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Integrated freshwater aquaculture, crop and livestock production in the Mekong delta, Vietnam: Determinants and the role of the pond

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Abstract

Promotion of integrated aquaculture with agriculture, including crops and livestock (IAA-farming), requires consideration of both bio-physical and socio-economic contexts. The major factors influencing the adoption of IAA-farming by households at three sites in the Mekong delta were identified. Special attention was given to the multiple roles ponds play in IAA-farming systems. Information was collected through semi-structured interviews and discussions with focus groups and key individuals. Data were analyzed using multivariate factor analysis, analysis of variance or participatory ranking methods. Three major IAA-systems were identified: (1) low-input fish farming integrated with intensive fruit production (system 1), (2) medium-input fish farming integrated with less intensive fruit production (system 2), and (3) high-input fish farming integrated with less intensive fruit production (system 3). System 1 was commonly practised in a rural fruit-dominated area with fertile soils, while systems 2 and 3 were more evident in peri-urban rice-dominated areas with less fertile soils. In the study area, only 6% of poor farmers adopted IAA-farming, while this was 42% for intermediate and 60% for rich households. Richer farmers tended to intensify fish farming and seek a more commercial orientation. The major factors why farmers did not start aquaculture were the inappropriateness of technology, insufficient land holding or poor access to extension services, limited farm management, and through a fear of conflicts associated with pesticide use on crops. The main motivations for practising IAA-farming included increased income and food for home consumption from the available farm resources while reducing environmental impacts. Further improvements to IAA-systems can be realized by strengthening nutrient recycling between different IAA-system components while enhancing farming output and safeguarding the environment.

Keywords: Integrated agriculture–aquaculture; Participatory approach; Factor analysis; Nutrient recycling; Vietnam

1. Introduction

In the Mekong delta, rice culture has been the principal farming activity and alternative land use and livelihood options such as aquaculture, fruit production and livestock were minor components limited to meeting subsistence needs. In the early 1990s, less than 5% of the total area suited for aquaculture was devoted to it, while a vast area of rice fields and, increasingly, trenches in fruit orchards remained under-utilized from an aquaculture point of view. Commercial horticulture has expanded rapidly in certain areas but aquaculture has also developed quickly in recent years: by 2004 22% of the agricultural space was devoted to aquaculture (Fig. 1; CSO, 2002; GSO, 2005). These changes are strongly supported by government policy.

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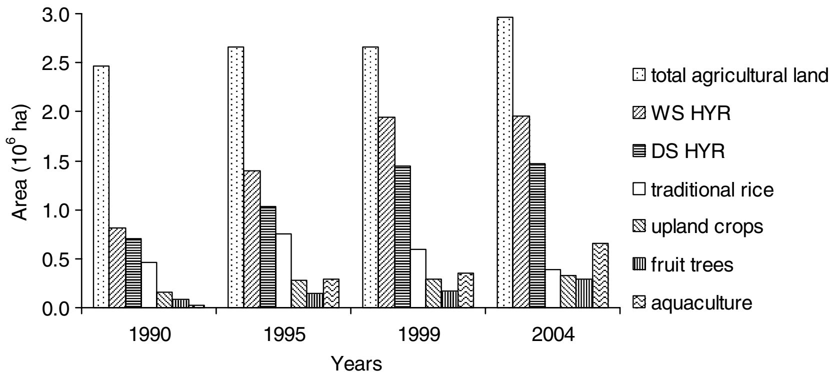

Fig. 1. Changes in land use in the Mekong delta between 1990 and 2004. Total agricultural land was calculated as the surface area while areas devoted to rice, upland crops, fruit and aquaculture were based on farming areas. In rice areas, 2 or 3 crops of rice are practised per year (with WS and DS HYR or traditional rice crops). DS (dry season), WS (wet season), HYR (high yielding rice) (reproduced from CSO, 2002; GSO, 2005).

Recognizing the potential of aquaculture, since 1999, the Vietnamese government promoted diversification in agriculture, aiming to reduce the share of rice to the total agricultural output value while increasing the contribution of aquaculture to economic growth and poverty reduction (Luu, 2002). In this context, stimulating integration between fish, shrimp/prawn, fruit, livestock and rice production on the same farm, further referred to as integrated agriculture–aquaculture (IAA) systems, is expected to contribute to agricultural diversification and enhance its sustainability. In Vietnam, IAA-farming has been promoted through mass organizations such as the Vietnam Gardening Association and Government Agricultural Extension Agencies.

Between 1999 and 2004, the growth rate of aquaculture production was faster than that of both fisheries and agriculture (GSO, 2003, 2005). Aquaculture production contributed approximately 29% in 1999 and 47% in 2004 to the total fish production in the delta. Between 1999 and 2004, annual aquaculture growth rates were 31% for production and 19% for culture area (GSO, 2003, 2005), suggesting a gradual intensification of aquaculture. Coastal aquaculture, mainly shrimp, and intensive *Pangasius* culture inland, however, have been the main drivers of this expansion of aquaculture production in the Mekong delta, rather than fish culture within IAA-farming, but there are indications that this growth is not sustainable. By 2004, coastal aquaculture occupied more than 90% of suitable sites (GSO, 2005). Techniques for integration of brackish water aquaculture within agriculture remain undeveloped. In contrast, aquaculture based on freshwater can, in principle, be integrated closely within diversified farming systems.

An important characteristic of IAA-farming is the recycling of nutrients between farm components (Little and Muir, 1987; Prein, 2002). Through nutrient recycling, IAA-farming allows intensification of production and income, while reducing environmental impacts (Edwards, 1998; Costa-Pierce, 2002; Devendra and Thomas, 2002). Intensive export-orientated *Pangasius* culture in both cages and ponds is characterized by large nutrient flows supported by the use of off-farm feeds and water exchange making local nutrient recycling problematic (Beveridge et al., 1997; Phillips, 2002, p. 42; Hao, 2006). Moreover, the industrial scale of the business and its sensitivity to fluctuations in global trade make it risky and the domain of the resource-rich (Naylor et al., 2000). IAA-farming in contrast appears to be a realizable approach for diversification of rice production whereby synergism between on-farm components can be realized and whole system productivity optimized rather than that of individual enterprises (Edwards, 1989, 1998). The potential integration of farm components and attainable intensification levels of IAA-systems are in part determined by the bio-physical setting and the farmer's aspirations and decisions (Lo, 1996; Pant et al., 2005). In Vietnam the benefits of traditional VAC (garden-pond-livestock) integrated systems (Luu et al., 2002) have been widely reported but the complementarity between commercial orchard and fish production systems have yet to be investigated.

In the Mekong delta, freshwater IAA-farming is commonly practised in the central region, where soil and hydrological conditions are favourable for aquaculture. Development agencies have tended to promote a rather standardized IAA-system for the region in a "conventional, linear" approach (cited in Stür et al., 2002). Within the central zone of the delta, however, different agro-ecologies exist and market opportunities for farming inputs and outputs differ. In particular differences between rural and peri-urban areas are likely and might be expected to have an impact on optimal forms of IAA. In Northeast Thailand Demaine et al. (1999) found that location relative to urban centres was more important than agro-ecology in determining farmer attitudes and any likelihood of intensification. Better market accessibility in peri-urban areas and access to nutrients often stimulates intensification of aquaculture compared with more rural areas (Little and Bunting, 2005), allowing IAA-farming to raise income and to produce cheap food for urban consumers (Edwards, 1998).

The potential benefit of IAA for poorer farming households on the delta is also an issue given the resource dependent nature of aquaculture. Pond-based diversification was found to benefit poorer farmers in Bangladesh (Karim, 2006) but many forms of integrated aquaculture are dominated by resource-rich entrepreneurs in Asia (Little and Edwards, 2003). Edwards et al. (2002) suggested that poor farmers are generally not early adopters of aquaculture technologies, and that aquaculture only becomes an option given certain predisposing conditions. The current profiles and predisposing factors of IAA for different locations and households of different socio-economic level are therefore investigated in this study to inform more contextualized approaches to its promotion.

2. Materials and methods

2.1. Study framework

The present study, carried out in 2002, investigated IAA-farming systems in the central region of the Mekong delta at community and household level considering a range of bio-physical and socio-economic settings. Three sub-areas were identified within the target areas, based on secondary data (i.e. maps, statistical data and literature) and information obtained during reconnaissance visits; one study site was selected in each sub-area (Fig. 2). At each study site, one indicative hamlet was selected, based on village statistics and participatory mapping in respect of population density (intermediate level), household wealth status (intermediate level), current practices of agriculture (aquaculture, fruit, rice and livestock) and advocacy of the local government for IAA-farming. Subsequently, different wealth groups (poor, intermediate and rich) and major IAA-farming systems were identified, applying participatory wealth and farm ranking. This was followed by monitoring IAA-farming practices at household level.

2.1.1. Study sites

Site 1, located in Thien Tri village (Cai Be district, Tien Giang province), is a rural area dominated by intensive fruit production (fertilizer input of $\geqslant$100 kg N ha^{-1} yr^{-1} and fruit production >5000 kg ha^{-1} yr^{-1}) and fertile alluvial soil. In IAA-farming, farmers grow fish in a system of parallel trenches between fruit orchards. Rice farming is a secondary activity and yields three crops a year.

Site 2, located in Song Phu village (Tam Binh district, Vinh Long province), and site 3, located in Thoi Long village (O Mon district, Can Tho city), are peri-urban areas dominated by rice production and less fertile slightly acid sulphate soils. In IAA-farming, farmers grow fish in ponds adjacent to the homestead or in rice fields. Two rice crops a year are grown. Fruit production is usually less intensive (fertilizer input of $\leqslant$50 kg N ha^{-1} yr^{-1} and fruit

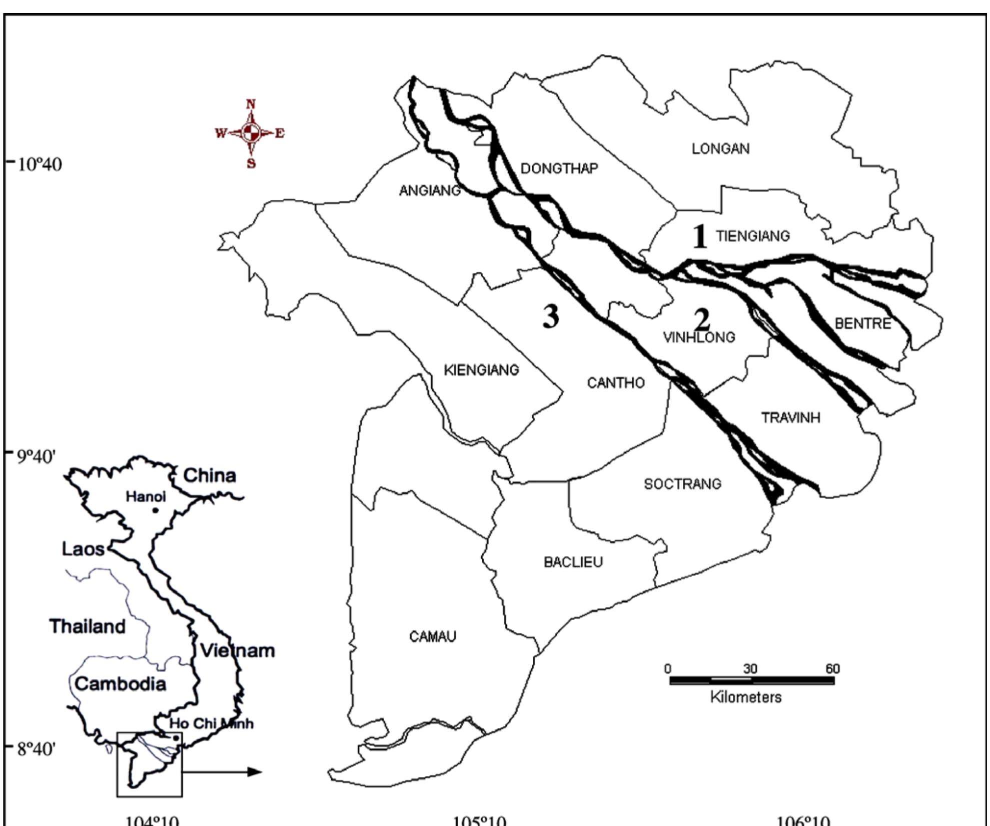

Fig. 2. Mekong delta map with locations of the study sites. 1, site 1; 2, site 2; 3, site 3.

production <2000 kg ha^{-1} yr^{-1}) than site 1, except on the levees along the Bassac river at site 3. Site 2 is located closely to Can Tho city while site 3 is located in between Can Tho and Long Xuyen cities. Therefore, market accessibility is easier at site 3 than at site 2.

The study sites are located within the monsoon tropics with an annual rainfall of 1.4–1.6 m, mainly from May to November (data from provincial weather stations). The annual monsoon flood occurs between August and November. Site 1 has an elevation of 1.0–1.5 m and sites 2 and 3 are 0.5–1.0 m above mean sea level.

2.1.2. Identification of focus groups and IAA-farming systems

Standard participatory rural appraisals tools and methods were used (Mukherjee, 1993; van Veldhuizen et al., 1997). At each site, group semi-structured interviews and discussions with key informants were used at village level to get a general overview of socio-economic context, current farming practices and opportunities for IAA-farming. Key informants were village officials, extension workers, hamlet heads and elderly farmers who knew much about their village. Wealth ranking was carried out in each selected hamlet independently by three key informants (head of the hamlet people's committee and two selected farmers) based on the list of all households obtained from the hamlet administration. The key informants classified each household as poor, intermediate or rich using their own criteria (Table 1; Mukherjee, 1993). In addition, each household was classified by farming activity in terms of intensity of fish culture (low-, medium- or high-input levels; Edwards, 1993), orchard (intensive or less intensive) and livestock (subsistence or commercial) production. Farm households practising or not practising pond aquaculture were identified. IAA-adopters were identified as households that stock juveniles in their pond and that had nutrient linkages with other on-farm components (Little and Muir, 1987). Households not practising aquaculture often also had a pond within their farm, but did not stock hatchery juveniles; such ponds are typically used for trapping wild fish. At each site, three groups representing the most frequent combinations of wealth and IAA-farming patterns were selected for subsequent data collection (Table 2). Three IAA-farming systems, considering aquaculture intensity levels, were identified across the sites: (1)

Table 2
Different selected focus groups with wealth, aquaculture, fruit and livestock production categories by site

Sites	Groups	n	Categories			
			Wealth	Aquaculture systems	Fruit culture systems	Livestock culture systems[a]
1	1	7	Intermediate	Low-input	Intensive	Subsistence
	2	8	Rich	Low-input	Intensive	Subsistence
	3	7	Rich	Medium-input	Intensive	Commercial
2	1	6	Intermediate	Low-input	Less intensive	Subsistence
	2	7	Rich	Medium-input	Less intensive	Commercial
	3	9	Rich	Medium/high-input	Less intensive	Commercial
3	1	7	Intermediate	Low-input	Intensive	Subsistence
	2	8	Rich	Medium-input	Less intensive	Commercial
	3	6	Rich	High-input	Less intensive	Subsistence or commercial

n, Group size.
[a] Subsistence = poultry production mainly for home consumption, commercial = pig production.

Table 1
The criteria used for wealth ranking by key informants at three sites in the Mekong delta

Criteria	Criteria used			Number of rankers using the criterion		
	Poor	Intermediate	Rich	Site 1	Site 2	Site 3
Land holding area (ha)	<0.3	<1.0	>1.0	3	6	6
Type of house	Nippa	Wooden	Wooden or brick	3	6	6
Recreation facilities (TV, video)	None	Yes	Yes	3	6	6
Major sources of household income	Mainly wage labour	Farming activities or wage labour	Farming or non-farming activities	3	6	6
Transportation facilities (motorbikes)	None	Yes	Yes	3	5	5
Farm equipment (pumping engine, hand tiller, rice thresher)	None	Pump	Pump, tiller or thresher	2	4	5
Type of farming	Subsistence	Commercial	Commercial	2	4	4
Subsidy from the government	Yes	None	None	2	6	2
Receiving remittance from abroad	None	None	Yes	1	4	3
Educational level of children	Illiterate or elementary	Secondary	Secondary or higher	1	4	3
Contribution to social activities	None	Yes	Yes	0	1	0

Persons doing the wealth ranking are referred to as rankers.
In each hamlet or sub-hamlet, three rankers did wealth raking. At sites 2 and 3, due to hamlet size, each selected hamlet was split into two sub-hamlets for the ranking.

low-input, (2) medium-input, and (3) high-input aquaculture. Poor households did not participate as members of focus groups, because very few poor households practised IAA-farming at all sites.

2.2. Data collection

Reasons why households either did or did not adopt IAA-farming were investigated through a semi-structured interview conducted with the household head. Based on the results from the wealth and farm ranking, stratified random sampling was used to select farmers for the interviews at each site (Gomez and Gomez, 1984). At sites 1, 2 and 3, a total of 39, 50 and 40 farmers practising IAA-farming and 37, 48 and 40 farmers not practising pond culture, respectively, were interviewed independently. The interviewed farmers were requested to list reasons why they adopted IAA-farming or did not start pond culture, and to score them in order of the importance on a scale from 0 (not important) to 5 (extremely important).

Current practices of and possible improvements to IAA-farming were understood through group discussions with the selected focus groups. Individual household data on farm area devoted to each farming activity were collected through interviewing households within the focus groups. Pond:dike ratios were calculated as the ratio of pond to orchard area. Nutrient linkages between the pond and other farming components were identified through bio-resource flow diagrams (Prein, 2002). The importance of pond nutrient resources and the role of the pond within the IAA-system and to household economy were evaluated by ranking according to farmers' opinions. Possible improvements to the whole IAA-system, including the pond, were discussed. As a validation and verification step, analyzed results were presented to and discussed with representatives of the focus groups, local government officials, extension workers, colleague farmers, bank officers and agro-traders at a stakeholder meeting in each hamlet.

2.3. Data analysis

Multivariate factor analysis was used to analyze cross-relationships between reasons for the adoption IAA-farming or for not starting aquaculture and to identify major underlying factors of those relationships. Two models were established: (1) one for the adoption of IAA-farming and (2) another for not starting aquaculture. The reasons perceived by farmers were considered variables and were included in the respective models. In each model, factors were extracted using principal components method with the eigenvalue $\geqslant 1$. The factors were rotated using the varimax method so that they are independent of each other. Factor loadings of 0.5 and above were used for result interpretation (Hair et al., 1998).

Effects on area devoted to each farming activity and pond:dike ratio were analyzed by one-way analysis of variance (ANOVA) for the factor system and two-way ANOVA for the factors site and wealth group. Tukey HST *post hoc* multi-comparisons of means were applied at 5% significant level. The ANOVA assumptions were tested for homogeneity of variances (Hartley's $F_{\max}$, Cochran's C and Bartlett's χ^2) and for normality of residuals (Fry, 1993).

Results from the data analyses, in combination with qualitative information collected during the discussions with the key informants and farmers were used to describe the IAA-systems, to identify the role of the pond, and to suggest possible improvements to each farming systems.

3. Results

3.1. Determinants of IAA-farming adoption

IAA-farming was more common in the peri-urban rice-dominated areas (sites 2 and 3) than in the rural fruit-dominated area (site 1), more common with intermediate and rich farmers than poor farmers, and more commonly associated with low- and medium-input than high-input fish farming systems (Table 3). In the fruit-dominated area, the low-input fish farming system was most important, while in the rice-dominated areas both low- and medium-input systems were most common. The high-input system was practised mainly at site 3, where farmers could easily access markets for aquaculture inputs and outputs. Poor farmers usually practised the low-input system, while only rich farmers practised the high-input system.

Farmers suggested nine reasons why they adopted IAA-farming (Table 4). The factor analysis identified four major groups of interrelated variables. These four factors accounted for 67% of the total variance (Table 4). Factor 1 included positive contributions of government advocacy,

Table 3
Percentage of farm households practising aquaculture by site (1, 2 and 3), wealth group (poor, intermediate and rich) and system (low-, medium- and high-input)

Items	*n*	Aquaculture systems			All systems combined
		Low-input	Medium-input	High-input	
By site[a]					
Site 1	349	15.8	4.6	0.0	20.4
Site 2	461	18.2	34.1	2.0	54.3
Site 3	351	12.3	24.8	12.3	49.4
By wealth group					
Poor	184	4.3	1.6	0.0	5.9
Intermediate	569	20.6	19.2	2.1	41.8
Rich	408	14.0	36.3	9.8	60.0
Average by system		15.7	22.4	4.5	42.5

n, The total number of households in each community per site or in each wealth group at three sites.
Percentages are always given as a fraction of *n*.
[a] Sites 1 (rural fruit-dominated area), 2 (peri-urban rice-dominated area), 3 (peri-urban rice-dominated area with good market accessibility).

Table 4
Major factors explaining adoption of IAA-farming among households at three sites in the Mekong delta

Reasons (variables)	Factor 1	Factor 2	Factor 3	Factor 4
Government advocacy	**0.59**	0.31	−0.23	0.28
Suitability of soil and water	**0.72**	−0.16	0.20	0.00
Recycling of nutrients	**0.73**	−0.21	−0.14	0.12
Pest control in rice fields	**0.63**	0.20	−0.22	0.12
Creation of jobs for family	**0.82**	0.04	0.06	−0.18
Income generation	0.38	**−0.69**	0.13	−0.12
Fish market value	−0.28	**−0.70**	−0.23	0.21
Environmental conservation	−0.07	0.06	**0.90**	0.08
Improved family nutrition	−0.07	0.05	−0.08	**−0.93**
Variance explained (%)	31	13	12	11
Factor interpretation	Increased use of on-farm resources	Income generation	Environmental conservation	Nutrition

Variables with bold values of factor loading were considered in interpretation of the respective factor. $n = 129$.

Table 5
Major factors explaining why aquaculture was not practised among households at three sites in the Mekong delta

Reasons (variables)	Factor 1	Factor 2	Factor 3	Factor 4
Inappropriate technology	**0.87**	0.10	0.02	−0.03
Lack of capital	**0.63**	−0.26	0.29	0.36
Insufficient farm size	0.08	**0.84**	0.23	0.02
Poor access to extension	0.14	**−0.62**	**0.47**	0.08
Lack of family labour	0.21	0.06	**0.77**	−0.05
Farm far from house	−0.03	−0.01	**0.70**	0.14
Poor soil and water quality	−0.35	−0.36	0.41	0.39
Pesticide use for crops	0.10	0.01	0.04	**0.94**
Variance explained (%)	27	17	13	11
Factor interpretation	Inappropriate technology	Insufficient farm area or poor access to extension	Limited farm management	Pesticide use for crops

Variables with bold values were considered in interpretation of the respective factor. $n = 125$.

suitability of soil and water, recycling of nutrients, pest control in rice fields, and creation of jobs for family members. Factor 1 accounted for 31% of the total variance, and showed that farmers perceived IAA-farming as a way to increase the use of on-farm resources. Factor 2 accounted for 13% of the total variance, and reflected income generation through aquaculture. Farmers perceived that fish is a high value commodity within their IAA-system. Factor 3, accounting for 12% of the total variance, showed that farmers are aware of positive environmental impacts, resulting from the recycling of livestock or human wastes or reduced agrochemical use in rice fields. Factor 4, accounting for 11% of the total variance, showed that improved nutrition is considered an additional advantage of IAA-farming.

Farmers suggested eight reasons why they did not start pond culture (Table 5). The factor analysis produced four major factors, together accounting for 68% of the total variance (Table 5). Factor 1 accounted for 27% of the total variance, and reflected that inappropriateness of technology due to limited availability of capital were important reasons not to adopt pond culture as a farming activity. Factor 2, accounting for 17% of the total variance, showed that either insufficient land holding or poor access to extension was an important constraint. Access to information was thought not to constraint the adoption of aquaculture by farmers perceiving that their land holding was too small to incorporate aquaculture. Poor access to extension, in contrast, was an important constraint for farmers perceiving that small land holding was not a problem. Factor 3, accounting for 13% of the total variance, reflected limited farm management. Insufficient availability of family labour, distance between house and farm, and poor access to extension service are important constrains to start pond culture. Finally, factor 4, accounting for 11% of the total variance, suggests that farmers perceived that use of pesticides for rice or fruit production might undermine fish culture. In addition, farmers believed poor soil and water quality as a constraint, although this variable had low loadings in the selected factors.

3.2. Farm components

In the freshwater areas of Mekong delta, a farm usually has three components: (1) the homestead and fruit orchard, (2) the pond, and (3) the rice field. The homestead, the fruit orchard and the pond are usually co-located. Livestock, fruit crops, vegetables and other trees are located close to the residence constituting the "homestead", which rarely exceeds an area of 400 m^2.

For IAA-farms, the ANOVAs revealed differences in farm area for each component by site, wealth group or system (Table 6). At the fruit-dominated site 1, farmers had much larger fruit orchards and slightly larger ponds. They also owned smaller rice fields. The pond:dike ratio was lower at the fruit-dominated site than at the rice-dominated sites. The total farm size did not significantly differ among sites. Land holdings of intermediate farmers were considerably smaller than those of rich farmers, and the former had

Table 6
Farm area (ha) devoted to different farm components by site (1, 2 and 3), wealth group (intermediate and rich) and system (low-, medium- and high-input)

Effects[a]	n	Homestead & orchard	Pond	Rice field	Total farm	Pond:dike ratio
Two-way ANOVA significance						
Site		***	*	***	ns	*
Group		***	**	**	***	*
Site × Group		**	**	**	ns	***
Multi-comparisons of means by site[b]						
Site 1	22	0.71 (0.09)^{b}	0.29 (0.03)^{b}	0.33 (0.05)^{a}	1.33 (0.10)	0.58 (0.10)^{a}
Site 2	22	0.40 (0.07)^{a}	0.26 (0.04)^{ab}	0.89 (0.10)^{b}	1.55 (0.12)	0.96 (0.11)^{b}
Site 3	21	0.28 (0.03)^{a}	0.20 (0.03)^{a}	1.10 (0.15)^{b}	1.58 (0.18)	0.73 (0.07)^{ab}
Multi-comparisons of means by wealth group						
Intermediate	20	0.22 (0.03)^{a}	0.19 (0.03)^{a}	0.55 (0.07)^{a}	0.96 (0.06)^{a}	0.89 (0.09)^{b}
Rich	45	0.58 (0.06)^{b}	0.28 (0.02)^{b}	0.86 (0.10)^{b}	1.72 (0.09)^{b}	0.70 (0.07)^{a}
One-way ANOVA significance						
System		ns	ns	**	***	ns
Multi-comparisons of means by system						
Low-input	28	0.40 (0.07)	0.20 (0.03)	0.49 (0.06)^{a}	1.09 (0.07)^{a}	0.72 (0.08)
Medium-input	28	0.56 (0.07)	0.28 (0.03)	0.93 (0.12)^{b}	1.77 (0.11)^{b}	0.75 (0.09)
High-input	9	0.33 (0.06)	0.31 (0.06)	1.20 (0.17)^{b}	1.84 (0.25)^{b}	0.99 (0.13)

Pond:dike ratios are given in the right column (dimensionless). *n*, sample size. Mean with standard error in parenthesis.

[a] ANOVA significance: ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. Means with the same superscript (a or b) in a column per effect do not differ significantly at 5% level.

[b] Sites 1 (rural fruit-dominated area), 2 (peri-urban rice-dominated area), 3 (peri-urban rice-dominated area with good market accessibility).

higher pond:dike ratios than the latter. The interaction effect between site and group was not significant for total farm size, but was for homestead and orchard, pond and rice field area. This was also reflected in a significant interaction between site and group for pond:dike ratio. At site 3, rich farmers with the high-input fish farming system had smaller homestead and fruit orchards, but larger rice fields than rich households with a medium-input fish farming system at sites 1 and 2 (Fig. 3a and c). At site 1, intermediate farmers residing in a relatively low-lying area with

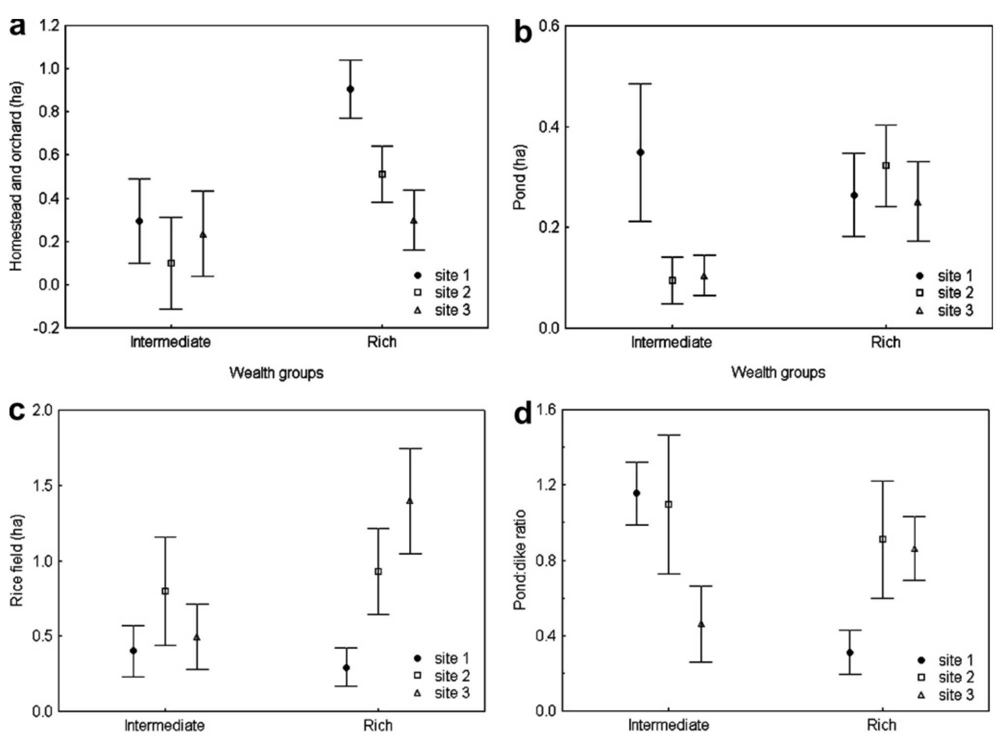

Fig. 3. Site and wealth group interactions for area devoted to homestead and orchards (a), pond (b), rice field (c) and for pond:dike ratio (d). Mean ± 0.95 confidence interval.

less fertile soils had to excavate larger trenches or ponds to build orchard dikes high enough to reduce the risk of flood. Thus, they had larger ponds than intermediate farmers at sites 2 and 3 (Fig. 3b). This is also indicated by the high pond:dike ratio characteristic of intermediate farmers at site 1 (Fig. 3d).

3.3. Production technology and driving factors of IAA-systems

In general, three major IAA-systems were identified: (1) the low-input fish farming integrated with intensive fruit production, (2) the medium-input fish farming integrated with less intensive fruit production, and (3) the high-input fish farming integrated with less intensive fruit production system. System 1 was commonly practised in the fruit-dominated area. System 2 was more typical of the rice-dominated areas, while system 3 was practised in the rice-dominated areas with good market accessibility. Fig. 4 illustrates the main driving factors determining the dominant farming system.

3.3.1. The low-input fish farming integrated with intensive fruit production system

At site 1, pond culture was introduced in the early 1990s. Farmers grew fish in low-input polyculture in narrow and shallow trenches (2–3 m wide, 0.5–0.8 m deep) within the orchards (Table 7). Fish production ranged from 0.5 to 2.0 tons ha^{-1} yr^{-1}. Low fish yields were mainly due to the restricted use of nutrients and to the shading of the pond by the extended canopy of fruit trees grown on pond embankments. On-farm nutrient resources were the major inputs for the pond (Fig. 5a). Farmers ranked livestock or human wastes and rice by-products as important nutrient sources. However, pig manure was preferentially applied to fruit crops, and rice by-products were mainly used for livestock production.

Table 7
Major fish species stocked in the different aquaculture systems in the Mekong delta

Species	Aquaculture systems		
	Low-input	Medium-input	High-input
Silver barb (*Barbodes gonionotus*)	+		
Silver carp (*Hypophthalmichthys molitrix*)	+		
Giant gourami (*Osphronemus goramy*)	+	+	
Mrigal (*Cirrhina mrigalla*)	+		
Nile tilapia (*Oreochromis niloticus*)		+	
Kissing gourami (*Helostoma temminckii*)		+	
Common carp (*Cyprinus carpio*)	+	+	
Hybrid catfish (*Clarias macrocephalus* × *C. gariepinus*)		+	
Climbing perch (*Anabas testudineus*)			+
River catfish (*Pangasianodon hypophthalmus*)	+	+	+

The system is usually practised in areas with relatively high elevation and alluvial, nutrient rich, soils favouring fruit production. While farmers focused on fruit production, they paid little attention to aquaculture, which was considered of minor economic importance.

3.3.2. The medium-input fish farming integrated with less intensive fruit production system

At sites 2 and 3, the systems were introduced in the late 1980s and the early 1990s, respectively. Farmers grew fish in polyculture in large or deep ponds (5–30 m wide, >1 m deep) receiving on-farm nutrient resources as the major inputs (Table 7). Fish yields ranged between 2 and 10 tons ha^{-1} yr^{-1}. Farmers ranked livestock or human wastes, rice by-products or snails and crabs collected from rice fields as important nutrient sources for fish production (Fig. 5a). However, the availability of the nutrient

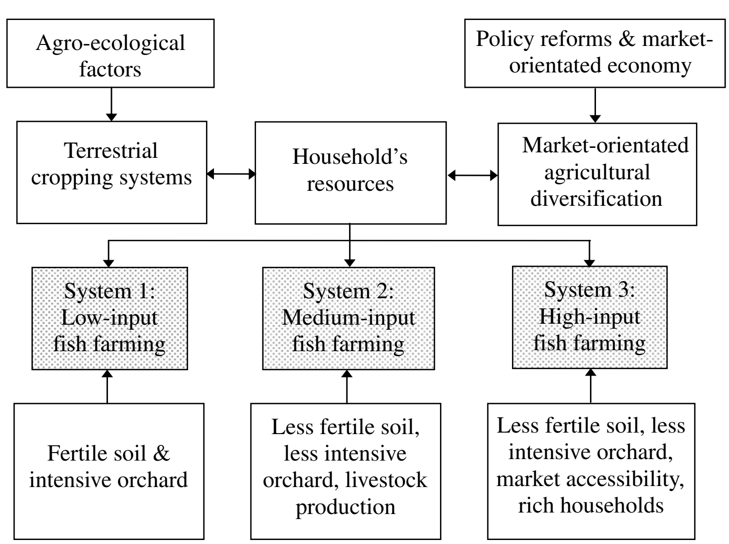

Fig. 4. Three integrated fish farming systems and their driving factors.

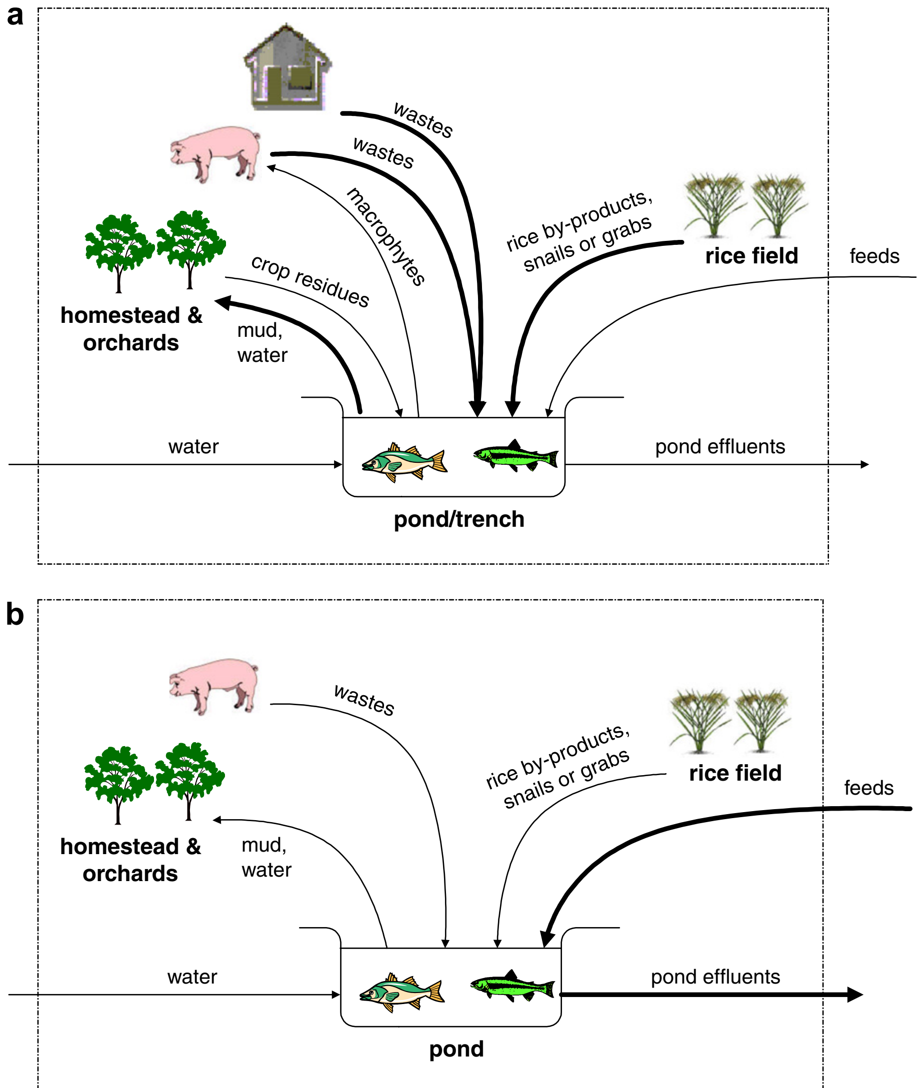

Fig. 5. Diagrams of pond nutrient flows: (a) low- or medium-input and (b) high-input systems. Thin and thick arrows refer to less important and important sources or sink, respectively. Dotted lines refer to the farm boundary.

resources collected from the rice fields was seasonal. Also the availability of livestock wastes as the nutrient input for the pond was highly variable, depending on the status of pig production. In most cases, farmers did not control the waste load to their pond, and managed waste overloading through frequent water exchange.

This system was usually practised in areas of relatively low elevation, medium or high monsoon flood levels and less fertile soils, where rice production was the major farming component. Commercial pig production, however, is gradually gaining in importance, especially since 1999 when the government started to advocate market-orientated agricultural diversification.

3.3.3. The high-input fish farming integrated with less intensive fruit production system

The system was introduced in the mid-1990s. Farmers started growing river catfish or climbing perch (*Anabas testudineus*) with high inputs of off-farm nutrient resources in larger or deeper ponds (>10 m wide, >1 m deep). These fish species are highly valued in export (catfish) or local niche markets (*Anabas*). In this system, aquaculture can be considered a stand-alone system because of weak integration between the pond and the other terrestrial components on the farm. Fish production depends mainly on pelleted feed or off-farm by-products (Fig. 5b). On-farm nutrient resources like livestock wastes and crop residues were perceived as less important. For river catfish farming, fish yields ranged between 50 and 200 tons ha^{-1} yr^{-1}. Farmers changed on average 25% of the pond volume per day.

This system is usually practised in areas with less fertile soil, where rice production was the major farming activity. These farms have excellent market accessibility. Site 3 lies in the peri-urban area of the cities Can Tho and Long Xuyen, where many fish- and feed-processing industries are located. Only rich farmers adopted this farming system, due to high investment costs and technical skill requirements.

3.4. The role of the pond

3.4.1. Past uses

In the past, the initial and important purposes of digging ponds or trenches included the need for soil to raise the level of low-lying ground for house construction and for establishing orchard dikes, especially for farmers with low- or medium-input fish farming systems. In addition, farmers used pond water for household purposes and for orchard irrigation. Fish farming was not considered a high priority. In contrast, among farmers engaged in high-input fish farming, fish production was the major goal from the outset, rather than the pond being an outcome of homestead and fruit dike construction.

3.4.2. Current uses

Current uses of ponds have exceeded the original expectations of most farmers. Fish production has become an important activity in each of the systems studied. In the low-input system, about 70% of the fish produced was used for home consumption (Fig. 6). In the medium and high-input systems, in contrast, fish was primarily a cash crop. Only 30% of the fish produced in the medium-input system and 10% in the high-input system were used for home consumption, while the remaining fractions were sold. In the low- and medium-input systems, in terms of economic value, farmers considered fish as a secondary farm activity. In the high-input fish farming system, aquaculture was a primary activity.

In the low-input system, supplying water for crop irrigation and extracting nutrient-rich mud as crop fertilizers were perceived as being most important. In contrast in the high-input system, these factors were considered of minor importance (Fig. 5). In the medium-input system, the pond was currently perceived as being important for crop irrigation and for disposal of animal and human wastes. In the high-input system, large amounts of pond

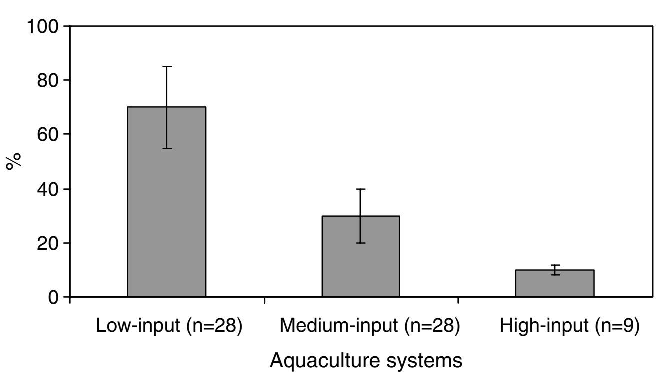

Fig. 6. Percentage of fish production used for home consumption by system. *n*, sample size; error bars in graph represent the standard error of the mean.

nutrients were discharged with outflow water because high water exchange rates were practised.

4. Discussion

4.1. Determinants of the adoption and the patterns of IAA-farming

The results of the present study confirm our initial hypothesis that the adoption of aquaculture by farmers and degree of integration between farming components is influenced by a mixture of bio-physical and socio-economic factors. This is similar to the situation observed in other Asian countries (Pant et al., 2005; Thapa and Rasul, 2005; Iqbal et al., 2006). The lower levels of adoption observed among poorer households, despite attempts to promote IAA-systems as a way to reduce poverty, relate to a combination of limited availability of human and capital resources (technical and farm management knowledge/skills, small land areas, and capital) and constrained accessibility to extension services. The problem of heavy pesticide uses on surrounding crops (factor 4) perceived by non-adopters appears to illustrate their limited technical knowledge in IAA-system practice. It is likely that use of agrochemicals was lower among adopters (Rothuis et al., 1998; Berg, 2002; the present study). These factors are often characteristic of poor farmers (Minot, 2000; AusAID, 2003; Cramb et al., 2004; Table 1). In contrast, the principal factors why farmers adopted IAA-farming are related to optimization of farm resources for income generation and food supply while positive environmental impacts are considered as an additional advantage. Such a perception is common among better-off farmers (Devendra, 2002).

Differences in the pattern of IAA-farming are clearly recognisable among the study sites but within each study site most farms also diversified. First, the differences among the sites are in part related to bio-physical characteristics (elevation, soil fertility, pond conditions and crop and livestock farming practices) and farmer's options, including market accessibility. In the fruit-dominated area, fruit production is the major farming activity, and narrow and shallow orchard trenches, which are shaded by fruit canopies, are unfavorable for fish. Thus, farmers prioritized fruit production and gave little attention to fish production. This could explain the reason why at site 1 the low-input fish farming system was common, and the proportion of farmers practicing IAA-farming was lower than that at sites 2 and 3.

Pant et al. (2005) and Thapa and Rasul (2005) found that market accessibility is an important factor for terrestrial crop farming intensification. In the present study, market accessibility and intensity of aquaculture production were related. The good market accessibility in peri-urban areas boosted the intensification of aquaculture; i.e. the shift from medium-input to high-input systems (i.e. site 3). Second, the differences in the pattern of IAA-farming within each site are partly related to the household's available human and capital resources. Richer farmers tended to intensify fish production more.

In the Mekong delta, aquaculture is a recently introduced activity (Rothuis, 1998; Pekar et al., 2002), and local knowledge on aquaculture is still limited, compared with fruit, rice or livestock production. This can partly explain why only intermediate or rich farmers, with sufficient human and capital resources and strong social connections, ventured into higher input IAA-farming. The results of the present study illustrate that technical knowledge and farm management skills are not enough, and that socio-economic conditions strongly influence the adoption of IAA-farming. In turn, the pattern of IAA-farming system adopted is largely influenced by the bio-physical settings. Hence, the "conventional, linear" approach used by the development agencies to promote IAA-farming systems, which focuses mainly on technology transfer, giving little attention to the local context, might not be appropriate. It requires personal access to knowledge, technology and production resources to adapt generic advice to the local conditions. In the present study, rich farmers were earlier adopters than poor farmers. Therefore, a package of initial and long-term support including "baskets" of choices of appropriate technologies, credit provision and technical training would be advisable to pull poor farmers into IAA-farming (Edwards, 2000). Several examples show positive impacts of IAA-farming on the livelihoods of the poor in Asia, in terms of improved food supply, employment and income generation (Prein, 2002).

4.2. The role of the pond and possibilities for improving the farming systems

Successful development of IAA-farming needs a systems approach (Edwards, 1998; Naylor et al., 2000; Devendra, 2002). Accordingly, the pond in the IAA-system should be integrated in such a way that the overall productivity is maximized while nutrient resources are used efficiently. The pond fulfils multiple roles, the benefits being more than fish production alone (Edwards, 1980; Lo, 1996; Prein et al., 1996). In the present study, the role of the pond perceived by farmers differed. Farmers practising the low- and medium-input systems were well aware of the benefits of integration in IAA-farming and its potential effects on their livelihoods. In the high-input system, integration between the pond and the terrestrial components was relatively weak, and negative environmental impacts due to pond effluent discharges are an important problem. To strengthen the integration between the pond, other farm components and the environment requires scenario testing in combination with nutrient recycling studies. The latter is of great importance to further develop IAA-systems (Edwards, 1989, 1998; Naylor et al., 2000). Suggestions to further strengthen linkages between farming components by system are given below.

4.2.1. The low-input fish farming integrated with intensive fruit production system

While fruit production is well taken care of, little attention is given to the fish component and time availability seems to be a major constraint besides the lack of any specific and appropriate technology. Currently, farmers appear to be attempting to meet subsistence needs and intensification requiring significant additional resources would force them to sell surplus quantities. Karim (2006) found that intensification of fish culture did not lead to greater levels of fish consumption among IAA households in Bangladesh. Appropriate changes in management such as applications of manures or inorganic fertilizers to the pond and adapted pruning of fruit trees were suggested as promising improvements. Ponds are nutrient traps as a high proportion of added nutrients accumulate in the sediment (Edwards, 1993; Green and Boyd, 1995; Hargreaves, 1998). Thus, any increase in pond productivity could deliver dual benefits: more fish and larger amounts of nutrients stored in ponds sediments to later fertilize fruit crops grown on adjacent orchard dikes. According to this scenario, fish production can meet subsistence needs without raising input costs while reducing costs and risks for fruit production. Such a scenario is likely to be adopted by farmers fruit-dominated areas, including poor households.

4.2.2. The medium-input fish farming integrated with less intensive fruit production system

The temporal availability of nutrients collected from rice fields and livestock wastes does not match well with the nutrient requirements of ponds. These temporal mismatches constrain fish production, due to either lack or overload of nutrients. According to Prein (2002), a key to the successful operation of IAA-farming is to organize the system in such a way that residues from each component are available at the right time in appropriate quantities and quality. In reality, however, this is difficult for farmers because they have to deal simultaneously with more than one constraint; e.g. downturns in margins associated with pig production and dramatic short-term declines in availability of manures. A possible solution might be coordinating manure supply with pond requirements between farms located in the same area as suggested by Little and Muir (1987) and Edwards (1998). Marketing of by-products between households specializing in different enterprises appears to offer employment opportunities to poorer people as service operators and potentially increase efficiency of reuse. These are characteristic of areas where aquaculture competes in a more modern economy such as central Thailand (Little and Edwards, 2003). The application of livestock and human waste to ponds is socially accepted in Vietnam and is of importance for poor farmers to reduce production costs, thus increasing net income. To increase fish harvests and the amounts of nutrients stored in sediments per unit of livestock and human waste input, a better control of pond water exchange rates will be instrumental. Such an approach will also reduce environmental pollution and public health risks (Piedrahita and Tchobanoglous, 1987; Wohlfarth and Hulata, 1987; Edwards, 1998).

4.2.3. The high-input fish farming integrated with less intensive fruit production system

The high-input fish farming system faced problems in relation to high external nutrient inputs, high financial risks, and environmental pollution. The system can be considered a non-integrated or stand-alone pond farming system. Ponds received large amounts of external nutrient inputs, and discharged large quantities of nutrients into surrounding surface waters. The investment costs and risks of the system are high, making them out of reach for poor and intermediate farmers. For example, many farmers in the Mekong delta saw revenues decline or suffered losses from catfish farming in the period 1999–2002 due to quick shifts in market prices. Flushing of ponds with "clean" water from the river resulted in pollution of surrounding surface waters and a loss of nutrients, which otherwise could have been used for other products. Therefore, reusing pond effluents to produce an extra crop of fish or aquatic plants before discharge is advised (Beveridge et al., 1997; Naylor et al., 2000). Yi et al. (2003) demonstrated that Nile tilapia could be semi-intensively cultured in an integrated system that recycles nutrients in effluents released from an intensively cultured hybrid catfish pond. Other possibilities include the production of aquatic plants like water hyacinth (*Eichhornia crassipes*) (Costa-Pierce, 1998; Sooknah and Wilkie, 2004), duck weed (*Lemna* spp. and *Spirodela polyrrhiza*) (Jana, 1998), water spinach (*Ipomea aquatica*) (Costa-Pierce, 1998) and rice (Lan, 1999). All these crops can extract nutrients from wastewaters, while producing food for human, fish or livestock (Edwards et al., 1985; Fasakin et al., 1999; Azim and Wahab, 2003; El-Sayed, 2003). Although these systems look promising, they are not widely adopted by farmers in the study area. In contrast the production of aquatic vegetables using wastewater is well established on the urban fringes of Ho Chi Minh City and other urban centers of Southeast Asia (Rigg and Salamanca, 2004). One possible reason is that a wastewater-fed wetland system consumes land at the expense of other, more profitable or less risky farming activities. In the present study, the possibility of recycling nutrients between farms was not explored, but could be explored in situations where land holdings are too small to allow many farming activities. Such an approach could create more jobs, food and income for the poor and reduce environmental impacts (Edwards, 1998; Edwards et al., 2002).

5. Conclusion

On average, for all study sites combined, 43% of the farmers in the central Mekong delta practised aquaculture. Considering aquaculture was introduced about two decades ago, this is a high percentage. Wealth to a large extent influences whether or not aquaculture can be undertaken. Poor farmers usually do not adopt fish culture in the region. Important reasons perceived by the poor farmers for not practising aquaculture included inappropriateness of technology, either insufficient farm area or poor access to extension services, limited farm management, and pesticide use for terrestrial crops.

Considering farmers who practise aquaculture in the Mekong delta, a low-input fish farming system was commonly practised in fruit-dominated areas while medium- and high-input fish farming systems were commonly practised in rice-dominated areas. In a situation of good market accessibility, richer farmers tended to intensify fish farming. The adoption by farmers and the patterns of IAA-farming were strongly influenced by a combination of technical, bio-physical and socio-economic factors.

The pond fulfils various roles in IAA-systems. To further promote IAA-farming, improving linkages between the pond and other components within the IAA-system will be instrumental in improving nutrient use efficiency at farm level. If the latter is not possible, seeking nutrient linkages between farms is also an option. Paying attention to farmers' contexts and needs is important for supplying appropriate advice to households seeking to diversify, as wealth status, agro-ecology and market opportunities are important drivers for the successful application of aquaculture in IAA-systems.

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