Rice seed rate	-0.0023	0.0010	-0.192^{*}
Constant	1.896		
Multiple R^2	0.400		
Adjusted R^2	0.367		
F-value	12.382		
Probability	<0.001		
Durbin-Watson statistic	1.76		

*) $p<0.05$
**) $p<0.01$
***) $p<0.001$

4.3.2. Significance of indigenous and introduced fish

Indigenous fish made up 30% of the total fish yield. The high perception of indigenous fish among farmers in the study area was also observed by Setboonsarng (1994), and Fujisaka & Vejpas (1990) in North-east Thailand. Farmers regarded hatchery-produced fish as a secondary crop, and objected measurements to limit the entrance of more valuable indigenous species. This raises the question whether this activity is competitive or complementary to the production of introduced fish. In the present study the yield of indigenous fish was correlated to the yield of introduced fish ($R^2=0.57$, $p<0.01$; Table 4.4). In a previous study Rothuis et al. (1998) found a significant lower indigenous fish yield from rice monoculture fields than from rice-fish fields. This suggests that indigenous fish benefit from the modifications made to the ricefield (refuge trench) and the specific rice-fish management (high water levels). Apparently, the presence of indigenous fish did not adversely affect the yield of introduced fish. Although most indigenous fish were carnivorous, only snakehead can be regarded as a vigorous predator, feeding on frogs, fish and small aquatic snakes (Kok 1982).

Climbing perch feeds mainly on insects while *Clarias* spp. feed on a variety of small organisms (insect larvae, worms, shells, shrimp, small fish), aquatic plants and detritus (Ukkatawewat 1979). Probably, the abundant small indigenous fish (*Rasbora* spp. and *Esomus* spp.) and shrimp (*Macrobrachium lanchesteri* DeMan) served as primary feed for piscivorous predators whereas introduced fish escaped predation because of their size advantage. The coexistence of introduced- and indigenous fish production in ricefields was also observed by Middendorp (1992).

In conclusion, the fish yield from rice-fish culture in the semi-deep waters of the Vietnamese Mekong Delta mainly depends of a combined effect of mortality and escape of stocked fingerlings from the ricefields. Rice- and fish husbandry management options available to the farmer for improvement of fish production, are feeding (particularly at the beginning of the fish rearing period), stocking fish early in the dry season, proper field construction, and a reduced rice seeding rate. The study illustrated the use of multiple regression analysis as a tool to identify technological constraints of rice-fish culture at farmer level. Its results should be completed with an appraisal of the management variables by the farmers themselves, and verified at controlled on-station experiments.

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CHAPTER 5

THE EFFECT OF RICE SEEDING RATE ON RICE AND FISH PRODUCTION IN DIRECT-SEEDED RICE-FISH CULTURE

ABSTRACT

Rice (paddy) and fish yields in concurrent, direct-seeded rice-fish culture with three different rice seeding rates (100, 200 and 300 kg ha^{-1}) in absence or presence of fish (*Oreochromis niloticus* (all male), *Puntius gonionotus*, and *Cyprinus carpio*) were investigated at the Co Do station located in the Mekong Delta, Vietnam. Significantly ($P<0.05$) higher paddy and fish yields were obtained at the lowest rice seeding rate. No significant effect of the rice seeding rate on aquatic weed biomass was found, whereas water temperature, dissolved oxygen concentration and pH were significantly ($P<0.05$) higher at 100 kg rice seed ha^{-1}. The presence of fish resulted in a significant ($P<0.05$) reduction of the aquatic weed biomass, significant ($P<0.05$) lower dissolved oxygen and PO_4 concentrations, and higher chlorophyll-a levels. Analysis of the results indicated that the effect of rice seeding rate on fish production was most likely related to a "growth effect" resulting from available oxygen and food. Paddy yields at high seeding densities were affected by mutual shading. Interactions of fish, paddy yield and the aquatic environment are discussed. A further study should disclose whether a reduction of the rice seeding rate is beneficial for rice-fish farmers, from an economical- as well as from a practical point of view.

5.1. INTRODUCTION

In the Vietnamese Mekong Delta, concurrent rice-fish production is mainly practiced in the semi-deep fresh water zone (Fig. 1 in Rothuis et al. 1998a). The rice cultivation in this area is characterized by a high level of intensification (double or triple cropping). Soon after the introduction of high yielding rice varieties in the late 1960's, farmers shifted from transplanting to broadcast seeding for rice crop establishment (Xuan pers.inf.). In many other Southeast Asian countries broadcast seeding is also commonly used, mainly because of a significant reduction of the labour costs involved (De Datta and Nantasomsaran, 1991). However, since weeds emerge simultaneously with the germinating rice seeds, the rice yield can be substantially affected by the presence of weeds, especially when land preparation is not well done. In direct seeded rice, weed control can be achieved by using a high seeding rate (Moody, 1977). In the Co Do cooperative farming area, agro-ecological representative for the semi-deep fresh water zone of the Mekong Delta, the rice seeding rate is high, in the order of 250 kg ha^{-1} (Rothuis et al. 1998a). In a previous study of fish husbandry management and rice culture management factors at integrated rice-fish farms, a significant negative effect of rice seeding rate on fish production was found

(Rothuis et al. 1998b). It can be hypothesized that high seeding rates result quickly in a dense stand which suppresses the production of natural fish foods through a limitation of light penetration into the water.

The present study was undertaken to analyze the effect of rice seeding rate on fish production through a controlled on-station experiment, and to determine interactions between rice seeding rate, weed abundance, rice yield and the aquatic environment (water quality, plankton and benthos).

5.2. MATERIALS AND METHODS

5.2.1. Rice-fish fields and sampling methodology

The experiment was carried out in the dry season from 12 December 1996 to 14 March 1997 at the experimental rice-fish station located in the Co Do cooperative rice farming area, Can Tho province, Vietnam.

Eighteen rice-fish fields (plots), with an area of 650 m^2 each, were used. Every field had a peripheral L-shaped trench serving as fish refuge (Fig.5.1). The total refuge area was circa 97 m^2, with an average depth of 1 m, conform the characteristics of rice-introduced fish systems in the area (Rothuis et al. 1998a). All fields were divided into 9 equal sub-plots by two transversal and two longitudinal ditches circa 20 cm deep and 10 cm wide, to facilitate the access of fish into the ricefield. The total non-planted area was circa 107 m^2 per plot. A bund between the trench and the field confined the fish in the trench for 17 days during the initial phase of rice cultivation, for prevention of fish damage to the young rice plants. A 5 mm mesh size screen at the field water inlets, and a 10 mm mesh size screen at the main water gate of the station prevented indigenous fish and aquatic predators from entering the fields. The soil consisted of heavy clay (Typic Tropaquepts) of alluvial origin. The water originated from the main irrigation canal of the Co Do cooperative farming area, which also supplied water to neighbouring rice farms.

The experiment was laid out as a 3×2 factorial experiment in a complete randomized design with three replicates. The rice factor consisted of three seeding rates: 100, 200 and 300 kg seed ha^{-1}. The fish factor consisted of two levels: fish present (rice-fish culture) and fish absent (rice monoculture).

The soil of the experimental ricefields was harrowed and puddled by using buffalo, and leveled manually. The germination rate of the rice seed (IR 56279) was determined by placing 100 seeds on humid tissue paper, in three-fold. After 3 days the number of germinated seeds was counted and expressed as percentage. Pre-germinated rice seed was broadcasted at 100, 200 and 300 kg ha^{-1}, corrected for the actual germination rate. Urea fertilizer was applied in 5 equal split-doses (total 216 kg ha^{-1}), di-ammoniumphosphate in 3 doses (total 141 kg ha^{-1}), and potassiumchloride in 2 doses (total 50 kg ha^{-1}), between 6 and 65 days after seeding (DAS), to achieve maximum fertilizer uptake by the rice plants, and to sustain production of fish food organisms (Singh et al., 1980). No insecticides were utilized before or during the cropping season and no chemical or manual weed control methods were applied. According to the needs of the rice plants, the water level was gradually raised from 3-5 cm initially to 15-17 cm just before rice harvest. The plots were not inter-connected by pipes, therefore water levels were adjusted for each plot individually.

Data on paddy yield and weeds were collected by stratified random sampling based on sub-plots, in order to reduce the variability within a plot (Gomez, 1972). Three sub-plots, referred to as the rice yield sub-plots, were reserved exclusively for collecting rice yield data at harvest. The other 6 subplots, referred to as the sampling subplots, were used for sampling water quality parameters, phyto- and zooplankton, chlorophyll, zoobenthos, weed and rice dry matter (Fig. 5.1a).

To understand the effect of the seeding rate on the rice biomass, the aboveground dry matter of rice was estimated at 19 and 40 DAS (vegetative phase of the rice crop), 68 DAS (reproductive phase), and 92 DAS (ripening phase). The number of tillers m^{-2} was estimated by counting the tillers within a 25×25 cm frame placed at random (once at 40 and 68 DAS, and twice at 19 DAS) in all sampling subplots of fields with the rice treatments 100 and 300 kg ha^{-1}. Within every frame, one rice tiller was removed for later determination of the dry weight. At 92 DAS, 10 random 40×40 cm samples were taken within each field, including the fields with a seeding rate of 200 kg ha^{-1}. After removing the roots, the tillers were washed and oven-dried at 60°C for 48 hours. All tillers from one field were bulk weighed to the nearest 0.001 g, and the average tiller weight was calculated. The aboveground dry matter was then calculated as the number of tillers m^{-2} multiplied with the average tiller weight.

The gross paddy yield at harvest of every ricefield was determined by cutting all the rice plants from a randomly chosen 4 m^2 area of the 3 rice yield subplots. After threshing by feet, cleaning and sun-drying, the total seed weight, and the moisture content of each sample was measured with a Riceter L. paddy moisture meter (Kett). The grain weight for each sample was adjusted to 14% moisture (Gomez, 1972). For this study, the term paddy refers to rough unprocessed rice. In all other cases the general term rice will be used.

The aboveground dry matter of weeds was measured at 34, 47 and 61 DAS. In each sampling subplot, weeds were collected from one (34 DAS) or two (47 and 61 DAS) randomly placed 1 m^2 frames. After cutting the roots, weeds were washed and classified as (1) emergent and (2) submerged and floating weeds. Weeds were oven-dried at 60°C for 48 hours and the aboveground dry matter was weighed to the nearest 0.001 g.

Oxygen, temperature and pH were measured twice a week in the trench (30 cm below the water surface) and the ricefield, both in the morning (6:00-7:00) and afternoon (14:00-15:00), by using portable electronic probes (Hanna Instruments HI9143). Secchi disc visibility was measured twice a week in the trench (afternoon). The water level was measured daily from a graduated stick placed in each ricefield.

In order to have an approximate understanding of the effect of the rice seeding rate on plankton abundance, phyto- and zooplankton and chlorophyll-a were sampled fortnightly, in total 6 times and water nutrients 7 times. Water from the trench was sampled randomly at 5 places with a 2-l column sampler (Boyd and Tucker, 1992) and pooled. Similarly a volume of circa 10 l was collected from between the rice plants (sampling subplots) with a 1-l beaker. After mixing, a sub-sample of 50 ml was preserved with Lugol's iodine for determination of phytoplankton. Another sub-sample of circa 1 l was taken for analysis of chlorophyll and water nutrients. A known volume of the remaining of the water sample was filtrated through a 55 µm mesh and the zooplankton concentrated in

200 ml, preserved with 10% buffered formalin. The ammonium and phosphate concentration were measured the day of sampling using test kits (Riedel-de Haen 37400 and 37411), and a portable spectrophotometer (Riedel-de Haen Aquanal-plus 37560). Within 4 hours after taking the chlorophyll sample, two subsamples (150 ml) were filtrated over a 0.45 μm membrane filter and kept frozen until analysis. Chlorophyll-a was determined using the acetone extraction method (Strickland and Parsons, 1972). Through successive steps of sedimentation the phytoplankton was concentrated into 5 ml over a period of 6 days. Phytoplankton specimens in 64 cells were counted using an haemacytometer, and identified into broad taxonomic groups (Shirota, 1966; Guillard, 1978). In total 2 sub-samples per sample were counted and the average numbers were converted to cell concentration of the original sample. Zooplankton was counted in a 5 ml counting chamber using an inverted microscope. The volume of the zooplankton sub-sample ranged from 2 to 5 ml to achieve sub-sampling densities of more than 60 individuals of a specific group per sub-sample (Bottrell et al., 1976). Zooplankton counts were converted to number l^{-1} of the original sample.

Zoobenthos was collected 28, 48 and 76 DAS by a hand-pushed core sampler cutting the sample at 10 cm depth. Twelve replicate samples per ricefield were taken and combined into one composite sample. Organisms retained at a 250 μm sieve were preserved in 5% buffered formalin.

Due to labour constraints, water quality, chlorophyll, plankton and benthos were measured only at treatments 100 and 300 kg rice seed ha^{-1}, with and without fish.

5.2.2. Fish stocking and harvesting

Silver barb *Puntius gonionotus*, common carp *Cyprinus carpio*, and Nile tilapia *Oreochromis niloticus* were raised in polyculture according to local practice (Rothuis et al., 1998b). Fry of silver barb and common carp were first nursed for 2.5 months, whereas tilapia was nursed for circa 4 months, in earthen ponds at the research station. One week before stocking of the fish, the ricefield trenches and the irrigation and drainage canal inside the station were treated with 15 ppm Derris root (5% rotenone) to eradicate wild fish. The fish were stocked 6 days after seeding the rice, by counting and bulk weighing the required number of fish per ricefield (Table 5.1). The average body weight (W_0) was calculated accordingly. Tilapia were hand-sexed and only males were stocked. The fish were confined to the trench for 17 days and supplementary fed with finely grounded rice bran (5% biomass day^{-1}). Afterwards, the bund was removed and feeding suspended. Fish were harvested 84 days (t) after stocking by seining the partially drained trench, and sorted according to species.

Of the silver barb, tilapia and common carp, circa 40, 80, and 100% respectively were weighed individually to the nearest 0.1 g (W_t), and measured for total length to the nearest mm (L_t). The rest was bulk-weighed and counted. Total fish biomass was calculated as the sum of the individual weights and the bulk weight. Net fish production was the total fish biomass at harvest minus the biomass at stocking. Growth was expressed as daily growth rate $(W_t-W_0)/t$ in g day^{-1}. Fish survival rate was calculated as the number of fish harvested as percentage of the number of fish stocked. The condition of the fish was calculated from the modified Fulton's Condition Factor $K' = (100 \times W_t)/L_t^b$, with b = the exponent of the regression of log length and log weight (Bagenal and Tesch, 1978).

Table 5.1. Rice seeding rates and stocking/harvest characteristics of fish species used in ricefields at the experimental station in the Mekong Delta, Vietnam (means of 3 replications; standard deviation in parenthesis).

			STOCKING			HARVEST	
Rice Seed (kg/ha)	Fish Species	Density (No./ha)	Tot.Weight (kg/ha)	Avg.Weight (g)	Density (No./ha)	Tot.Weight (kg/ha)	Avg.Weight (g)
100	Silver Barb	3148 (9.32)	58.1 (5.20)	18.4 (1.67)	2712 (95.9)	141.7 (7.97)	52.4 (5.05)
200		3154 (30.3)	57.7 (3.91)	18.3 (1.41)	2522 (100)	129.8 (16.0)	51.3 (3.80)
300		3134 (12.1)	59.8 (5.95)	19.1 (1.89)	2691 (135)	128.8 (15.8)	47.8 (3.87)
100	Tilapia	543 (18.3)	39.7 (0.84)	73.1 (0.93)	517 (24.4)	72.2 (1.04)	140.0 (8.35)
200		548 (8.14)	37.2 (3.19)	67.8 (4.79)	427 (71.9)	60.9 (16.7)	142.7 (25.7)
300		544 (16.3)	37.8 (3.90)	69.3 (6.09)	399 (18.6)	54.5 (9.90)	136.5 (23.3)
100	Common Carp	310 (10.5)	7.27 (1.99)	23.7 (6.94)	233 (28.4)	34.1 (1.01)	148.5 (19.2)
200		313 (4.65)	10.0 (0.62)	32.0 (1.63)	235 (14.2)	30.7 (2.31)	131.9 (19.9)
300		311 (9.29)	8.27 (1.13)	26.5 (2.86)	212 (13.5)	26.1 (2.91)	122.9 (5.47)
100	Total of silver barb, tilapia, and common carp	4001 (37.4)	105 (4.16)		3462 (140)	248.1 (7.77)	
200		4015 (39.6)	105 (2.35)		3184 (39.6)	221.4 (6.16)	
300		3989 (26.7)	106 (9.56)		3302 (136)	209.4 (6.16)	

5.2.3. Statistical analysis

Data were analyzed as two factor ANOVA (fixed effects model). Means at a significant factor effect were compared with the Tuckey Honest Significant Difference test. In case assumptions of ANOVA were violated and transformations were not successful, the non-parametric Scheirer-Ray-Hare extension of the Kruskal-Wallis test was used (Sokal and Rohlf, 1995). In this situation treatment means were compared by the multiple pairwise testing procedure (Neter et al., 1996). Data on water quality parameters (temperature, oxygen, pH, NH_4, PO_4, and Secchi disc visibility), phyto- and zooplankton and chlorophyll were analyzed by averaging the measurements over time (Gomez and Gomez, 1983), for the period that the fish were actually present.

Data related to fish (production, growth, survival etc.) were analyzed as one-way ANOVA in complete randomized design, or by the non-parametric Rank F-test (Neter et al., 1996). Means at a significant rice factor effect were compared with the Tuckey Honest Significant Difference test, or with multiple Mann-Whitney U tests. All significance testing was done at the 0.05 level.

5.3. RESULTS

5.3.1. Rice, weeds, water quality, plankton and benthos

The gross paddy yield for the lowest and highest seeding rate was significantly different, 5550 and 4980 kg ha^{-1} respectively (Table 5.2). The gross paddy yield was not significantly different amongst fish treatments.

The rice aboveground dry matter weight was determined by the seeding rate during the vegetative and the reproductive phase, the highest seeding rate resulted in a higher weight (Table 5.2). At 68 DAS and harvest, there was a significant effect of fish on the rice aboveground dry matter weight.

In the group of the emergent weeds, *Monochoria vaginalis* and *Sphenoclea zeylanica* were the dominant species. For the submerged and floating weeds, *Utricularia aurea* and *Nymphoides indica* were the principal species. No significant effect of the rice seeding rate on weed biomass was found (Table 5.3). Fish significantly reduced the total aboveground dry matter of weeds (Table 5.3). The total weed aboveground dry matter at 34, 47 and 61 DAS was reduced with 92, 97 and 54% respectively in the presence of fish. Submerged and floating weeds, easily accessible for feeding by fish, were reduced between 92 to 100% (Table 5.3).

During the first 40 days of the experiment, considered as the critical period for weed development (Bhagat et al., 1996), the average waterdepth (9.0 cm) did not differ between treatments ($P<0.05$). The same applied for the average waterdepth (12.1 cm) over the whole experimental period ($P<0.05$).

Table 5.2. ANOVA and mean comparisons of the total paddy yield and the rice aboveground dry matter. ANOVA significance levels: ns (not significant), * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Abbreviations: DAS (Days after seeding)

	Paddy yield (kg ha^{-1})	Rice aboveground dry matter (kg dw ha^{-1})			
		19 DAS	40DAS	68DAS	92DAS
ANOVA					
Significance					
Seed density	*	***	**	*	ns
Presence of fish	ns	ns	ns	***	***
Interaction	ns	ns	**	ns	*
FACTOR MEANS					
Rice seed density					
100 kg ha^{-1}	5550^{a}	840^{b}		8640^{b}	
200 kg ha^{-1}	5150^{a,b}	-		-	
300 kg ha^{-1}	4980^{b}	1400^{a}		9380^{a}	
Presence of fish					
Rice-fish	5340^{a}	1140^{a}		9650^{a}	
Rice monoculture	5120^{a}	1100^{a}		8370^{b}	
TREATMENTS MEANS					
100 kg, rice-fish			3300^{a}		21460^{a,b}
100 kg, rice mono			2540^{b}		22070^{a,b}
200 kg, rice-fish			-		18820^{b}
200 kg, rice mono			-		24330^{a}
300 kg, rice-fish			3390^{a}		20840^{a,b}
300 kg, rice mono			3560^{a}		23990^{a}

In case of a significant interaction, treatment means instead of factor means are presented.

Table 5.3. ANOVA and mean comparisons of the aboveground dry matter of weeds (g dw ha^{-1}). ANOVA significance levels: ns (not significant), * (P<0.05), ** (P<0.01), *** (P<0.001). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Abbreviations: DAS (Days after seeding); TOTAL (total weed aboveground dry matter); EMER (aboveground dry matter for emerged weeds); SUBM (aboveground dry matter for submerged and floating weeds)

	34 DAS			47DAS			61DAS		
	SUBM	EMER	TOTAL	SUBM	EMER	TOTAL	SUBM	EMER	TOTAL
ANOVA									
Significance									
Seed density	ns	ns	ns	ns	*	ns	ns	ns	ns
Presence of fish	ns	**	**	**	***	***	**	***	***
Interaction	ns	ns	ns	ns	**	*	ns	ns	ns
FACTOR MEANS									
Rice seed density									
100 kg ha^{-1}	3.6^{a}	39.7^{a}	43.3^{a}	56.4^{a}			62.1^{a}	202.5^{a}	264.6^{a}
200 kg ha^{-1}	0.0^{a}	84.7^{a}	84.7^{a}	481.7^{a}			213.2^{a}	569.9^{a}	783.1^{a}
300 kg ha^{-1}	4.4^{a}	713.9^{a}	718.3^{a}	6.8^{a}			32.9^{a}	861.8^{a}	894.7^{a}
Presence of fish									
Rice-fish	0.0^{a}	40.7^{b}	40.7^{b}	0.0^{b}			13.6^{b}	391.9^{b}	405.5^{b}
Rice monoculture	5.4^{a}	518.2^{a}	523.5^{a}	363.2^{a}			191.9^{a}	697.6^{a}	889.4^{a}
TREATMENT MEANS									
100 kg, rice-fish					2.9^{c}	2.9^{d}			
100 kg, rice mono					838.1^{a}	950.8^{b}			
200 kg, rice-fish					20.3^{c}	20.3^{d}			
200 kg, rice mono					2938.1^{a}	3901.4^{a}			
300 kg, rice-fish					161.7^{c}	161.7^{d}			
300 kg, rice mono					1446.9^{b}	1460.6^{c}			

In case of a significant interaction, treatment means instead of factor means are presented.

Table 5.4. ANOVA and mean comparisons of water quality parameters in the ricefield, averaged over the duration of the experimental period. ANOVA significance levels: ns (not significant), * (P<0.05), ** (P<0.01), *** (P<0.001). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Number of observations refers to the total number of original observations. Parameter code AM (6:00-7:00), PM (14:00-15:00).

	Temp.AM (^{o}C)	Temp.PM (^{o}C)	Oxygen AM (ppm)	Oxygen PM (ppm)	pH AM	pH PM	NH_4 (ppm)	PO_4 (ppm)
ANOVA								
Significance								
Seed density	ns	*	ns	**	ns	*	ns	ns
Presence of fish	ns	ns	ns	*	ns	ns	ns	**
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
FACTOR MEANS								
Rice seed density								
100 kg ha^{-1}	25.6^a	30.3^a	2.41^a	5.53^a	6.71^a	6.75^a	0.26^a	0.04^a
300 kg ha^{-1}	25.1^a	29.5^b	2.17^a	3.70^b	6.62^a	6.58^b	0.23^a	0.04^a
Presence of fish								
Rice-fish	25.2^a	29.7^a	2.31^a	4.00^b	6.63^a	6.61^a	0.30^a	0.03^b
Rice monoculture	25.5^a	30.2^a	2.26^a	5.22^a	6.71^a	6.72^a	0.19^a	0.05^a
Observations (n)	192	192	192	192	192	192	48	48

Table 5.5. ANOVA and mean comparisons of water quality parameters in the trench, averaged over the duration of the experimental period. ANOVA significance levels: ns (not significant), * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Number of observations refers to the total number of original observations. Parameter code AM (6:00-7:00), PM (14:00-15:00).

	Temp.AM (^{o}C)	Temp.PM (^{o}C)	Oxygen AM (ppm)	Oxygen PM (ppm)	pH AM	pH PM	NH_4 (ppm)	PO_4 (ppm)
ANOVA								
Significance								
Seed density	ns	ns	ns	ns	ns	*	ns	ns
Presence of fish	ns	ns	**	***	ns	ns	ns	*
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
FACTOR MEANS								
Rice seed density								
100 kg ha^{-1}	25.6^{a}	29.4^{a}	3.44^{a}	6.67^{a}	6.74^{a}	6.95^{a}	1.06^{a}	0.17^{a}
300 kg ha^{-1}	25.6^{a}	29.5^{a}	3.28^{a}	6.74^{a}	6.72^{a}	6.73^{b}	0.91^{a}	0.28^{a}
Presence of fish								
Rice-fish	25.5^{a}	29.2^{a}	3.03^{b}	5.05^{b}	6.72^{a}	6.77^{a}	0.90^{a}	0.15^{b}
Rice monoculture	25.7^{a}	29.7^{a}	3.68^{a}	8.36^{a}	6.74^{a}	6.91^{a}	1.06^{a}	0.29^{a}
Observations (n)	252	252	252	252	252	252	84	84

Table 5.6. ANOVA and mean comparisons of chlorophyll (Chl), and cell counts of Cyanophyceae (Cyano), Chlorophyceae (Chlor), Euglenophyceae (Eugl), Bacillariophyceae (Baci), and total number of algae (Total), in the ricefield, averaged over the duration of the experimental period. ANOVA significance levels: ns (not significant), * (P<0.05), ** (P<0.01), *** (P<0.001). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Number of observations refers to the total number of original observations.

	Chl (mg m^{-3})	Cyano (No. ml^{-1})	Chlor (No. ml^{-1})	Eugl (No. ml^{-1})	Baci (No. ml^{-1})	Total (No. ml^{-1})
ANOVA						
Significance						
Seed density	ns	ns	ns	ns	ns	ns
Presence of fish	***	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	*	ns
FACTOR MEANS						
Rice seed density						
100 kg ha^{-1}	21.2^{a}	130^{a}	839^{a}	573^{a}		1688^{a}
300 kg ha^{-1}	13.1^{a}	167^{a}	1000^{a}	604^{a}		1891^{a}
Fish factor means						
Rice-fish	24.6^{a}	151^{a}	938^{a}	677^{a}		1911^{a}
Rice monoculture	9.7^{b}	146^{a}	901^{a}	500^{a}		1667^{a}
MEANS OF TREATMENT						
100 kg, rice-fish					198^{a}	
100 kg, rice mono					83^{a}	
300 kg, rice-fish					84^{a}	
300 kg, rice mono					135^{a}	
Observations (n)	4	4	4	4	4	4

In case of a significant interaction, treatment means instead of factor means are presented.

Table 5.7. ANOVA and mean comparisons of secchi disc visibility (Sec), chlorophyll (Chl), and cell counts of Cyanophyceae (Cyano), Chlorophyceae (Chlor), Euglenophyceae (Eugl), Bacillariophyceae (Baci), and total number of algae (Total), in the trench, averaged over the duration of the experimental period. ANOVA significance levels: ns (not significant), * (P<0.05), ** (P<0.01), *** (P<0.001). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Number of observations refers to the total number of original observations.

	Sec (cm)	Chl (mg m^{-3})	Cyano (No. ml^{-1})	Chlor (No. ml^{-1})	Eugl (No. ml^{-1})	Baci (No. ml^{-1})	Total (No. ml^{-1})
ANOVA							
Significance							
Seed density	ns	ns	ns	ns	ns	ns	ns
Presence of fish	***	***	ns	ns	ns	ns	ns
Interaction	ns	ns	*	ns	ns	ns	ns
FACTOR MEANS							
Rice seed density							
100 kg ha^{-1}	32.5^a	43.5^a		2736^a	1618^a	188^a	5420^a
300 kg ha^{-1}	32.2^a	38.5^a		2826^a	1382^a	163^a	5132^a
Presence of fish							
Rice-fish	18.4^b	53.9^a		2583^a	1444^a	146^a	4979^a
Rice monoculture	46.3^a	28.0^b		2979^a	1557^a	205^a	5573^a
MEANS OF TREATMENT							
100 kg, rice-fish			1097^a				
100 kg, rice mono			653^a				
300 kg, rice-fish			500^a				
300 kg, rice mono			993^a				
Observations (n)	252	6	6	6	6	6	6

In case of a significant interaction, treatment means instead of factor means are presented.

Table 5.8. ANOVA and mean comparisons of zooplankton abundance: Protozoa (Prot), Rotifera (Rotif), Cladocera (Clado), Copepoda (Cop), Copepod nauplii (Naup), Microzooplankton (Micro; total of Protozoa, Rotifera and Copepod nauplii) and Macrozooplankton (Macro; total of Cladocera and Copepoda), in the ricefield, averaged over the duration of the experimental period. ANOVA significance levels: ns (not significant), * (P<0.05), ** (P<0.01), *** (P<0.001). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Number of observations refers to the total number of original observations.

	Prot (No. l^{-1})	Rotif (No. l^{-1})	Clado (No. l^{-1})	Cop (No. l^{-1})	Naup (No. l^{-1})	Micro (No. l^{-1})	Macro (No. l^{-1})
ANOVA							
Significance							
Seed density	ns	ns	ns	ns	ns	ns	*
Presence of fish	ns	ns	*	ns	*	ns	*
Interaction	*	*	ns	ns	ns	*	ns
FACTOR MEANS							
Rice seed density							
100 kg ha^{-1}			206^{a}	121^{a}	937^{a}		327^{b}
300 kg ha^{-1}			422^{a}	151^{a}	930^{a}		572^{a}
Presence of fish							
Rice-fish			196^{b}	160^{a}	744^{b}		355^{b}
Rice monoculture			432^{a}	112^{a}	1123^{a}		544^{a}
MEANS OF TREATMENT							
100 kg, rice-fish	1011^{a}	391^{a}				2182^{a}	
100 kg, rice mono	411^{a}	181^{a}				1686^{a}	
300 kg, rice-fish	620^{a}	211^{a}				1539^{a}	

300 kg, rice mono	1203^{a}	292^{a}				2646^{a}	
Observations (n)	4	4	4	4	4	4	4

In case of a significant interaction, treatment means instead of factor means are presented.

Table 5.9. ANOVA and mean comparisons of zooplankton abundance: Protozoa (Prot), Rotifera (Rotif), Cladocera (Clado), Copepoda (Cop), Copepod nauplii (Naup), Microzooplankton (Micro; total of Protozoa, Rotifera and Copepod nauplii) and Macrozooplankton (Macro; total of Cladocera and Copepoda), in the trench, averaged over the duration of the experimental period. ANOVA significance levels: ns (not significant), * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level. Number of observations refers to the total number of original observations.

	Prot (No. l^{-1})	Rotif (No. l^{-1})	Clado (No. l^{-1})	Cop (No. l^{-1})	Naup (No. l^{-1})	Micro (No. l^{-1})	Macro (No. l^{-1})
ANOVA							
Significance							
Seed density	ns	ns	ns	ns	ns	ns	ns
Fish presence	**	ns	*	**	*	ns	ns
Interaction	ns	ns	ns	ns	*	*	ns
FACTOR MEANS							
Rice factor means							
100 kg ha^{-1}	1491^{a}	591^{a}	137^{a}	148^{a}			285^{a}
300 kg ha^{-1}	1308^{a}	1163^{a}	110^{a}	164^{a}			274^{a}
Fish factor means							
Rice-fish	2184^{a}	527^{a}	69^{b}	211^{a}			280^{a}
Rice monoculture	614^{b}	1126^{a}	178^{a}	101^{b}			279^{a}
MEANS OF TREATMENT							

100 kg, rice-fish					$03^{a,b}$	3761^{a}	
100 kg, rice mono					791^{b}	1997^{a}	
300 kg, rice-fish					718^{b}	3184^{a}	
300 kg, rice mono					1219^{a}	3694^{a}	
Observations (n)	6	6	6	6	6	6	6

In case of a significant interaction, treatment means instead of factor means are presented.

The effects of the rice seeding rate and fish presence on water quality parameters from the ricefield and trench are presented in Tables 5.4 and 5.5. In the ricefield, at 100 kg rice seed ha^{-1}, the afternoon temperature, oxygen and pH were significantly higher as compared to 300 kg rice seed ha^{-1}. The presence of fish resulted in significantly lower afternoon oxygen levels, and a lower PO_4 concentration. In the trench, at 100 kg rice seed ha^{-1} the afternoon pH was significantly higher than at 300 kg rice seed ha^{-1}. The presence of fish resulted in significantly lower morning and afternoon oxygen levels, and a lower PO_4 concentration.

The effects of the rice seeding rate and fish presence on secchi disc visibility, chlorophyll and phytoplankton abundance in the ricefield and trench are presented in Tables 5.6 and 5.7. No significant effect was found of the rice seeding rate on secchi disc visibility and chlorophyll, in the ricefield and trench. The presence of fish resulted in a significantly higher chlorophyll concentration in the ricefield and trench, and a significantly lower secchi disc visibility in the trench. The phytoplankton population in the ricefield and trench was dominated by Chlorophyceae (*Chlamydomonas* and *Ankistrodesmus* spp.), and to a lesser extend by Euglenophyceae (*Euglena* and *Trachelomonas* spp.) but was not affected by the rice seeding rate nor the presence of fish.

The effects of the rice seeding rate and fish presence on zooplankton abundance in the ricefield and trench are presented in Table 5.8 and 5.9. Protozoa, Rotifera, Cladocera and Copepoda were dominated by respectively *Diffugiae*, *Polyarthra* spp., *Diaphanosoma* and *Bosmina* spp., and *Cyclopidae* and *Calanoida*. Macrozooplankton numbers in the ricefield were significantly higher at 300 kg rice seed ha^{-1}, while no significant rice effects were found in the trench. In the ricefield, the presence of fish resulted in significantly lower numbers of Cladocera, Copepod nauplii and macrozooplankton. In the trench, the presence of fish resulted in significantly higher numbers of Protozoa and Copepoda, and significantly lower numbers of Cladocera, and Copepod nauplii particularly at 300 kg rice seed ha^{-1}.

If the factor means “rice-fish” of the water quality parameters of the trench and ricefield are compared, it shows that the morning and afternoon oxygen, chlorophyll-a, total algae numbers, and micro zooplankton were considerably lower in the field, whereas macro zooplankton numbers were higher in the field.

The zoobenthos population, consisting of Oligochaeta and Chironomidae, was not significantly affected by the rice seeding rate (Table 5.10). A significant reduction in zoobenthos numbers was found 76 DAS, from the presence of fish.

Table 5.10. ANOVA and mean comparisons of zoobenthos (Oligochaeta and Chironomidae) in the ricefield. ANOVA significance levels: ns (not significant), ns (not significant), * ($P<0.05$), ** ($P<0.01$), *** ($P<0.001$). For mean comparison: indices with the same superscript are not significantly different at the 0.05 level.

	Zoobenthos (No. m^{-2})		
	28 DAS	48DAS	76DAS
ANOVA			
Significance			
Seed density	ns	ns	ns
Presence of fish	ns	ns	*
Interaction	ns	ns	ns
FACTOR MEANS			
Rice factor means			
100 kg ha^{-1}	170^a	242^a	131^a
300 kg ha^{-1}	105^a	203^a	59^a
Fish factor means			
Rice-fish	163^a	157^a	13^b
Rice monoculture	111^a	288^a	176^a

5.3.2. Fish

At harvest the total fish biomass at 100, 200 and 300 kg rice seed ha^{-1} was 248.1, 221.4 and 209.4 kg ha^{-1} respectively (Table 5.1). The biomass of indigenous fish (mostly *Rasbora* spp. and *Esomus* spp.) was 5.90, 4.79 and 3.45 kg ha^{-1} respectively (not significantly different), and neglected in the following of this study. The average biomass of tilapia recruits was circa 0.8 kg ha^{-1}. The effect of the rice seeding rate on fish production parameters is presented in Table 5.11. The net fish production of all species increased with a decreasing rice seeding rate (significant only for common carp), which resulted in a significant higher total fish biomass at 100 kg rice seed ha^{-1} as compared to 200 and 300 kg ha^{-1}. The growth rate of the total fish biomass was significantly higher at 100 kg rice seed ha^{-1} as compared to 300 kg rice seed ha^{-1}. The survival rate was not affected by the rice seeding rate. In general the condition factor did not differ much between the different rice seeding rates, only for silver barb it was significantly higher at 200 kg rice seed ha^{-1} as compared to 100 and 300 kg ha^{-1}.

Table 5.11. Production parameters of fish at different rice seeding rates (means; standard deviation in parenthesis); for mean comparison: indices with the same superscript within a line are not significantly different at the 0.05 level.

Fish species and production parameters	Rice seeding rate (kg ha^{-1})		
	100	200	300
Silver barb			
Net fish production (kg ha^{-1})	83.7^{a} (6.67)	72.1^{a} (12.0)	69.0^{a} (12.4)
Growth rate (g day^{-1})	0.40^{a} (0.05)	0.39^{a} (0.03)	0.34^{a} (0.05)
Survival (%)	86.2^{a} (3.45)	80.0^{a} (4.75)	85.9^{a} (5.14)
Condition factor (n=649)	0.71^{b} (0.037)	0.73^{a} (0.040)	0.72^{b} (0.04)
Tilapia			
Net fish production (kg ha^{-1})	32.5^{a} (1.51)	23.8^{a} (14.0)	16.7^{a} (6.58)
Growth rate (g day^{-1})	0.80^{a} (0.09)	0.89^{a} (0.24)	0.80^{a} (0.21)
Survival (%)	95.2^{a} (1.65)	78.1^{a} (16.2)	73.3^{a} (1.65)
Condition factor (n=225)	2.07^{a} (0.168)	2.04^{a} (0.192)	2.03^{a} (0.14)
Common carp			
Net fish production (kg ha^{-1})	26.8^{a} (2.81)	$20.7^{a,b}$ (2.67)	17.8^{b} (4.12)
Growth rate (g day^{-1})	1.49^{a} (0.24)	1.19^{a} (0.24)	1.15^{a} (0.09)
Survival (%)	75.0^{a} (10.0)	75.0^{a} (5.00)	68.3^{a} (7.64)
Condition factor (n=127)	1.44^{a} (0.149)	1.49^{a} (0.248)	1.49^{a} (0.14)
Total fish			
Net production (kg ha^{-1})	143.1^{a} (5.03)	116.6^{b} (4.44)	103.6^{c} (7.3)
Growth rate (g day^{-1})	110.1^{a} (8.30)	88.8^{b} (1.75)	79.5^{b} (8.30)
Survival (%)	86.5^{a} (3.31)	79.4^{a} (2.01)	82.8^{a} (3.50)

5.4. DISCUSSION

5.4.1. Paddy yield, weeds, water quality, plankton and benthos

Paddy yields decreased with an increasing seeding rate. Ten Have (1967) found an optimal seeding rate of 85 to 110 kg ha^{-1} for high and moderate yielding varieties, and IRRI recommended 100 kg pregerminated rice seed ha^{-1} (De Datta and Nantasomsaran, 1991). At higher seeding rates and with the aging of the plants, mutual shading of rice plants results in a lower photosynthetic rate per total leaf area (Yamada, 1963), whereas respiration rises proportionally with the total leaf area resulting in an unfavourable effect on the rice yield (Takeda and Maruta, 1955).

In an analysis of eighteen rice-fish studies Lightfoot et al. (1992) discussed the tendency that the integration of fish with rice increased rice yields (4.6 to 28.6%). In the Co Do area, paddy yields were not significantly different between rice-fish and rice monoculture farms (Rothuis et al., 1998a). In the present study the paddy yield in rice-fish culture was 4.5% higher, but considering the non-planted area (16.5% of the total field), the rice yield was actually 12% lower as compared to rice monoculture. In general, information on rice-fish interaction is difficult to interpret because of the diversity of locations, rice-fish agronomy, research methodology etc. Even comparisons under controlled conditions at research stations seldom find a significant effect of fish on paddy yield (Suharto et al., 1994; Haroon and Pittman, 1997).

The positive effect of fish on the rice aboveground dry matter weight at 68 DAS is possibly related to an increased nitrogen availability in the soil as a result of fish activity (Lightfoot et al., 1992). However, the rice aboveground dry matter at 92 DAS in all rice-fish treatment means was lower than in rice monoculture. Since the paddy yield was not affected by fish presence, the difference in rice aboveground matter is a difference in leafy material. The importance of rice leafs in the diet of silver barb has been demonstrated by Rothuis et al. (1998c). Probably, the growing fish biomass consumed an increasing amount of rice leafs, which resulted in a net reduction of the leaf biomass at 92 DAS.

High seeding densities are effective to control weeds in direct seeded rice. Moody (1977) showed a significant decrease in the total dry weed weight from 2682 kg ha^{-1} to 602 kg ha^{-1}, as the seeding rate increased from 50 to 250 kg ha^{-1}. In the present experiment, higher seeding densities resulted in a higher total rice aboveground dry matter weight but this did not affect the weed abundance. In general, the weed biomass was very low (at most 4 kg ha^{-1}). In an experiment on the effect of water depth on weeds in transplanted ricefields with and without fish, Piepho (1993) found that the number of sedges, broad-leaved weeds and grasses were reduced with 85, 53 and 60% respectively as the waterlevel increased from 3 to 9 cm in rice monoculture fields. Bhagat et al. (1996) reported that continuous shallow flooding for the first few weeks after seeding effectively supressed weed growth. In the present experiment all fields had an average depth of 9.0 cm during the first 40 DAS. A combination of high water levels and careful land preparation probably explains the low amount of the weed aboveground dry matter under both rice-fish and rice monoculture conditions. Apparently, under the situation of high water levels, no weed control benefit is obtained from high seeding rates. However, apart from the cost aspect of high water levels, precise water control is not generally available in tropical Asia (de Datta, 1980 in Bhagat et al., 1996), which means that high seeding rates are probably more practical for farmers.

Fish have been reported to control weeds in ricefields, either through direct consumption of weeds (e.g. *P. gonionotus*), or through specific feeding behaviour (Piepho, 1987 cited in Cagauan, 1991; Moody, 1992; Cagauan, 1995). Common carp, during their foraging activities, can disturb rooted plants. Subsequent perturbation of the soil will result in an increased water turbidity which affects the growth of submerged weeds. Satari (1962, cited in Cagauan, 1995) reported a decrease in weed abundance by 30% if common carp was cultured in ricefields, and a weed reduction of 40 to 47% when common carp and Nile tilapia were cultured together. The reduction of both submerged and floating, and emergent weeds by fish in our study probably resulted from direct as well as indirect effects.

Temperature, oxygen and pH of the ricefield floodwater were affected by the rice seeding rate. The rice seeding rate was proportional to the rice aboveground dry matter. At a low rice seeding rate more solar radiation could penetrate into the water due to a less dense rice stand, resulting in an increased temperature and photosynthetic activity of aquatic biomass, and higher oxygen and pH levels.

The presence of fish resulted in higher chlorophyll, lower oxygen and lower PO_4 levels in the ricefield and trench, and a lower Secchi disc visibility in the trench. Fish are known to affect the phytoplankton population and increase the turbidity through resuspension of bottom sediment by benthophagous fish, and selective grazing by planktivorous fish (Milstein and Svirsky, 1996). At higher algal densities, light and nutrients (PO_4) become limited, the net oxygen production per algal biomass unit decreases, and the algal respiration increases (Smith and Piedrahita, 1988). The increased phytoplankton respiration together with the respiration of the fish biomass resulted in lower dissolved oxygen concentrations in the ricefield and trench. The increased water turbidity (plankton and suspended clay particles) helped in suppressing the growth of aquatic weeds.

Numerous factors affect plankton dynamics in ricefields and, given the used sampling framework, a detailed discussion would be beyond the scope of the present study. However, the observed lower macrozooplankton numbers in rice-fish fields are probably the result of predation by fish, whereas at a high rice seeding rate fish predation was less effective due to refuges in the dense rice stand (Straskraba, 1965 and Ali, 1988, cited in Ali, 1990).

Although mean oxygen concentrations in the ricefields (stocked with fish) were lower than in the trench as a result of lower algae numbers, values were still within the acceptable range for fish production. However, this does not mean that the trench was unnecessary. Rothuis et al. (1998d) recorded a daily maximum temperature and minumum oxygen concentration in ricefields of 41.7 ^{o}C and 0.40 ppm respectively, in a wet season rice-fish experiment at the same station. Fluctuations in the deeper peripheral trench were less extreme, and the authors concluded that the trench helped fish to endure times of unfavourable conditions in the field. In general, the necessity of a trench in rice-fish systems should be judged on absolute values rather than on the means of water parameters.

5.4.2. Fish production parameters

Fish yields from rice-fish culture are preferably expressed as net fish yields to have a clear understanding of the yield potential (Haroon and Pittman, 1997). These authors reported net fish yields of silver barb and tilapia in monoculture of 227 and -58 kg ha^{-1} respectively (size 11.2 g and 30.7 g respectively, density 7500 ha^{-1}, period 78 days). In our polyculture experiment, silver barb net production was considerably lower despite a lower stocking density, probably because of the low weed biomass. Tilapia net production in our experiment was higher because of a much higher growth rate, and comparable to data from northern Vietnamese ricefields (Dan et al., 1997).

The survival rate of fish in ricefields is determined by mortality and escape of stocked fingerlings. Present survival rates compare favourably to an average on-farm survival rate of 16% from Thai ricefields (Middendorp, 1992). Since the experiment was conducted in the dry season, predatory fish were scarce and there was no risk of escape due to floods.

5.4.3. Rice seeding rate and fish yield

Our data clearly indicate that the net fish production in direct seeded, concurrent rice-fish culture was affected by the rice seeding rate. In general, fish production can be described as a function of growth (increment of fish body weight) and the number of fish harvested. The latter is determined by mortality and reproduction. In the present study fish survival was not affected by the rice seeding rate, and offspring numbers were insignificant. Therefore, the effect of the rice seeding rate on fish production was most likely related to a "growth" effect. In aquaculture systems depending at least to some extend on natural food, fish growth is primarily determined by the size of the "scope for production" (i.e. the difference between routine- and maximum metabolism), and the quantity and quality of food available (van Dam, 1995).

The scope for production depends (among other factors) on the dissolved oxygen concentration and temperature. At a rice seeding rate of 100 kg ha^{-1} the average afternoon temperature was 0.8 ^{o}C higher, and the average oxygen concentration 1.83 ppm higher, as compared to 300 kg rice seed ha^{-1}. Although an increase in temperature will increase the fish routine metabolism, this effect is counteracted by a higher increase in the scope for production due to a higher available oxygen concentration (Fig. 7.2 in van Dam, 1995).

In the present study no evident effect of the rice seeding rate on phyto- and zooplankton, zoobenthos and the dry aboveground weed biomass was found. However, from this observation an effect of the seeding rate on the quality and/or quantity of natural fish food resources cannot be entirely excluded. In ricefields, with a bigger surface to volume ratio than fish ponds, the bottom is probably a more important food source than the water column (van Dam, 1990). Accordingly, Chapman and Fernando (1994) found that the volumetric diet composition of *O. niloticus* raised in ricefields consisted of 75% detrital aggregate (of periphytic nature) and of 17% plant matter, whereas the volumetric diet composition of *C. carpio* consisted of 93% detrital aggregate (inclusive plant material). Preferred foods such as Cyanophyta (*O. niloticus*) and benthic macroinvertebrates (*C. carpio*) were only a small proportion of the diet of these fish. During the present study, it was observed that fish were frequently feeding on periphyton attached to the submerged part of the rice plant. It can be theorized that an increased light availability at lower rice seeding rates stimulated the development of these periphytic organisms which contributed to an increased fish growth at low rice seeding rates. A study on the periphyton productivity in ricefields with different seeding rates is currently being untertaken.

Another aspect of high seeding rates is the possible restriction of fish movement into the ricefield, thus restraining the access to food organisms. This phenomenon has been reported in transplanted ricefields by Halwart et al. (1996). Wider spacing or leaving rows unplanted, as a management strategy to enhance fish production in transplanted ricefields has been recommended by Halwart (1991).

5.5. CONCLUSION

For the tested range of 100-300 kg ha^{-1}, low rice seeding rates resulted in higher paddy and fish yields. The weed biomass was not affected by the rice seeding rate, but fish proved to be effective in controlling weeds. The established relationship between rice seeding rate and fish production confirmed the results of the previous on-farm study (Rothuis et al., 1998b). A further study should disclose whether a reduction of the rice seeding rate is beneficial for rice-fish farmers, from an economical- as well as from a practical point of view.

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CHAPTER 6

POLYCULTURE OF SILVER BARB, *PUNTIUS GONIONOTUS* (BLEEKER), NILE TILAPIA, *OREOCHROMIS NILOTICUS* (L.) AND COMMON CARP, *CYPRINUS CARPIO* (L.) IN VIETNAMESE RICEFIELDS: 1. FEEDING ECOLOGY AND IMPACT ON RICE AND RICEFIELD ENVIRONMENT

ABSTRACT

Rice production , ricefield environment, and the feeding ecology of fish were studied in an experiment conducted at a rice-fish station in the Mekong Delta, Vietnam. In total 6 treatments (3 replicates) were investigated: 4 different polyculture combinations of small sized silver barb, *Puntius gonionotus* (Bleeker), Nile tilapia, *Oreochromis niloticus* (L.), and common carp, *Cyprinus carpio* (L.), 1 treatment with pre-grown fingerlings, and a control (no fish stocked). No insecticides or fungicides were utilized before or during the experiment. Frequent fertilization of the water and a low rice plant biomass during the early vegetative growth phase stimulated the development of phyto- and zooplankton. The total weed biomass was low (maximal 5.3 g dw m^{-2}) and not significantly ($p<0.05$) different among the treatments. A major component of the silver barb diet consisted of rice plants and accessible grains. The introduction of silver barb however had only a significant effect on the number of rice tillers in the ratoon crop, but not on the paddy yield. Quantitative differences in the diets of tilapia and common carp were minimal, both species fed mostly on detritus. Ricefields without silver barb produced the highest paddy yield (3120 kg ha^{-1}). Total yield of introduced fish increased with increasing stocking density of silver barb from 319.9 to 494.1 kg ha^{-1}. The highest fish yield (541.8 kg ha^{-1}) was obtained by stocking pre-grown fingerlings in the ricefields.

6.1. INTRODUCTION

In the Vietnamese Mekong Delta, concurrent rice-fish culture in the area under irrigation control, is characterized by a high level of intensification (double or triple rice cropping). Farm management is basically aimed at maximizing the rice production. Inputs for fish are usually restricted to on-farm food resources, which are used at limited quantities particularly during the early phase of fish rearing (Rothuis, Nhan, Richter & Ollevier 1998a). Fish production therefore depends to a great extent on naturally occurring food resources in the ricefield. At present, farmers stock a wide variety of species in polyculture, primarily silver barb, *Puntius gonionotus* (Bleeker) and common carp, *Cyprinus carpio* (L.), and to a lesser extend Nile tilapia, *Oreochromis niloticus* (L.) (Rothuis et al. 1998a).

The herbivorous (macrophyte feeding) silver barb is frequently used in Asian rice-fish systems, e.g. Thailand (Fedoruk & Leelapatra 1992) and Bangladesh (Dewan 1992). Not much is known about the feeding behaviour of silver barb in ricefields. However, herbivorous fish are known to cause damage to rice plants (Mathes 1978; Khoo & Tan 1980; Moody 1992).

Common carp and Nile tilapia are usually regarded as benthic invertebrate and phytoplankton feeders respectively (Edwards, Pullin & Gartner 1988). In the situation of distinguished trophic niches, competition among fish species for natural food is unlikely (Tang 1970). In the present experiment, silver barb were polycultured with common carp and Nile tilapia. First aim was to investigate the interaction between the fish species combination, rice production and the ricefield environment, in relation to the feeding ecology of the fish. In a second paper the relation between fish species composition and fish production parameters will be described (Rothuis, Nam, Richter & Ollevier 1998b in prep.)

6.2. MATERIALS AND METHODS

6.2.1. Experimental facilities and design

The experiment was carried out in the wet season, from 23 April (rice seeded) to 3 October 1996 (fish harvested), at the experimental rice-fish station located in the Co Do co-operative rice farming area, Can Tho province, Vietnam. Ricefield lay-out, soil and water resources have been described by Rothuis, Vromant, Xuan, Richter & Ollevier (1998c). On the dike surrounding the station a fence of mosquito screen (height 1 m) was installed to prevent the entrance of terrestrial and aquatic predators.

The experiment was conducted as a one factor experiment in randomized complete block design. In total 6 treatments (3 replicates) were investigated (table 6.1). In treatments 1-4 an increasing number of silver barb fingerlings was stocked, whereas the ratio common carp:tilapia was fixed at 2:1. Fingerlings were small (<2 g), and the total stocking density was fixed at 20,000 fingerlings ha^{-1}. Treatment 5 served to test the effect of stocking big silver barb and tilapia fingerlings, at a total density of 8300 ha^{-1}. Treatment 6 was the control (no fish stocked).

6.2.2. Rice, weeds and water quality

Remaining rice straw of the previous crop was burned, and after irrigation, the soil was harrowed and puddled with a hand tractor. Fields were levelled manually, and pre-germinated rice seed (IR 56279) was broadcasted at 160 kg/ha, corrected for the actual germination rate. Urea fertilizer was applied in 5 split doses (total 184 kg ha^{-1}), di-ammoniumphosphate in 2 doses (total 141 kg ha^{-1}), and potassiumchloride in 2 doses (total 50 kg ha^{-1}), between 11 and 73 days after seeding (DAS), to achieve maximum fertilizer uptake by the rice plants, and to sustain production of fish food organisms (Singh, Early & Wickham 1980). No insecticides or fungicides were utilized before or during the experiment. Herbicide (Ally 20 WG; Metsulfuron Methyl, 1.09 l ha^{-1}) was applied once at 23 DAS. The water level was gradually raised as the rice plants developed, from 3-5 cm initially to circa 20 cm at rice harvest (106 DAS). Afterwards, the rice plants were left for ratooning and the water level was gradually raised to circa 50 cm at fish harvest (163 DAS).

Table 6.1. Details of stocking and harvest of introduced fish, and harvest of other1) fish (means of 3 replicates).

		STOCKING				HARVEST		
Treatment	Fish Species	Density (No.ha^{-1})	Species (%)	Tot.Weight (kg ha^{-1})	Avg.Weight (g)	Density (No.ha^{-1})	Tot.Weight (kg ha^{-1})	Avg.Weight (g)
T1	Silver barb	0	0	0.00	0.0	0	0.0	0.0
	Tilapia	6600	33	11.89	1.8	4839	189.3	39.1
	Common carp	13400	67	16.09	1.2	3238	130.6	41.3
	Total introduced fish	20000	100	27.98	1.4	8077	319.9	39.6
	Total other fish	-	-	-	-	-	45.9	-
T2	Silver barb	4000	20	3.60	0.9	2691	176.4	65.6
	Tilapia	5400	27	9.72	1.8	3135	134.8	43.2
	Common carp	10600	53	12.72	1.2	1804	44.7	55.5
	Total introduced fish	20000	100	26.04	1.3	7630	355.9	46.6
	Total other fish	-	-	-	-	-	14.5	-
T3	Silver barb	10000	50	9.00	0.9	5472	212.0	39.5
	Tilapia	3400	17	6.12	1.8	2355	116.6	51.2
	Common carp	6600	33	7.92	1.2	2473	60.6	26.9
	Total introduced fish	20000	100	23.04	1.2	10299	389.3	37.8
	Total other fish	-	-	-	-	-	8.5	-
T4	Silver barb	16000	80	14.40	0.9	12729	389.9	31.6
	Tilapia	1400	7	2.52	1.8	688	56.3	89.0
	Common carp	2600	13	3.12	1.2	1431	48.0	34.1
	Total introduced fish	20000	100	20.04	1.0	14848	494.1	33.3
	Total other fish	-	-	-	-	-	17.5	-
T5	Silver barb	4500	54	42.87	9.5	2513	369.9	149.3
	Tilapia	3800	46	109.49	28.8	2615	171.9	66.0
	Common carp	0	0	0.00	0.0	0	0.0	0.0
	Total introduced fish	8300	100	152.36	18.4	5128	541.8	105.7
	Total other fish	-	-	-	-	-	105.3	-
T6	Total introduced fish	0	0	0.00	0.0	0	0.0	0.0
	Total other fish	-	-	-	-	-	33.4	-

1) other fish = indigenous fish and tilapia offspring (T5)

The aboveground dry matter of weeds in treatments 1, 4, 5 and 6 was investigated at 57 and 140 DAS, and classified as (1) submerged and (2) emerged and floating weeds. Weed biomass and the paddy yield were determined according to Rothuis et al. (1998c). During the ratoon rice crop the number of rice tillers was counted at 134 and 147 DAS in quadrants of 1 m^2, in total 6 m^2 per plot. The rice above ground biomass was estimated after Rothuis et al. (1998c) and from tiller counts in the ratoon rice crop. For this study, the term paddy refers to rough unprocessed rice. In all other cases the general term rice will be used.

Oxygen, temperature and pH were measured twice a week in the ricefield and peripheral trench, both in the morning (6.00-7.00 hr.) and afternoon (14.00-15.00 hr.), by using portable electronic probes. The water level was measured daily from a graduated stick placed in the ricefield. Zooplankton and chlorophyll-a were sampled 9 times, and chironomids (in the ricefield only) 4 times (after Rothuis et al. 1998c). The shrimp biomass was quantified by pulling a net (mesh 1 mm) horizontally over a distance of 10 m through the trench, filtrating 1215 l of water. The collected shrimp spp. were preserved in 10% buffered formalin, oven-dried at 60 ^{o}C for 48 hours, and weighed to the nearest mg. The above mentioned variables were only measured at treatments T1, T4, T5 and T6.

6.2.3. Fish

Fingerlings of *P. gonionotus*, *O. niloticus*, and *C. carpio* were obtained from a commercial trader. The fish for treatment 5 were first nursed for circa 2.5 months in a fish pond at the station. One week before stocking of the fingerlings, the ricefield trenches and the irrigation and drainage canal inside the station were treated with 15 ppm Derris root (5 % rotenone) to eradicate wild fish. The fish were stocked at 14 DAS. For treatments 1-4 the required number of fingerlings per plot was measured volumetrically, whereas for treatment 5 the required number of fish was counted (table 6.1). The average body weight of the fish was measured by weighing and counting a sample of circa 10% of the total fish biomass per species. The fish were confined to the trench for 15 days and supplementary fed with finely grounded rice bran (10 % biomass day^{-1} for treatments 1-4; 3% for treatment 5). Afterwards, the bund separating the ricefield and trench was removed to give fish access to the ricefield, and feeding was suspended. Fish were harvested 149 days after stocking by seining the partially drained trench, and sorted according to species. Tilapia consisted of two distinguishable size classes. The smallest (recruits of the originally stocked fish) were separated and classified, together with indigenous fish, as "other fish".

During the experiment, fish were sampled in the early morning by means of a seine net (mesh 10 mm) pulled through the trench and a gill net (mesh 10 mm) placed between the rice plants, at 49, 104 and 155 DAS, for stomach content analysis (treatments 1, 4, and 5 only).

Fish sampled for stomach content analysis (on average 12 fish per species per treatment and sampling period) were injected with a 10% buffered formaline solution to stop digestion. Thereafter, the stomachs were excised, stored in 70% ethanol and stained with Rose of Bengal for identification of animal material. Since *C. carpio* and *P.*

gonionotus lack a real stomach, a section of the gut from the oesophagus to a point were the gut bends sharply was removed and similarly preserved. The relative amount of each food item present in the stomach was quantified by estimating the area covered by that food item, as an indication for the volumetric significance (after Hyslop 1980). The entire stomach content was transferred on a graduated dish in a uniform layer, and the surface area of distinguishable food items as % of the total area of one grid was estimated by eye using a zoom stereomicroscope. The area of rice grains was estimated as the number of the (hard) rice seed bases multiplied by the average surface area of intact grains, since most rice grains were found partially digested. In the case of *P. gonionotus*, plant material was estimated as the difference between the total area of distinguishable material and the area of rice grains. The area of indistinguishable food items was estimated as one item and transferred to a graduated chamber or slide. The area of clumps of detritus, finely dispersed plant material, and phyto- and zooplankton species was estimated using an inverted microscope with ocular grid, following a slightly modified drop-transect method (Edmondson 1969). Afterwards, the area of food items was calculated as the percentual composition multiplied by the original surface area. Phytoplankton in *O. niloticus* stomachs was enumerated by subsampling the diluted and homogenized stomach content, and estimating the area of plankton species along a diagonal transect using a system microscope with ocular grids. The minimal number of grids to be counted was determined with a Chi-square test for homogeneity (Prepas 1984).

6.2.4. Statistical analysis

Treatment effects of rice yield, rice tiller number, weed biomass, chlorophyll, zooplankton, zoobenthos, and shrimp biomass were analyzed as a one-way ANOVA in randomized complete block design. If assumptions of ANOVA were violated and transformations were not successful, the non-parametric Rank F-test was used (Neter, Kutner, Nachtsheim & Wasserman 1996). Means were compared with the Tuckey Honest Significant Difference test, or with multiple Mann-Witney U tests. Means of water quality parameters in the ricefield and trench were compared with a t-test. The Pearson product-moment correlation coefficient (R^2) was computed to analyze the relationship between the paddy yield and the silver barb total weight at harvest.

Fish stomach content data were averaged within a block per treatment per sampling date, and analyzed as a split-plot design with "treatment" as the main plot and "time" as subplot (Gomez & Gomez 1983). In some cases the assumption of homogeneity of variance could not be tested due to absence of variance ("zero" values). However, since the F statistic is quite robust against violations of this assumption (Sokal & Rohlf 1995) these data were not excluded from the analysis. Means at significant treatment/time effect were compared with the Least Significant Difference test (Gomez & Gomez 1983). All significance testing was done at the 0.05 level.

Fig. 6.1. Estimated rice biomass during the vegetative rice stage (Veg.), reproductive- and ripening stage (repr./Rip), and the ratoon stage, in relation to the water level in the ricefield (T6).

6.3. RESULTS

6.3.1. Ricefield environment

The relation between the rice development stage, rice biomass and field water level is illustrated in figure 6.1. For the present study three periods related to the growth stage of the rice were differentiated, a vegetative (0-50 DAS) period, a reproductive- and ripening period (51-106 DAS), and a ratoon period (107-163 DAS). In the vegetative growth stage the rice plants developed from seed into fully tillered rice plants. Subsequent panicle development, flowering and grain formation resulted in the highest biomass just before harvesting. Afterwards, the cropped plants shoot again, but (due to a lack of nutrients and high water levels) the biomass remained low. Changes in the aquatic environment as a result of developing rice (and increasing water levels) are illustrated in fig. 6.2. Frequent fertilization and a low rice biomass at the vegetative growth phase

Fig. 6.2. Total zooplankton (No./l) and chlorophyll-a concentration (mg m-3*100) in the ricefields without introduced fish (T6), during the vegetative rice stage (Veg), reproductive- and ripening stage (repr/Rip) and ratoon stage.

stimulated the development of phyto- and zooplankton. Afterwards, progressive shading during the reproductive- and ripening phase of the rice, and a limited nutrient availability during the ratoon period diminished plankton populations. Consequently, water quality conditions in the shallow ricefield were characterized by large variations in temperature, oxygen and pH (table 6.2). Whereas the overall average morning and afternoon temperature and oxygen were respectively 28.4 and 35.6 ^{o}C, and 2.39 and 9.09 ppm, these parameters ranged from 24.6-41.8 ^{o}C and 0.47-16.2 ppm respectively. In the deeper peripheral trench variations were less extreme. Afternoon temperature was significantly lower in the trench than in the ricefield, whereas the morning oxygen concentration was significantly higher in the trench.

Apart from rice plants, the aquatic macrophyte community was dominated by the submerged weed *Utricularia aurea* (Lour.), and by the emergent and floating weeds *Echinochloa crus-galli* (L.)(at 57 DAS) and *Nymphaea* spp. (at 140 DAS). The phytoplankton population in the ricefields was dominated by Chlorophyceae, Cyanophyceae, Euglenophyceae, and to a lesser extent by Bacillariophyceae. The zooplankton was mainly comprised of Rotifera, Protozoa, and copepod nauplii, followed by Copepoda and Cladocera. Collected shrimp species were basically *Macrobrachium lanchesteri* (DeMan).

Table 6.2. Water quality parameters in the trench and ricefield without fish present (T6) (means, minimum, maximum and t-test significance: ns (not significant), * ($p<0.05$), ** ($p<0.01$), *** ($p<0.001$))

Parameter	Observ. (n)	Trench Mean	Minimum	Maximum	Ricefield Mean	Minimum	Maximum	T-test[1)] p-value
Temperature AM (^oC)	105	29.0	24.8	31.9	28.4	24.6	31.8	*
Temperature PM (^oC)	105	33.1	27.0	38.3	35.6	27.6	41.8	***
Oxygen AM (ppm)	105	4.00	1.51	6.98	2.39	0.47	7.20	***
Oxygen PM (ppm)	105	7.79	3.18	17.2	9.09	3.79	16.2	**
pH AM	105	6.40	4.98	6.89	6.40	5.62	6.97	ns
pH PM	105	7.05	5.20	8.98	7.09	5.02	8.72	ns

1) Comparison trench versus ricefield mean

6.3.2. Impact of fish on rice and ricefield environment

Ricefields without silver barb (T1) produced the highest paddy yield (3120 kg ha^{-1}), but differences among treatments were not significant (table 6.3). Nor was the paddy yield significantly correlated with the silver barb final biomass ($R^2 = 0.10$). In the ratoon crop the highest number of rice tillers was found in absence of silver barb, while the number of tillers was significantly higher in T2 (20% silver barb) than in T4 (80% silver barb) (table 6.3). Submerged weeds were absent at 57 and 140 DAS in the treatments stocked with silver barb. However, in general the total weed biomass in the ricefields was low (maximal 5.31 g dw m^{-2}), and not significantly different among the treatments. Fish did not affect the chlorophyll-a concentration in the ricefield and trench, but total zooplankton numbers in the ricefield were significantly lower in T5 as compared to T4 and T6 (table 6.4). The shrimp biomass was significantly reduced by the presence of fish. Chironomid densities were higher in the absence of fish, but this difference was not significant.

6.3.3. Fish diets

Stomach content analysis indicated that silver barb was mainly feeding on plant material (rice plants and weeds), and rice grains (table 6.5). Although leaves of rice and weeds could not be differentiated in the stomach of silver barb, rice leaves were most likely a more important food source since the weed biomass in treatments with and without fish was very low. The capability of silver barb to feed on rice plants was evidenced by a significant reduction in rice tiller number during the ratoon crop. The proportion of plant material was significantly higher at 49 DAS as compared to 104 and 155 DAS. Consumption of rice grains was significantly higher at 104 DAS than at 155 DAS, and rice grains were not consumed at 49 DAS. Unfavourable weather conditions and an unbalanced nitrogen application caused severe lodging of rice plants near harvest time, enabling silver barb to consume rice grains. Besides, during the ratoon crop silver barb have been observed to pull down rice panicles. Detritus was of minor importance, and significantly less consumed by bigger fish (T5).

Detritus was the major food item for tilapia (table 6.6). A low tilapia biomass (T4) resulted in a significant lower consumption of detritus, compensated by a (non-significant) higher consumption of various algae. A significant time effect was found for the quantitatively less important food items Cyanophytes, Euglenophytes, Protozoans, and other zooplankton, which were generally more consumed at 49 DAS.

Single major food item for common carp was detritus (table 6.7). Of the minor food items, plant material was significantly more consumed at 104 DAS, while Cladoceran consumption was significantly higher at 155 DAS. The relative amount of Chironomids in the stomach of common carp was very low.

Table 6.3. Paddy yield and rice tiller number, weed biomass (submerged, sum of emergent- and floating weeds, and total weeds) at different treatments (means; standard deviation in parenthesis; for mean comparison at significant ($p<0.05$) treatment effect: indices with the same superscript in a row are not significantly different at the 0.05 level).

Parameter	T1	T2	T3	T4	T5	T6
Rice						
Paddy yield (kg ha^{-1})	3120^{a} (477.4)	2517^{a} (365.7)	2860^{a} (457.1)	2583^{a} (615.4)	3054^{a} (382.1)	2770^{a} (421.6)
Tillers at 134 DAS (No m^{-2})	84.9^{c} (26.7)	36.1^{b} (17.8)	29.4^{a,b} (13.7)	22.3^{a} (13.0)	25.2^{a,b} (16.9)	70.9^{c} (24.0)
Tillers at 147 DAS (No m^{-2})	117.3^{d} (46.0)	37.3^{b} (29.2)	20.2^{a,b} (10.2)	14.1^{a} (13.5)	14.7^{a} (9.65)	77.8^{c} (53.6)
Weed biomass at 57 DAS						
Submerged (g dw m^{-2})	0^{a}	-	-	0^{a}	0^{a}	0.45^{a} (0.40)
Emer + Float (g dw m^{-2})	0.11^{a} (0.16)	-	-	0.87^{a} (1.29)	0.82^{a} (0.27)	0.65^{a} (0.21)
Total (g dw m^{-2})	0.11^{a} (0.16)	-	-	0.87^{a} (1.29)	0.82^{a} (0.27)	1.11^{a} (0.35)
Weed biomass at 140 DAS						
Submerged (g dw m^{-2})	0.44^{a} (1.15)	-	-	0^{a}	0^{a}	5.31^{a} (6.46)
Emer + Float (g dw m^{-2})	0.11^{a} (0.29)	-	-	0^{a}	0^{a}	0^{a}
Total (g dw m^{-2})	0.55^{a} (1.29)	-	-	0^{a}	0^{a}	5.31^{a} (6.46)

Table 6.4. Chlorophyll concentration, zooplankton abundance, chironomid density, and shrimp biomass in different treatments (means; standard deviation in parenthesis; for mean comparison at significant ($p<0.05$) treatment effect: indices with the same superscript in a row are not significantly different at the 0.05 level).

Parameter/location	T1	T4	T5	T6
Ricefield				
Chlorophyll-a (mg m^{-3})	26.6^{a} (2.20)	28.3^{a} (3.73)	24.6^{a} (2.63)	22.9^{a} (4.53)
Total zooplankton (no. l^{-1})	$2597^{a,b}$ (1789)	4349^{c} (2913)	1989^{a} (1010)	$3692^{b,c}$ (2458)
Chironomids (No. m^{-2})	35.9^{a} (90.8)	39.2^{a} (62.6)	36.1^{a} (112.7)	98.0^{b} (171.1)
Trench				
Chlorophyll-a (mg m^{-3})	27.0^{a} (1.53)	29.2^{a} (1.53)	24.6^{a} (1.94)	33.0^{a} (9.62)
Total zooplankton (no. l^{-1})	4156^{a} (4719)	4764^{a} (4843)	2596^{a} (1635)	7437^{a} (9123)
Shrimp biomass (mg dw l^{-1})	0.021^{a} (0.005)	0.025^{a}(0.018)	0.059^{a} (0.027)	0.200^{b} (0.122)

Table 6.5. Stomach content of *P. gonionotus* by major food items as percentage (Tr=treatment, T=time; ANOVA significance levels: ns (not significant), * (p<0.05), ** (p<0.01), *** (p<0.001). For mean comparison: indices with the same superscript in a row (per treatment or per time) are not significantly different at the 0.05 level).

	ANOVA Significance				Mean Comp. Tr.		Mean Comparison Time		
Food Item	Tr	Time	Tr*T		T4	T5	49 DAS	104 DAS	155 DAS
Plant material	ns	**	ns		60.9^{a}	62.7^{a}	82.8^{b}	42.4^{a}	60.2^{a}
Rice grains	ns	***	ns		24.3^{a}	32.8^{a}	0.0^{a}	57.6^{b}	28.0^{c}
Detritus		*	ns	ns	12.2^{b}	3.4^{a}	11.6^{a}	0.0^{a}	11.8^{a}
Copepods	ns	ns	ns		1.4^{a}	0.1^{a}	2.2^{a}	0.0^{a}	0.0^{a}
Shrimp spp.	ns	ns	ns		0.9^{a}	1.0^{a}	2.9^{a}	0.0^{a}	0.0^{a}
Total phytoplankton	ns	ns	ns		0.3^{a}	0.0^{a}	0.5^{a}	0.0^{a}	0.0^{a}

Table 6.6. Stomach content of *O. niloticus* by major food items as percentage (Tr=treatment, T=time; ANOVA significance levels: ns (not significant), * ($p<0.05$), ** ($p<0.01$), *** ($p<0.001$). For mean comparison: indices with the same superscript in a row (per treatment or per time) are not significantly different at the 0.05 level).

	ANOVA Significance				Mean Comp. Treatment					Mean Comparison Time				
Food Item	Tr	Time	Tr*T		T1	T4	T5		49 DAS		104 DAS		155 DAS	
Detritus		*	ns	ns		79.7^{b}	73.8^{a}	79.4^{b}		73.3^{a}		80.1^{a}		79.5^{a}
Plant material	ns	ns	ns		8.0^{a}	7.7^{a}	8.5^{a}		4.7^{a}		10.8^{a}		8.8^{a}	
Cyanophytes	ns	*	ns		4.4^{a}	9.9^{a}	3.3^{a}		9.3^{b}		2.6^{a}		$5.7^{a,b}$	
Euglenophytes	ns	*	ns		2.8^{a}	3.5^{a}	3.4^{a}		5.3^{b}		$2.6^{a,b}$		1.8^{a}	
Bacillariophytes		ns	ns	ns		1.3^{a}	2.7^{a}	1.4^{a}		2.5^{a}		1.7^{a}		1.3^{a}
Chlorophytes	ns	ns	ns		2.2^{a}	0.5^{a}	1.4^{a}		1.9^{a}		0.9^{a}		1.4^{a}	
Protozoa	ns	**	ns		0.7^{a}	0.8^{a}	1.4^{a}		1.8^{b}		0.8^{a}		0.3^{a}	
Other zooplankton	ns	**	ns		0.6^{a}	0.9^{a}	1.0^{a}		1.2^{b}		0.4^{a}		0.9^{b}	
Other phytoplankton	ns	ns	ns		0.2^{a}	0.1^{a}	0.1^{a}		$<0.05^{a}$		$<0.05^{a}$		0.2^{a}	

Table 6.7. Stomach content of *C. carpio* by major food items as percentage (Tr=treatment, T=time; ANOVA significance levels: ns (not significant), * ($p<0.05$), ** ($p<0.01$), *** ($p<0.001$). For mean comparison: indices with the same superscript in a row (per treatment or per time) are not significantly different at the 0.05 level).

	ANOVA Significance			Mean Comp. Treatment		Mean Comparison Time		
Food Item	Tr	Time	Tr*T	T1	T4	49 DAS	104 DAS	155 DAS
Detritus	ns	ns	ns	86.4^{a}	86.2^{a}	86.6^{a}	87.3^{a}	84.9^{a}
Copepods	ns	ns	ns	7.2^{a}	8.7^{a}	9.7^{a}	7.0^{a}	7.1^{a}
Plant material	ns	*	ns	3.8^{a}	3.3^{a}	3.0^{a}	5.0^{b}	2.7^{a}
Shrimp spp.	ns	ns	ns	1.0^{a}	1.0^{a}	0.1^{a}	0.0^{a}	2.9^{a}
Cladocerans	ns	**	ns	0.9^{a}	0.3^{a}	0.2^{a}	0.3^{a}	1.3^{b}
Molluscs	ns	ns	ns	0.5^{a}	0.2^{a}	0.1^{a}	0.1^{a}	0.8^{a}
Total phytoplankton	ns	ns	ns	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}
Chironomids	ns	ns	ns	$<0.05^{a}$	0.1^{a}	0.1^{a}	0.0^{a}	$<0.05^{a}$
Copepod nauplii	ns	ns	ns	0.0^{a}	0.1^{a}	$<0.05^{a}$	$<0.05^{a}$	0.1^{a}

6.3.4. Fish yields

In treatments 1-4 the total weight of the introduced fish increased with an increasing stocking density of silver barb, from 319.9 kg ha^{-1} (T1) to 494.1 kg ha^{-1} (T4) (table 6.1). The highest yield of introduced fish was obtained by stocking pre-grown silver barb and tilapia fingerlings, 541.8 kg ha^{-1} (T5). The yield of ''other' fish in treatment 6 was only 33.4 kg ha^{-1}, whereas treatments 1-5 yielded respectively 45.9, 14.5, 8.5, 17.5, and 105.3 kg ha^{-1}. These consisted mostly of small indigenous species (*Rasbora* spp. and *Esomus* spp.), except in T5 in which the other fish consisted of 70 % tilapia fingerlings. The fish production parameters will be discussed more into detail in the succeeding paper (Rothuis et al. 1998b in prep).

6.4. DISCUSSION

6.4.1. Ricefield environment

The present observations on water quality parameters, chlorophyll and plankton are comparable to data from Ali (1990, 1992) who conducted similar studies in Malaysian ricefields. Chlorophyll-a concentrations were rather low in comparison to data from Boyd (1973) (62.7 mg m^{-3}), and Hepher (1962) (103.4-212.3 mg m^{-3}), for fertilized fish ponds. Total zooplankton abundance was a factor 5 lower as compared to zooplankton abundance in fertilized fish ponds in Bangladesh (Wahab et al. 1995). The chironomid density was low in comparison to other rice-fish studies (Chapman & Fernando 1994), as well as compared to fish ponds and lakes (Fernando 1995). As such, the aquatic environment in ricefields is rather different from fish ponds. Temperature and oxygen vary often beyond the tolerance limits for most tropical fish species. Therefore, a deep peripheral trench is essential to provide shelter when water quality conditions in the ricefield are unfavourable for fish. Furthermore, conventional natural food items are less abundant in ricefields than in fish ponds. On the other hand, ricefields accumulate high detritus loads as a result of decomposition of rice stubbles and other macrophytic material (Fernando 1995). Although detritus is typically low in both energy and amino acids (Bowen 1987), the attached micro-organisms can represent a major nutritional source for fish under ricefield conditions.

6.4.2. Feeding ecology

Quantitative differences in the diets of tilapia and common carp were minimal, both species fed mostly on detritus. Silver barb had a notable different diet with plant material and rice grains as the dominant food items. Macrophyte-feeding fish favour mostly soft plants such as submerged aquatic weeds, filamentous algae and grasses (Edwards 1987). In absence of submerged weeds, silver barb probably favour rice plants over emergent and floating weeds since these weeds were still present at 57 DAS (table 6.3). A reduced consumption of rice by grass carp in presence of *Hydrilla verticillata* (Royle) has been reported by Soewardi, Nurdjana & Lelana (1979).

In an analysis of eighteen rice-fish studies Lightfoot, van Dam & Costa-Pierce (1992) found that the integration of fish with rice increased rice yields with 4.6 to 28.6%. This effect could be attributed to the specific rice-fish agronomy, weed, pest and disease control by fish, and an increased nutrient availability through soil perturbation and decomposition of fish excrements. Such a rice yield increase was not evident from our study. Moreover, in view of the significant importance of rice plant material and rice grains in the diet of silver barb, an adverse effect of this fish on the paddy yield would be expected. However, this was not the case in our experiments. In general, rice plants do not suffer from leaf damage during the reproductive and ripening period when the plants are fully developed. Even in the critical vegetative stage, Raposas, Dedolph, Escalada & Heong (1994) showed that artificial defoliation by as much as 50 % did not affect the paddy yield. It is thus likely that, under the current stocking densities, consumption of rice leaves by fish does not affect the paddy yield. Concerning the importance of rice grains in the diet of silver barb, an overestimation of the volume of the grains could have occurred due to the few number of intact grains noticed in the stomach. Otherwise, no consistent explanation could be found for the observation that the consumption of rice grains did not decrease the paddy yield, although it conformed similar observations from Haroon & Pittman (1997).

The dominance of detritus in the stomach of tilapia and common carp was also observed by Chapman & Fernando (1994) in ricefields in Northeast Thailand, and for tilapia by Haroon et al. (1997). According to Schroeder (1980) fish feed at lower trophic levels (particularly detritus) if their usual feeds become limited. This was illustrated in the present study by tilapia feeding more on detritus at higher stocking densities.

Although zooplankton was a minor component of the fish diets, it was found in the stomach of common carp and tilapia throughout the study, whereas for silver barb zooplankton (Copepods) were only observed at 49 DAS. This could explain the high zooplankton numbers in the ricefields under T4, where the final fish biomass consisted of circa 80% silver barb. The relative importance of Cyanophytes, Euglenophytes and to a lesser extend zooplankton and protozoans for tilapia during the vegetative stage of the rice is probably linked to forage abundance (Fig.6.2). The unimportance of chironomids in the diet of common carp can be attributed to their abundance as well.

6.4.3. Practical implications

The present study clearly showed the specific characteristics of the ricefield habitat for fish production in terms of water quality conditions and available food resources. Nile tilapia and common carp occupied basically the same trophic niche. This implies that -contrary to pond fish culture- in rice-fish culture there is no advantage in culturing these species together. The herbivorous silver barb may help to control submerged weeds in the ricefield, but a major component of its diet consisted of rice plant material and accessible grains. However, under the current fish densities, this does not restrict the use of this species in rice-fish culture since no adverse effect on the paddy yield was evidenced.

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CHAPTER 7

POLYCULTURE OF SILVER BARB, *PUNTIUS GONIONOTUS* (BLEEKER), NILE TILAPIA, *OREOCHROMIS NILOTICUS* (L.) AND COMMON CARP, *CYPRINUS CARPIO* (L.) IN VIETNAMESE RICEFIELDS: 2. FISH PRODUCTION PARAMETERS

ABSTRACT

Fish production parameters of 5 polyculture combinations consisting of small and large silver barb, *Puntius gonionotus* (Bleeker), small and large Nile tilapia, *Oreochromis niloticus* (L.), and small common carp, *Cyprinus carpio* (L.), fingerlings, in 3 replicates, were investigated in a rice-fish culture experiment (duration 149 days) conducted in the Mekong Delta, Vietnam. The survival rate was not significantly ($P>0.05$) affected by the polyculture combination, but when grouped according to species, the mean survival of silver barb and tilapia was 64.3% and 63.7% respectively, significantly higher than the mean common carp survival rate (33.4%). Growth of silver barb and tilapia was proportionally related to the stocking density, probably because of intraspecific competition and a synergistic interaction between silver barb and tilapia. The growth of common carp was not significantly different among the polyculture combinations. The highest net production (474.1 kg ha^{-1}) was obtained in the polyculture combination consisting of 80% small sized silver barb fingerlings, but the fish was not marketable at that time. In concurrent rice-fish culture it is recommended to raise large silver barb fingerlings. Small tilapia can be polycultured with silver barb, provided that a stocking density lower than 1400 ha^{-1} is maintained. Common carp is considered less suitable because of a limited tolerance for water quality conditions in the ricefield and the large market size required.

7.1. INTRODUCTION

As in many regions of South-East Asia, fish culture in irrigated ricefields of the Mekong Delta, Vietnam, has evolved from a captural to a cultural system. The latter is based on a polyculture of hatchery produced fingerlings, basically composed of 50% silver barb, *Puntius gonionotus* (Bleeker), and completed with common carp, *Cyprinus carpio* (L.), and Nile tilapia, *Oreochromis niloticus* (L.). Rice culture, however, remains the major agricultural activity and fish production is rather determined by rice management factors (a.o. rice seeding rate) than by a fish polyculture strategy (Rothuis, Nhan, Richter & Ollevier 1998a).

The developing rice, and the low water level in the ricefield (3-5 cm initially, 20 cm at rice harvest), have an impact on the aquatic environment, and as such on the fish. Frequent fertilization of the rice early in the crop cycle and a low plant density at this stage stimulate the development of phyto- and zooplankton. Afterwards, progressive shading by the growing rice plants, and a limited nutrient availability, diminish plankton development.

Consequently, the ricefield environment is characterized by large fluctuations in temperature and oxygen, and a limited availability of natural food resources for fish (Rothuis, Duong, Richter & Ollevier 1998b in prep.). Since fish production depends to a great extend on natural food, the choice of the fish species is determined by their capacity to utilize available food efficiently, as well as by their tolerance towards prevailing water quality conditions.

The present experiment was undertaken as a first investigation on the performance of silver barb, Nile tilapia and common carp at different polyculture combinations. Furthermore, pre-grown fingerlings were stocked to explore the possibility of raising fish in ricefields to a large market size. The interaction between the fish species combination, rice production and the ricefield environment, in relation to the feeding ecology of the fish, has been described by Rothuis et al. (1998b in prep.). The present paper deals with the production parameters of the fish.

7.2. MATERIALS AND METHODS

7.2.1.Experimental facilities and design

The experiment was performed at the rice-fish research station (Co Do, Can Tho Province, Vietnam), from 7 May to 3 October 1996, and included a rice crop and ratoon period. Ricefield lay-out, soil and water resources have been described by Rothuis, Vromant, Xuan, Richter & Ollevier (1998c). Rice- and fish management, including oxygen, temperature and pH measurements are dealt with in a previous paper (Rothuis et al. 1998b in prep.). Water samples for NH_3/NH_4^+ measurements were taken fortnightly, in total 7 times after the fish were released into the ricefields, following the procedures of Rothuis et al. (1998c).

In total 5 treatments (3 replicates) were investigated. In treatments 1-4 (T1-T4) an increasing number of silver barb fingerlings was stocked (table 7.2), whereas the ratio common carp:tilapia was fixed at 2:1. All fingerlings were small (<2 g), and the total stocking density fixed at 20,000 ha^{-1}. Treatment 5 (T5) served to test the effect of stocking pre-grown silver barb (4500 ha^{-1}, average body weight 9.5 g) and tilapia (3800 ha^{-1}, average body weight 28.8 g) fingerlings in absence of common carp, on the net production and the attained size at harvest. Originally, a treatment No. 6 (no fish stocked) was included as control for the effect of fish on the rice yield. However, this aspect has been dealt with in the previous paper (Rothuis et al. 1998b in prep.), and the treatment is not included in the present analysis.

7.2.2. Fish

The average body weight of the fish at stocking (W_0) was measured by counting and weighing a sample of circa 10% of the total fish biomass per species. All fish were harvested 149 days (t) after stocking, and sorted according to species. Tilapia in T5 consisted of two distinguishable size classes. The smallest (recruits of the originally stocked fish) were separated and classified, together with wild fish, as "other fish". Of every introduced species, minimal 30% was weighed individually to the nearest gram (W_t), and measured for total length to the nearest mm (L_t). The rest was bulk-weighed and counted. Net fish production was the fish biomass at harvest minus the biomass at stocking. Growth was calculated as growth rate per day: $GR=(W_t-W_0)/t$. The relative growth rate of the metabolic weight (RGR_m) was calculated to compare fish of different sizes, based on the von Bertalanffy (1957) exponential growth model for fish. First, the metabolic mean body weight $BW_g^{0.8}=(\exp((\ln(W_t/1000)+\ln(W_0/1000))/2))^{0.8}$ ($kg^{0.8}$ refers to metabolic body weight; a value of 0.8 was chosen for the weight exponent c.f. Winberg (1956) and Heinsbroek (1989)), was calculated. The RGR_m was than calculated as $RGR_m=(W_t-W_0)/t/BW_g^{0.8}$ ($g\ kg^{-0.8}\ day^{-1}$). The fish survival rate was calculated as the number of fish harvested as percentage of the number of fish stocked.

7.2.3. Statistical analysis

The experiment was analyzed as a one factor (stocking combination) Anova in randomized complete block design. If assumptions of Anova were violated and transformations were not successful, the non-parametric Rank F-test was used (Neter, Kutner, Nachtsheim & Wasserman 1996). Means were compared with the Tuckey Honest Significant Difference test, or with multiple Mann-Witney U tests. From the experimental design however -although relevant for small-scale rice-fish farmers-, interspecific interaction between the macrophyte feeding silver barb on one hand, and the detrivorous tilapia and common carp on the other hand could not be differentiated from a density effect, since increasing silver barb densities in T1-T4 were associated with a decrease in tilapia and common carp density. The statistical results were interpreted in consideration of this limitation. Differences in the overall average survival rate among fish species were tested in a single classification Anova. All significance testing was done at the 0.05 level.

7.3. RESULTS

7.3.1. Water quality

The mean morning and afternoon temperature, oxygen and pH in the ricefields were respectively 28.4 ^{o}C and 34.3 ^{o}C, 2.25 ppm and 6.71 ppm, and 6.46 and 6.79 (table 7.1). This is within the acceptable range for fish production (Hajek & Boyd 1994). The highest recorded temperature (41.7 ^{o}C) as well as the absolute minimum oxygen concentration (0.40 ppm) were possibly exceeding the tolerance limits of the stocked fish. In the deeper peripheral trench however, variations were less extreme, and this may have helped fish to endure times of unfavourable conditions. Although the mean measured ammonia concentrations in the ricefield and trench were low (<0.1 ppm and 0.2 ppm respectively), a short term exposure of fish to high concentrations of un-ionized ammonia immediately after the application of urea and di-ammoniumphosphate fertilizer in the ricefield can not be entirely excluded.

7.3.2. Fish

Fish numbers, average individual and total weight at stocking and harvest, are given in table 7.2. Analysis of variance showed that the survival rate of the different fish species was not significantly affected by the polyculture combination (table 7.3). Grouping fish survival rates from all the individual ricefields according to species, resulted in an average survival rate of silver barb and tilapia of respectively 64.3% and 63.7%, significantly higher than the average survival rate of common carp (33.4%).

The daily weight gain (GR) and the relative growth rate of the metabolic weight (RGR_m) of silver barb were significantly higher in T2 than in T4, and inversely related to the initial stocking density of 4000 (T2) and 16000 fingerlings ha^{-1} (T4). The GR in T5 (0.94 g day^{-1}) was significantly higher than in each of the other treatments (as expected), but the relative growth rate of the metabolic weight in T5 (RGR_m: 12.9 g kg$^{-0.8}$ day^{-1}) was significantly lower than in T2 (21.3 g kg$^{-0.8}$ day^{-1}). This illustrates that the higher GR in T5 was the result of a size effect, rather than a feeding effect. For Nile tilapia, the GR as well as the RGR_m were inversely related to the initial stocking density in T1-T4, and significantly higher in T4. The GR in T5 (0.25 g day^{-1}) was not significantly different from T1, T2 and T3, but the RGR_m (3.06 g kg$^{-0.8}$ day^{-1}) was significantly lower than in each of the other treatments. The growth (GR and RGR_m) of common carp in T1-T4 was not related to the stocking density, and not significantly different among the treatments.

The net production of silver barb was significantly higher in T4 as compared to T2 and T3, but not higher than in T5. Tilapia net production was significantly higher in T1 than in T4 and T5, but not significantly different from T2 and T3. The common carp net production was significantly higher in T1 as compared to the other treatments. The net production of all stocked fish was in T4 significantly higher than T1, T2 and T3, but not significantly different from T5.

The average weight at harvest of silver barb in T2-T4 ranged from 65.6-31.6 g (table 7.2). The bigger silver barb fingerlings used in T5 reached a considerably higher average weight of 149 g, and 85% of the fish was marketable (>100 g). This was only the case for 6% in T2, and in T3 and T4 for less than 1%. The average tilapia weight at harvest in T1-T4 ranged from 39.1 g to 89.0 g. Despite a higher initial stocking weight, tilapia in T5 grew slow due to profilic breeding. The stunted population reached a final average weight of 66 g only. In T4 and T5 18% and 5% respectively of the fish was marketable (>100 g). In T1, T2, and T3 less than 1% of the fish was marketable. The average weight of common carp at harvest ranged from 55.5 g (T2) to 26.9 g (T3), but the fish was not marketable (>250 g).

The total yield of stocked fish ranged from 319.9 kg ha^{-1} (T1) to 541.8 kg ha^{-1} (T5). Other fish, consisting mostly of small indigenous species (*Rasbora* spp. and *Esomus* spp.), contributed on average circa 3% to the total weight of introduced- and other fish in T1-T4, whereas in T5 this was circa 16%, because of numerous tilapia offspring (circa 73 kg ha^{-1}).

Table 7.1. Water quality parameters in the trench and ricefield (average, minimum and maximum of the experimental plots stocked with fish during the rice crop and ratoon period; for NH_3/NH_4^+ average, minimum and maximum from T1, T4 and T5 only during the same period; AM 6.00-7.00 hrs., PM 14.00-15.00 hrs.; n.d.: non detectable).

Parameter	Observ. (n)	Trench Mean	Minimum	Maximum	Ricefield Mean	Minimum	Maximum
Temperature AM (°C)	465	28.7	21.0	31.7	28.4	24.6	39.0
Temperature PM (°C)	465	32.3	23.0	37.9	34.3	27.2	41.7
Oxygen AM (ppm)	465	2.92	0.9	7.06	2.25	0.40	7.30
Oxygen PM (ppm)	465	5.18	1.85	15.1	6.71	2.05	17.2
pH AM	465	6.53	5.24	6.99	6.46	4.89	7.21
pH PM	465	6.86	5.12	8.60	6.79	5.58	8.90
NH_3/NH_4^+ (ppm)	62	0.2	n.d.	1.6	<0.1	n.d.	0.8

Table 7.2. Details of stocking and harvest of introduced fish, and harvest of other[1] fish (means of 3 replicates).

		STOCKING				HARVEST		
Treatment	Fish Species	Density (No.ha^{-1})	Species (%)	Tot.Weight (kg ha^{-1})	Avg.Weight (g)	Density (No.ha^{-1})	Tot.Weight (kg ha^{-1})	Avg.Weight (g)
T1	Silver barb	0	0	0	0	0	0	0
	Tilapia	6600	33	11.89	1.8	4839	189.3	39.1
	Common carp	13400	67	16.09	1.2	3238	130.6	41.3
	Total introduced fish	20000	100	27.98	1.4	8077	319.9	39.6
	Total other fish	-	-	-	-	-	15.9	-
T2	Silver barb	4000	20	3.60	0.9	2691	176.4	65.6
	Tilapia	5400	27	9.72	1.8	3135	134.8	43.2
	Common carp	10600	53	12.72	1.2	1804	44.7	55.5
	Total introduced fish	20000	100	26.04	1.3	7630	355.9	46.6
	Total other fish	-	-	-	-	-	14.5	-
T3	Silver barb	10000	50	9.00	0.9	5472	212.0	39.5
	Tilapia	3400	17	6.12	1.8	2355	116.6	51.2
	Common carp	6600	33	7.92	1.2	2473	60.6	26.9
	Total introduced fish	20000	100	23.04	1.2	10299	389.3	37.8
	Total other fish	-	-	-	-	-	8.5	-
T4	Silver barb	16000	80	14.40	0.9	12729	389.9	31.6
	Tilapia	1400	7	2.52	1.8	688	56.3	89.0
	Common carp	2600	13	3.12	1.2	1431	48.0	34.1
	Total introduced fish	20000	100	20.04	1.0	14848	494.1	33.3
	Total other fish	-	-	-	-	-	17.5	-
T5	Silver barb	4500	54	42.87	9.5	2513	369.9	149.3
	Tilapia	3800	46	109.49	28.8	2615	171.9	66.0
	Common carp	0	0	0	0	0	0	0
	Total introduced fish	8300	100	152.36	18.4	5128	541.8	105.7
	Total other fish	-	-	-	-	-	105.3	-

[1] other fish = wild fish and tilapia offspring (T5)

Table 7.3. Production parameters of fish at different stocking combinations (treatment means; standard deviation in parenthesis; for mean comparison at significant ($p<0.05$) treatment effect: indices with the same superscript are not significantly different at the 0.05 level; for details see table 7.2).

Production parameter	Treatment				
	T1	T2	T3	T4	T5
Silver barb					
Survival (%)	-	67.3^{a} (7.65)	54.7^{a} (15.9)	79.6^{a} (19.3)	55.7^{a} (8.71)
Growth rate (g day^{-1})	-	0.44^{a} (0.01)	0.26^{a,b} (0.03)	0.21^{b} (0.05)	0.94^{c} (0.14)
RGR$_{m}$ (g kg$^{-0.8}$ day^{-1})	-	21.3^{a} (0.16)	15.6^{b} (1.21)	13.5^{b} (1.78)	12.9^{b} (1.18)
Net fish production (kg ha^{-1})	-	172.8^{a} (18.3)	203.0^{a} (49.3)	375.5^{b} (37.6)	327.0^{b} (11.2)
Tilapia					
Survival (%)	73.3^{a} (0.59)	58.1^{a} (3.07)	69.3^{a} (19.5)	49.2^{a} (23.4)	68.8^{a} (17.3)
Growth rate (g day^{-1})	0.25^{b} (0.08)	0.28^{b} (0.05)	0.33^{b} (0.10)	0.59^{a} (0.15)	0.25^{b} (0.03)
RGR$_{m}$ (g kg$^{-0.8}$ day^{-1})	11.4^{b} (2.09)	12.2^{b} (1.24)	13.5^{b} (2.37)	19.2^{a} (3.00)	3.06^{c} (0.25)
Net fish production (kg ha^{-1})	177.4^{b} (55.3)	125.1^{a,b} (14.7)	110.5^{a,b} (26.8)	53.8^{a} (17.1)	62.4^{a} (41.0)
Common carp					
Survival (%)	24.1^{a} (6.59)	17.0^{a} (22.5)	37.5^{a} (18.2)	55.0^{a} (7.91)	-
Growth rate (g day^{-1})	0.27^{a} (0.07)	0.37^{a} (0.30)	0.17^{a} (0.05)	0.22^{a} (0.09)	-
RGR$_{m}$ (g kg$^{-0.8}$ day^{-1})	14.1^{a} (2.15)	16.0^{a} (8.77)	10.7^{a} (2.02)	12.4^{a} (2.91)	-
Net fish production (kg ha^{-1})	114.5^{b} (29.9)	32.0^{a} (25.5)	52.7^{a} (10.5)	44.8^{a} (14.7)	-
All stocked fish					
Net production (kg ha^{-1})	291.9^{a} (26.9)	329.9^{a,b} (8.36)	366.2^{a,b} (55.6)	474.1^{c} (35.5)	389.5^{b,c}(29.8)

7.4. DISCUSSION

The average recovery rate (combined effect of mortality and escape) of stocked fingerlings from Thai ricefields has been reported as 16%, with the silver barb recovery rate a factor 3-4 higher than for common carp and Nile tilapia (Middendorp 1992). According to Chapman (1992), in rice-fish culture large fingerlings are required to ensure a reasonable survival rate. However, in an on-station rice-fish study, Haroon & Pittman (1997) reported mean survival rates of silver barb and tilapia of respectively circa 90% and 66%, for both small- and large sized fish. Overall survival rates of silver barb and tilapia in the present study were circa 64%, and similarly for small (T1-T4) and big (T5) fingerlings. Apparently the measurements taken to prevent the entrance of predators were effective, whereas at farmers situation such measurements are likely too costly, resulting in lower survival rates. Common carp were probably less tolerant towards the prevailing water quality conditions than the more “hardy” silver barb and Nile tilapia, which could explain their lower survival rate.

Table 7.4. Relative growth rates of the metabolic weight (RGRm), net production (Net prod.), and average body weight at harvest (Avg.W$_t$) in relation to average weight at stocking (W$_0$) and culture period, of different fish species raised in concurrent rice-fish systems (RF) and in fish ponds (FP). Data are based on recalculation of original data.

Fish species	Husbandry system	Rice variety	Avg.W$_0$ (g)	RGRm (g kg$^{-0.8}$ day^{-1})	Period (days)	Net prod. (kg ha^{-1})	Avg.W$_t$ (g)	Reference
Silver barb	RF/polyculture/on-station	modern	0.9	16.8	149	250	46	present study (avg. T2-T4)
	RF/polyculture/on-farm	traditional	1.5	18.3	160	37	81	Middendorp (1992)
	RF/monoculture/on-station	modern	2.7	20.5	78	271	47	Haroon & Pittman (1997)
	RF/polyculture./on-station	modern	9.5	12.9	149	327	149	present study (T5)
	RF/monoculture/on-station	modern	11.2	9.38	78	227	47	Haroon & Pittman (1997)
Nile Tilapia	RF/polyculture/on-station	modern	1.8	14.1	149	117	56	present study (avg. T1-T4)
	RF/monoculture/on-farm	modern	2.2	12.1	65	43	15	Torres, Macabale & Mercado (1992)
	RF/monoculture/on-station	modern	3.1	7.2	78	37	13	Haroon & Pittman (1997)
	RF/polyculture/on-farm	traditional(?)	5	14.0	102	?	61	Chapman & Fernando[a] (1994)
	RF/monoculture/on-station	modern	8.5	9.3	75	64	36	Mang-Umphan & Arce[a] (1988)
	RF/polyculture/on-station	modern	28.8	3.1	149	62	66	present study (T5)
	RF/monoculture/on-station	modern	30.7	0.6	78	-58	34	Haroon & Pittman (1997)
	FP/monoculture/monosex	-	32.9	7.5	150	1416	176	Green, Phelps & Alvarenga[a] (1989)
Common carp	RF/polyculture/on-station	modern	1.2	13.3	149	61	39	present study (avg. T1-T4)
	FP/polyculture/feed	-	6.0	27.1	120	460	246	Wahab, Ahmed, Islam, Haq & Rahmatullah[a] (1995)
	RF/monoculture/on-station	modern	6.7	17.3	69	89	58	Sevilleja, Cagauan, Lopez, Dela Cruz & van Dam[a] (1992)
	RF/polyculture/on-farm	traditional(?)	14.5	9.69	102	?	81	Chapman & Fernando[a] (1994)

[a] mean of different treatments or different sites

The concept of polyculture is based on the utilization of different trophic niches by different fish species. In a balanced polyculture system synergistic fish-fish and fish-environment relationships are maximized, and antagonistic relationships minimized (Milstein 1992). These interactions are related to food availability and environmental conditions. Besides, the fish density also affects the quantity of natural food available per fish (Hepher, Milstein, Leventer & Teltsch 1989). The increased growth of tilapia from T1 to T4 was probably the result of an improved feed availability due to a reduced stocking density of tilapia, as well as to a synergistic effect with silver barb. Excreta of the latter consist of partially digested plant material which could have been utilized by the detrivorous tilapia. For unknown reasons, such an interaction was not evidenced between silver barb and common carp, despite a similar feeding habit of common carp (Rothuis et al. 1998b in prep.). Intraspecific competition in silver barb in T2-T4 probably explains the growth reduction at higher stocking densities.

An overview of the RGR_m, net production and average body weight at harvest of silver barb, Nile tilapia and common carp in different rice-fish systems, as well as in pond culture, is given in table 7.4. Although growth rates from different studies are generally difficult to compare because of the numerous factors affecting the growth, the RGR_m of small and large silver barb in our study did not differ much from other studies. The RGR_m of small tilapia (T1-T4) was similar to the results of Chapman & Fernando (1994), and better than other rice-fish experiments stocked with a tilapia monoculture of comparable fingerling sizes. Haroon et al.(1997) contributed poor survival, condition and growth of tilapia to entanglement of the fish in aquatic macrophytes, and a slow ingestion of low nutrient food. Presumably, in rice-fish polyculture systems tilapia benefit from the presence of other species through habitat improvement, and through an improved food availability. Although the RGR_m of large tilapia in our study was better than in the experiment of Haroon et al. (1997), it was considerably lower as compared to monosex pond culture. Sexual maturity in tilapia can occur at 3-6 months of age and results often in stunted growth due to lack of food (Hepher & Pruginin 1982). Therefore, in rice-fish culture, as in pond culture, large tilapia fingerlings should preferable be cultured in an all-male population. The RGR_m of common carp in different rice-fish studies varies considerably, but is much lower as compared to pond polyculture (table 7.4). In our study the growth (GR and RGR_m) of common carp was not related to the density. This provides further evidence that for common carp in ricefields, water quality rather than food availability is the major constraining factor.

The net production of small silver barb did not differ much from the experiment of Haroon & Pittman (1997) but large silver barb (T5) performed better in the present study due to a higher growth rate (RGR_m) and longer culture period (table 7.4). Tilapia net production was generally higher but common carp net production lower as compared to other rice-fish studies. In general, the overall silver barb net production is factor 3 higher as compared to the Nile tilapia and common carp data which signifies the suitability of this species for concurrent rice-fish culture.

In South-East Asia even small-scale farmers are producing as much for the market as for home consumption (Edwards, Little & Yakupitiyage 1997). Therefore, besides the biological production (fish yield), economic considerations are of importance as well. From a farmers point of view, high net productions in concurrent rice-fish culture are attractive if the fish attain the marketable size, preferably within one rice cycle, i.e. in less than 4 months. Of the different rice-fish experiments listed in table 7.4, only the silver barb from the present study (T5) reached the Vietnamese market size, but the culture period was rather long (149 days).

7.5. CONCLUSIONS

The recommendation of Haroon & Pittman (1997) to use small silver barb in ricefields rather than *Oreochromis* spp. is not supported by the present study. Stocking of large silver barb can be considered as a management option to produce marketable fish within a short period, along with a reduced stocking density and less rigid weed control to provide more food to the fish. Moreover, small Nile tilapia can be reared successfully in polyculture with silver barb, but the stocking density should be lower than 1400 ha^{-1} (T4), in order to produce marketable fish. Contrary to observations from van Dam (1990) we consider common carp less suitable for rice-fish culture than Nile tilapia, because of their limited tolerance to prevailing water quality conditions and the large size required for the market.

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CHAPTER 8

GENERAL DISCUSSION: PERSPECTIVES FOR RICE-FISH DEVELOPMENT IN THE VIETNAMESE MEKONG DELTA

8.1. INTRODUCTION

The overall objective of the project was to contribute to the improvement of the living conditions of small scale rice farmers in the Mekong Delta of Vietnam, through the integration of fish culture in their farming system. The main emphasis of the present thesis was on the identification of the reasons for the low application rate of rice-fish culture, and the formulation of possible agronomical and aquacultural improvements.

In chapter 1 the main physical conditions in Mekong Delta are described in relation to agriculture land use and rice-fish farming practices. It was argued that existing intensive rice cultivation may not be sustainable on the long term, and that crop diversification and integrated crop-livestock-fish and rice-fish farming systems are of particular relevance for the future development of agriculture in the Mekong Delta. However, despite the large rice area in the Mekong Delta and the need for the development of sustainable integrated farming systems including rice-fish culture, the current area under rice-fish is estimated to be less than 5% of the total rice area.

In chapter 2 the physical conditions and socio-economical background of the Co Do Co-operative Farming area are described, as well as the lay-out of the experimental rice-fish research station.

In chapter 3 a socio-economical comparison was made between two rice-fish systems (rice-introduced fish and rice-indigenous fish) and rice monoculture. It was found that that the total farm profitability of the rice-fish systems was not different from rice monoculture. Despite the low fish yields and their rather insignificant contribution to the total farm profit, integration of fish production in the farm was found to be important in terms of environmental sustainability (a reduced pesticide use), and system biodiversity. A higher degree of farm diversification safeguards the household income against the risks associated with fluctuations in rice market prices and crop failures, and enhances the food security of the household.

In chapter 4 the technological constraints of fish production in rice-fish systems were identified using a multiple regression technique. The results indicated that low fish yields were basically the result of a combined effect of mortality and escape of fingerlings from ricefields, and a high rice seeding rate.

In chapter 5 the effect of the rice seeding rate on rice and fish production was verified at an on-station experiment during the dry season. It was found that the fish yield was higher at the lowest rice seeding rate, probably because of an improved growth rate resulting from available oxygen and food. Paddy yields at high seeding rates were negatively affected by mutual shading. The study furthermore proved that fish can control weeds in ricefields.

In chapter 6 the interaction between different fish species, rice production and the ricefield environment, in relation to the feeding ecology of the fish was studied. Phyto- and zooplankton were found to be abundant in the early (vegetative) growth stage of the rice, and declined afterwards due to progressive shading by the rice and a reduced nutrient availability. Temperature and oxygen varied often beyond the tolerance limits for most tropical fish species, and the construction of a refuge area (trench) was considered essential. A major component of the diet of silver barb consisted of rice plants and grains, but this did not affect the rice yield. Quantitative differences in the diets of Nile tilapia and common carp were minimal, both species fed mostly on detritus.

In chapter 7 the fish production parameters of silver barb, Nile tilapia and common carp were further investigated. It was found that the survival rate of silver barb and tilapia were considerably higher than that of common carp. Tilapia could have benefited from the presence of silverbarb since their growth rate was higher at higher silver barb stocking densities. In order to produce marketable fish within one rice cycle, stocking of large silver barb fingerlings in polyculture with small tilapia at low stocking densities was proposed as a means for farmers to improve their fish yield.

In this last chapter, the above summarized results will be discussed in view of the objectives of the present thesis.

8.2. RICE-FISH INTERACTIONS

In the present thesis, no differences in paddy yield (based on the seeded rice area) were found between rice-fish and rice monoculture. Of the synergistic interactions between fish and rice (paragraph 1.3.3), the ability of fish to reduce the weed biomass was evident from the experimental results (chapter 5 and 6). However, it should be realized that the weed biomass in both rice-fish fields as well as in rice monoculture fields were generally low, basically as a result of good water management and carefully prepared fields. Probably, the weed biomass was too low to have a negative effect on the paddy yield.

High water levels can affect the arthropod population in the ricefield, and might favour aquatic and semi-aquatic pests (Cruz & Litsinger 1988). Since in the experiments described in the present thesis no insecticides were used, outbreaks in particular of the semi-aquatic rice caseworm occurred, but were controlled by fish (Vromant, Rothuis, Cuc & Ollevier 1998). The total damage caused by various pests in rice-fish fields and in rice monoculture was rather insignificant, and the final paddy yields were comparable to yields from neighbouring farmers. According to Waibel (1992) in many experiments no statistical difference in crop loss was found between unsprayed fields and completely protected fields. The author argued that insecticide application on pest-resistant rice varieties are largely uneconomical. The rice variety used in the present experiments (IR56279) is resistant to a number or rice pests and diseases (a.o. brown plant hopper).

Although the effect of fish on soil fertility was not the subject of the present thesis, the positive effect of fish on the rice aboveground dry matter at 68 DAS in chapter 5 was argued to be related to an increased nitrogen availability in the soil, resulting in a higher rice leaf biomass but not in a higher paddy yield. Other evidence of fish affecting rice growth comes from the observation that rice plants are usually longer in rice-fish fields than in rice monocultures (Vromant pers.inf.), which could be related to nitrogen availability as well. These observations are the subject of currently on-going experiments in Co Do.

The average pH of the ricefield floodwater was not significantly different between rice-fish and rice monoculture (chapter 5). Also the absolute maximum pH levels in rice-fish fields did not differ much from rice monoculture fields (8.90 and 8.72 respectively; chapter 7 and 6). Moreover, the photosynthetic activity is usually the highest during the first two weeks after seeding, but the fish does not meet these conditions since they are not introduced in the ricefield at this time because of the risk of plant damage. Therefore, the hypothezied ability of fish to reduce nitrogen losses via volatilization (Lightfoot et al. 1992) is of limited practical value in directly seeded ricefields.

Above observations indicate that high water levels required in rice-fish culture, together with the presence of fish itself, diminish the need for herbicides and insecticides. Farmers stocking hatchery-produced fingerlings in ricefields were found to use significantly less pesticide sprayings in the wet season rice crop, mainly because of economic reasons, i.e. the risk of fish mortality (chapter 3). Both considerations support the view that rice-fish culture is complementary to IPM.

8.3. CONSTRAINTS TO A WIDER ADOPTION OF RICE-FISH CULTURE IN THE MEKONG DELTA

Paddy yields in our study were not statistically different between rice-fish and rice monoculture. However, these calculations were based on the area planted with rice. If the extra space requirement for the trench and high dikes is taken into account, paddy yields based on the total farm area were in fact lower than in rice monoculture. This resulted in a 20% reduction of the rice gross return at farmer level, but the total farm profitability was not affected because of an additional production from other resource systems within the farm (chapter 3). The contribution of ricefield fish to the total farm gross return was only 6% whereas homestead produce (vegetables, fruits, animals) contributed circa 13% (in the rice-introduced fish system). Therefore, some of the beneficial effects of rice-fish farming (system biodiversity, improved family nutrition etc.) are in fact the result of the integration of various agricultural activities within one farm, and fish is only a (minor) component of the system. Based on the fish component only, it is clear that there is no great direct economic incentive for farmers to start rice-fish culture. Furthermore, since rice contributed 77% to the total farm gross return, the overall profitability of rice-fish systems is more sensitive to fluctuating market prices of rice than of fish market prices. In 1996, shortages of rice in China resulted in a sharp increase of paddy prices in Vietnam which incited some rice-fish farmers to re-convert their field into rice monoculture. This illustrates that for the promotion of rice-fish culture, economical aspects should not be overlooked, although the non-economical benefits are often more emphasised.

In conclusion, it is believed that the major constraint for a wider adoption of rice-fish culture in the semi-deep fresh water area of the Mekong Delta is the low economical profitability of the fish component.

8.4. OPTIONS FOR IMPROVEMENT

Improvement of the profitability of rice-fish culture can be achieved by a) a reduction of the fish operational costs, b) an increase of the return from other farm resource systems, and c) an increase of the fish gross return.

Ad a). Fingerlings constituted 46% of the total operational costs for fish culture in rice-fish systems. These costs could be reduced by stocking fewer fish m^{-2}, or by acquiring fingerlings from alternative sources (on-farm, natural seed). Furthermore, current feeding practices should be reviewed critically. For example, the efficiency of feeding expensive fish meal as a dry feed in open water systems is questionable.

Ad b). The trench:field ratio affects the amount of rice loss. Further research should disclose the minimum trench area required for fish, in order to minimize rice production loss. Besides, the dike could be used more efficiently for the production of vegetables and fruits with a high market value.

Ad c). The fish gross return can be increased by an increased fish production and/or higher fish market prices. Higher fish yields can be obtained through feeding, stocking fish early in the dry season, proper field construction and by reducing the rice seeding rate in the dry season (chapter 4 and 5). Other options for an improved fish production are discussed in the following paragraph. Market prices of fish fluctuate according to the supply of fish from capture fishery, and are low between October to January. Therefore, rice-fish farmers should plan their fish harvest preferable before October.

8.5. OPTIMISATION OF FISH HUSBANDRY IN RICE-FISH CULTURE

8.5.1. Fish species

From an aquacultural point of view the ricefield environment is not very suitable for fish production. Water quality parameters such as temperature and oxygen temporarily exceeded the tolerance limits for most fish species. Furthermore, the application of urea and di-ammoniumphosphate fertilizer on the rice can result in short term exposure of fish to high concentrations of un-ionized ammonia (chapter 7). Pesticides had no negative effect on the fish production in our study (chapter 4), but this finding can not be generalized given the wide variation in products, and manner- and time of application.

Phyto and zooplankton diminished during the second half of the rice cycle (chapter 6). A similar trend was found for periphyton (Rothuis unpublished). The chironomid density was low in comparison to other rice-fish studies, as well as compared to fish ponds and lakes (chapter 6). Not all trophic levels could be studied in the present thesis. For example, the nutritional importance of rice insects for fish requires further research. However, Lightfoot, Roger, Cagauan & Dela Cruz (1993) rank microbial biomass, rice, and phytoplankton as the most important groups in terms of nitrogen production in their preliminary steady-state nitrogen model of a wetland ricefield ecosystem stocked with fish.Therefore, it can be assumed that the major natural food resources available for fish in ricefields are macrophytes (rice and weeds) and detritus.

All the rice-fish experiments conducted for the present study were done with silver barb, common carp and Nile tilapia because these species were commonly stocked by rice-fish farmers (chapter 4). In the following these species are compared with other commercially important freshwater fish species cultured in Asian ricefields. Available fish species in the Mekong Delta, and their main characteristics, are listed in table 8.1. The most common natural (indigenous) ricefield species are carnivorous/omnivorous and possess accessory air breathing organs. As such they are well adapted to live in deoxygenated, shallow and muddy water. Introduced species (originating from hatcheries) are predominantly herbivorous/omnivorous, and do not possess accessory air breathing organs. Consequently, these species are more sensitive to low oxygen levels.

There are indications that the capture fishery resources in the Mekong Delta are being overexploited (Interim Committee for Coordination of Investigations of the Lower Mekong Basin 1992, Nedeco 1993). In this situation, promotion of rice-fish culture using species originating from natural stocks can not be regarded as a sustainable production system. Of the species available from hatcheries, *Clarias* spp., *T. pectoralis*, *P. gonionotus* and *O. niloticus* are considered as the species best suited for culturing in ricefields, in view of the prevailing environmental conditions and available food resources. However, *Clarias* spp. can migrate over land (especially during the wet season), and are therefore difficult to confine to a specific rice-fish field (Rothuis pers. observation). Given the extensive nature of the production system and the large surface area of ricefields, the construction of fences on top of the surrounding dikes is not a realistic alternative. In the Mekong Delta, *T. pectoralis* fingerlings are available only from April to June, whereas silver barb and Nile tilapia fingerlings are almost year round available from hatcheries. Therefore, silver barb and Nile tilapia are probably the best fish species currently available for rice-fish culture in the semi-deep water area of the Mekong Delta, in the situation of limited supplementary feeding.

Table 8.1.Characteristics of potential ricefield fishes available in the Mekong Delta, Vietnam (after Bardach, Ryther & McLarney (1972); Edwards, Pullin & Gartner (1988); Fish Base (1996); Freshwater Aquaculture Department of the Can Tho University (pers.inf.)).

Fish species	Oxygen tolerance (ppm)	General feeding habit	Source	
			Nature	Hatchery
Anabas testudineus	air-breather	carnivorous (insects)	+	-
Channa striatus	air-breather	carnivorous (fish, frogs, small snakes)	+	-
Clarias spp.[1)]	air-breather	omnivorous (piscivorous)	+	+
Trichogaster pectoralis	air-breather	herbivorous (phyto-, zooplankton, macrophytes)	+	+
Trichogaster trichopterus	air-breather	herbivorous (phyto-, zooplankton, macrophytes)	+	-
Catla catla	?	herbi-omniv.surface + column (mostly zooplankton)	-	+
Labeo rohita	3	herbivorous column + bottom ((decayed) vegetation)	-	+
Cirrhinus mrigala	3	herbivorous bottom feeder (decayed vegetation)	-	+
Hypophthalmicthys molitrix	3	herbivorous (phytoplankton)	-	+
Cyprinus carpio	3	omnivorous (mostly bottom invertebrates)	-	+
Puntius gonionotus	2 (?)	herbivorous (macrophytes)	-	+
Oreochromis niloticus	0.5-1.0	omnivorous (mostly phytoplankton+ benthic fauna)	-	+

1) *C. macrocephalus, C. batrachus,* or hybrid of (*C.macrocephalus* * *C. gariepinus*)

8.5.2. Fish management

As discussed in chapter 7, production of marketable silver barb in ricefields requires the stocking of large fingerlings. Since these are not readily available from hatcheries or fish farms, rice-fish farmers preferably should nurse silver barb fingerlings themselves in the dry season rice crop (November-February). In this season aquatic predators are less of a problem (chapter 4). Since the stocking density in nurseries can be higher than in grow-out systems, nursing the fingerlings in a small ricefield will have a favourable effect on the survival rate as well (chapter 4). Subsequently, the nursed silver barb fingerlings, together with newly acquired tilapia fingerlings, can be polycultured to market size during the wet season rice crop and ratoon crop (April-September). In the fallow period between the two rice crops, the fish could be kept in the refuge pond or trench. In October and November (when the fields are flooded) fishing on indigenous species can take place.

A detailed discussion of the economical aspects of the proposed fish management strategy would be beyond the scope of the present study. However, it can be estimated that the potential production would be in the order of 375 kg silver barb ha^{-1} and 60 kg tilapia ha^{-1} (total 435 kg ha^{-1}). Given a 60% survival rate of silver barb in both nursing and grow-out, circa 7000 small fingerlings ha^{-1} are initially required. For tilapia circa 1000 small fingerlings are required (survival 60%), so that the total initial fingerling requirement would be 8000 ha^{-1}. The estimated fish production represents a gross return of circa 4,932,000 Dong ha^{-1}, and would be equivalent to circa 25% of the total farm gross return (chapter 3), comparable to data from Philippine rice-fish studies (Tagarino 1985). Since the stocking density is a factor two lower than commonly used by farmers (chapter 4), costs for the purchase of fingerlings will be accordingly reduced. Hence, the total farm return above variable costs would than be 8,518,000 Dong (for a one-ha farm), an increase of circa 57% in comparison with rice monoculture. Since these calculations are based on experiments where preventive measures against piscivorous predators were taken, farmers should take similar actions. These additional costs are not taken into account for the above calculations. However, before extending the proposed fish management strategy to farmers it should be verified by on-farm trials and evaluated on basis of biological and economical data, and observations from participating farmers.

8.6. OTHER AQUACULTURAL CONSIDERATIONS

The ricefield is a suitable habitat for the breeding of Nile tilapia (chapter 7). Although breeding of tilapia in fish ponds is generally considered as a constraint for the production of marketable fish because of stunted growth, it also has perspectives for rice-fish farmers. In the ideal situation, rice and fish are harvested (and marketed) at the same time. In the practice of concurrent rice-fish culture this is generally impossible since most fish species require more than 4 months to grow to marketable sizes. However, nursing of fish can be done in a much shorter time. The abundance of phyto-and zooplankton and periphyton early in the rice cycle provides excellent conditions for small fry. Growth can be sustained by supplementary feeding during the second half of the rice cycle. The importance of ricefields for tilapia breeding and nursing has been demonstrated by Dan, Thien & Trung (1997) in North Vietnamese ricefields, and by various other authors (Chapman 1992; Kangmin & Yinhe, 1992; Haroon & Pittman 1997). The success of rice-fish culture in Indonesia is related to the expansion of reservoir fish culture using floating net cages. The fingerlings stocked in these cages mostly originate from rice-fish culture (Costa-Pierce 1992). A further expansion of freshwater cage culture and rice-fish culture in the Mekong Delta could create a demand for large fingerlings, and open new possibilities for ricefield nurseries. Besides, an additional study should disclose the economical aspects of producing tilapia fingerlings in ricefields through the stocking of broodstock fish.

Silver barb is indigenous in Southern Vietnam (Yen & Trong 1988), but Nile tilapia and common carp are originally exotic species and have been introduced in the 1970’s and 80’s (Mekong Committee 1992; Singh 1990). Fingerlings used for the on-station experiments described in the present thesis were obtained from local traders, who in turn purchased the fish from various hatcheries. Since the origin of the fish is not clear and broodstock management at farms is almost non-existent, the genetic quality of the used fish could have influenced their performance under ricefield conditions. For example, performance tests of 5 different carp strains indicated a large variation in survival rate during a 2 months nursery period in cages, from 2.5% to 28.7% for local white carp and a Hungarian strain maintained at the Research Institute for Aquaculture in Hanoi (Bakos, Nga, Xuan & Kiem 1997).

Ricefields are rich in detritus and it forms the major food component in the diets of Nile tilapia and common carp (chapter 6). However, particularly Nile tilapia can not be considered as a typical detrivorous fish. Crayfish (*Procambarus clarkii*) production in Louisiana ricefields is in the order 500-4000 kg ha^{-1} yr^{-1} (Fernando 1995). The author contributes the success of the rice-crayfish system to the detrivorous nature of the crayfish, and their natural reproduction in ricefields. Therefore, further research on the aquacultural , ecological, and economical aspects of the culture of freshwater prawns (*Macrobrachium rosenbergii*) in ricefields in the Mekong Delta is required, as an alternative to rice-fish systems.

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