MODELING TAKE-UP OF RICE–FISH SYSTEMS WITH FUZZY LOGIC

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ABSTRACT

Most current models analyzing technology adoption are based on a function that assumes farmers make decisions upon utility maximization but ignores cultural or social factors. The traditional production systems of the Mekong Delta were based on floating rice varieties and fish harvested both from rivers and rice fields. Since 1980 the presence of fish in the rice fields decreased and research developed the so-called concurrent rice–fish system to capture the advantages of the synergy. Whether this is a feasible option depends on the farmers' drives and motives for taking-up the technology. In 2000 we made an inventory among 60 farmers who adopted the rice–fish system in four districts to describe their resources and motivations. In 2006 we repeated this survey among 94 farmers including potential adopters, in order to evaluate the take-up potential of the rice–fish system in the Mekong Delta. Income/person and income/ha of the farm households with a rice–fish system were close to double, while their land area (2.5ha) was not significantly larger than those farms without a rice–fish system (1.95ha). Usually farmers integrating also pigs and fish had the smallest land area. The farmers' non-adoption of the rice–fish system was mainly due to low availability of capital and land, and to inappropriate location of the field in relation to the homestead, water availability, and agro-ecological conditions. To create space for more upland crops was an important argument for the construction of a rice–fish system. Modeling confirmed that under appropriate agro-ecological conditions the take-up of rice–fish systems can be stimulated by increasing know-how on fish and on system component integration. The sensitivity of the fuzzy logic simulation did not confirm the importance of land size and wealth ranking for the take-up.

Keywords: systems, aquaculture, sustainability, ecological, economic, adoption

INTRODUCTION

The traditional agricultural production systems of the Mekong Delta were based on fishing and on cropping traditional rice varieties with long growth cycle. Fish was harvested from rivers but also from the rice fields. Improved water management systems, short-cycle rice varieties and pesticide use led to overproduction of rice and to decreased prices once economic policy changed after 1986 [1]. This guaranteed food security pushed farmers to transform part of the rice fields in fish-ponds, while others made orchards, sometimes with ditch–dike systems to produce both fruit and fish. The water of the ditches and the ponds is used for irrigation and once a year the sediment is used to fertilize the soil. Within 20 years, farmers earning cash mainly from rice, transformed their farms into mixed farms producing a large variety of goods for the market. Most farmers still cultivate a rice field to harvest each year two or three crops, mostly rice; but as a third crop also various vegetables for cash marketing.

In the Mekong Delta the presence of fish in the rice-fields decreased due to optimal water management and pesticide use on rice production since 1970 [2]. Can Tho University and its partners promoted the concurrent rice–fish system to capture the advantages of the synergy of both cultures [3]. On the dikes of the rice–fish system farmers also produce fruits and vegetables. Inevitably rice production

will stay in the Mekong Delta, but the challenge is to design it such that it does not impede, but rather improve the sustainability and productivity of the overall production system, including fish from capture fisheries. Though the ecological sustainability of the rice–fish system is higher [4], to capture a long-term economic advantage of the synergy, farmers need to invest in their land by making a ditch with high dike (Figure 1), increasing inputs and undergoing Integrated Pest Management training [3, 5]. If the rice–fish system becomes wide-spread, its improved ecological sustainability will have positive trade-offs on the quality of the open-water used, among others, for drinking, irrigation, and aquaculture. Whether this is a feasible option depends on the farmers' drives and motives for taking-up the technology.

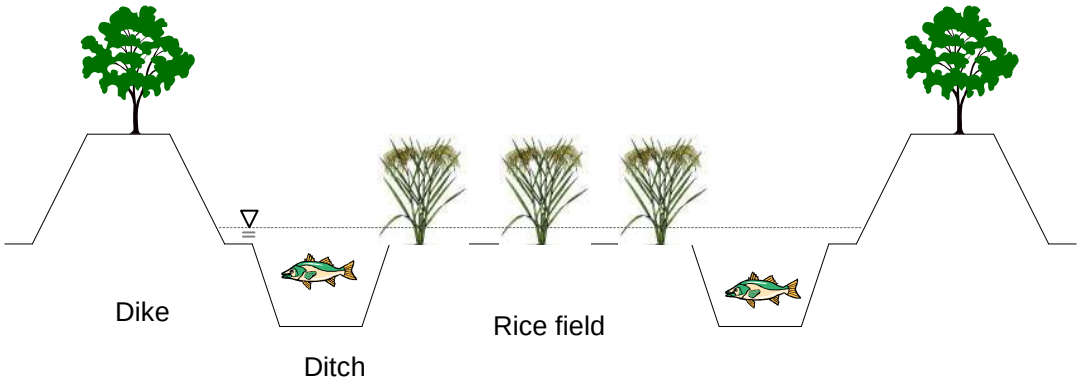


Figure 1. Transect of a typical rice–fish plot in the Mekong delta: a rice field, ditches as a refuge for fish when water is low and, to keep the fish inside, a peripheral dike with vegetables or fruit trees.

In 2000, we made an inventory among the farmers who adopted the rice–fish system and characterized their resources and motivations [6]. We found that the major determinants of farmers adopting a rice–fish system include: larger land size, greater family-labor availability, field closer to the homestead, better access to canal water, better social relationships/access to extension workers. Fish production and income depended on agro-ecological sites and integration with livestock production within the farm, rather than fish farming practices only. In 2006 we repeated this survey. Next to the simple objective of simulation as a first step in developing a decision support tool, we used the sensitivity analysis to give information on the characteristics of farmers who are likely to adopt the rice–fish system, and on policies that can stimulate this. In this paper, after the methodology section, we present and discuss results of the survey, of the data-analysis, and of a fuzzy logic simulation of farm composition, before we formulate recommendations.

METHODOLOGY

Sample and data collection

To collect data for the present study, we interviewed 94 farmers raising fish in 8 villages. The villages belonged to 4 districts in three provinces (Table 1). The villages were the same as those in the 2000 inventory of rice–fish systems in the fresh water agro-ecological areas of the Mekong Delta. In the original study, we interviewed 60 farmers having adopted a rice–fish system; while the present sample contained 48 farmers practicing a rice–fish system, either having started before or after 2000. In each village, the sample was complemented with non-practicing farmers; the total sample contained 48 practicing and 46 non-practicing farmers. These last were selected by the extension services among the farmers that they considered potential adopters of the system.

Table 1 Some characteristics* of the interviewed farm households per districts, including the average ratings for the importance of a rice-field for food-security (RFS) and integration (CI).

	Farms (n)		Area (ha) of				HH-	Distance to		Rating	Ratin
District	RF	no-RF	HS	LL	UL	Pond	size	LL	Market	RFS	CI
Long Ho	10	12	0.32	0.72 [a]	0.09	0.19	5.5 [ab]	0.21	1.0 [a]	3.7	4.1 [b]
Tan Hiep	14	10	0.25	3.32 [b]	0.34	0.22	6.5 [b]	0.06	5.1 [b]	4.1	4.1 [b]
Cao Lanh	12	14	0.36	1.26 [a]	0.12	0.17	5.0 [a]	1.47	2.3 [ab]	3.4	3.1 [a]
Vung Liem	12	10	0.27	0.96 [a]	0.18	0.15	4.6 [a]	0.54	3.6 [ab]	4.0	3.9 [b]

HH=household; HS= homestead; LL=lowland; UL=upland

*Numbers with different superscripts (a, b or c) are statistically different for $P < 0.05$

At the workshops we collected general information on the main products of the livelihood system. We asked farmers to rank these products for the need of capital, labor and know-how. We assessed the historical development of their market prices and the cost of their main inputs, and we collected data on the price development of land and on rainfall period and level. To asses the break-even prices of the products, we asked farmers to give three cost levels of the main input: the acceptable product price, the price below which they would stop producing, and the price they wished to receive. The workshop allowed to create a relationship of trust and to schedule the individual interviews. We asked three knowledgeable local experts to rank the interviewed farmers in three wealth categories: poor, intermediate, and well-off in each village.

We held the interviews in one or two centrally located places for efficiency of time and finance. We collected data on household and farm characteristics, present farming system and its resource flows, financial results, marketing and credit strategies. The household' members living in the farm were categorized into: adult, elder working, elder non-working, and children younger than 18 year. Children younger than 18 were distinguished in 4 categories: going to school, working on farm, both working and going to school, and non-working. The financial data considered cost of input, cash income, and household consumption for the various products, and cash income from off-farm activities by these household members, between November 2005 and December 2006. The farmers were requested to rate soil quality and water accessibility on a scale of 1 to 6, and to rate on a scale of 1 to 5 their know-how on various products, the importance given to a rice-field for food-security and to the integration of resources.

Close-ended questions on the source of their credit and the activity it was used for, allowed distinguishing six categories of risk behavior; namely: none, relatives, bank, input providers, private money lenders, and high risk credit. This method feebly estimates the risk behavior of people that never took or will take a credit because they had or estimated to have enough capital. In the model this is compensated for by including the rank of wealth as a variable of capital availability.

Statistical analysis

From the data we calculated household-size, household-labor availability, household gross income, household net income, income per head, and income per ha. The household-labor was derived from the weighted number of family members in the age categories: *adult* - 0.25 × *non-working* + 0.5 × *youngster* + 0.75 × *elder*. We checked the standard distribution of the data, calculated means, checked the interaction between village and district, and differences according to Gabriels, calculated correlations according to Spearman (rho) when appropriate, and applied a factor analysis of the past, actual or future presence of the rice–fish system with variables related to economics of the farming systems and the farmers' arguments for up-take or for non-adoption of the rice–fish system. We repeated the factor analysis of the economic variables and included the Boolean (0-1) value for, either the farmers practicing rice–fish systems in 2006, those practicing in 2000, or those considering it for the future. We did an attribute subset evaluation to assess the main decision factors related to practicing the rice–fish system by using forward greedy stepwise regression in WEKA [7].

Fuzzy modelling

To compose the model we applied a 10-step procedure (Figure 2). Both a qualitative livelihood analysis [8] and the statistical analysis of the collected data supported the identification of the following: the input and output variables, the model structure, the linguistic term sets, the parameters of the membership functions, the fuzzy rule-base, and the database. We structured the decision-making in a three layer hierarchical tree with five subsets of fuzzy inference systems (FIS): primary production factors, product opportunities, product's options, farmers' reference frames, and final output layer (Figure 3). For the inference we applied Mamdani with the min-max operators, respectively; using the fuzzy logic toolbox of Matlab®7 [9]. The fuzzy outputs of the 1st and 2nd layers were fed directly into the FISs of the 2nd and 3rd layers, respectively. The output of the 3rd layer could have a value between 0 and 1; a farmer was assumed to have a particular farm component if the membership for that output was larger than 0.5 [10].

1 Conceptualisation of the farmers' decision-making (DM): problem analysis and preliminary data collection
2 Determination of model output and input variables
3 Identification of the structure of the conceptual fuzzy inference system (FIS) mimicking the DM process
4 Determination of linguistic term sets for the universes of discourse (UoO) of the variables
5 Determination of parameterized membership functions covering the UoD for all variables
6 Determination of the fuzzy rules of a rule base replicating the decision-making process
7 Data collection to compose a database for training and validating the conceptual model
8 Implementation and verification: choosing the inference system and programming the model
9 Calibration and fine-tuning to fit the model for the training dataset (Training)
10 Validation and sensitivity analysis to test the model against reality (Testing)

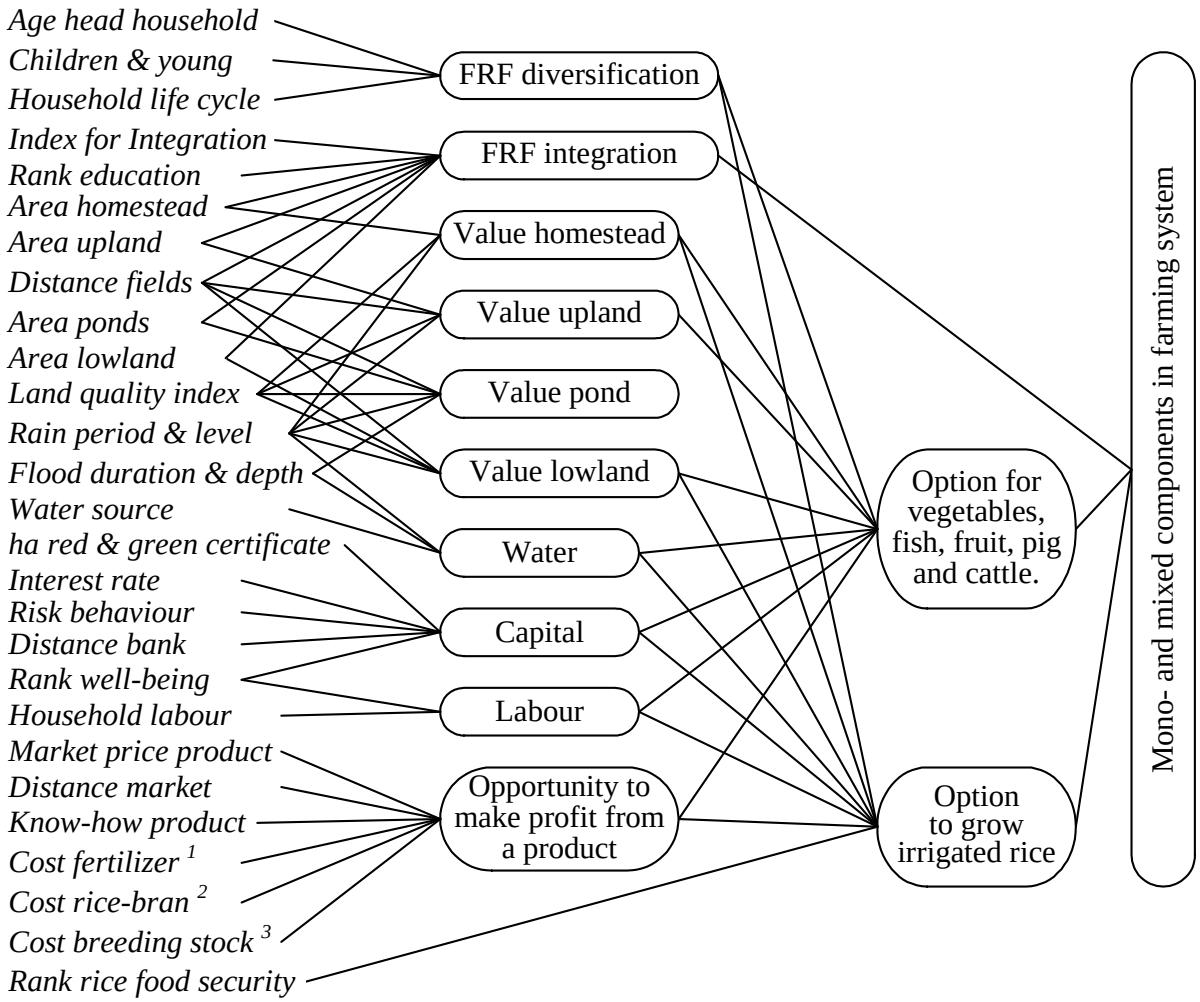
Figure 2. Ten steps to develop a fuzzy logic model simulating decision-making (adapted from [11]).

For the calibration, we composed a dataset of 64 cases by ranking all cases with the spreadsheet tool for district, for no or yes practicing rice–fish and for wealth class, before transposing every third case to a validation dataset. The calibration dataset contained 33 practicing and 31 non-practicing rice–fish farmers, while the validation dataset of 30 cases contained 15 of both categories. Calibration was done by adjusting the parameters and if needed the rules to attain optimal fit was checked by face-validation for the present farm composition. To attain rational sensitivity for crucial variables, we ran the model for a range of values. To validate, we ran the model on the data put aside. The model's performance was evaluated by the classification rate calculated as the square root of the product of individual classification rates: $\sqrt{[(\{n_{positives}\text{-type I errors}\}/\ n_{positives}) * (\{n_{negatives}\text{-type II errors}\}/\ n_{negatives})]}$.

Most farms in the concerned province of the Mekong Delta have more than one component, and we focused modeling on nine farming activities (Table 2). We included raising cattle as it may be a reason to need more upland and it becomes an alternative if the acidity of the land gets too high for rice and/or fish. Hereafter we present the input variables included in the FISs.

The availability of capital depended on the collateral value of the owned land, the rank of risk behavior, and the rank of well-being (income). The collateral value of land with a red certificate, attributing owner's rights, was twice as high than for land with a green user certificate, attributing user's rights and conferring obligations [8].

The availability of labor depended on two variables: the household labor and the capacity to hire labor. The rank of well-being was used as an indicator for the capacity to hire labor.



FRF=Farmers' Reference Frame; Cost for 1: rice, fruit, vegetables; 2: fish and pigs; 3: fish, pigs, cattle.

Figure 3. The three-layered hierarchical tree of the fuzzy logic model mimicking decisions on the composition of the farming system.

The water availability depended on five variables: length and level of rainy season and length and depth of flooding, and on farmers' rating of the water accessibility. The rainfall level was derived from national statistics and the length of the rainy season asked at the workshop; both were applied uniformly to all cases for each district.

Three groups of variables influenced the individual economic opportunity to practice a component: distance between the farm and the market, cost of the input and market price of the produce, and the farmers' rating of his know-how on the activity. We applied the same distance between farm and either input or output market, though for some produce those were different. The market price of the products applied in the model was equal for all farmers: the average of the farm gate prices for the various product categories in 2006 (Table 2). The FISs for the opportunity to raise pigs related to two types of product and the know-how and prices were represented by both specializations: fattening and breeding. A high price of piglets could either be positive if the farmer's know-how on breeding was high and piglets could be a precious output, or negative if this know-how was low and piglets were an input he had to buy.

Table 2 The nine (integrated) components included in the modeling and the cost of the main input and the market prices of the product applied (in VND/kg, unless specified)

System	Description	Cost main input *	Price of product
Mono-rice	Crop rice 2 or 3 cycles /yr depending on flood length	250,000	2,000
Rice-vegetables	Crop rice twice and vegetables as the third crop	250,000	1,000
Fish-pond	Raising fish in a pond	30,000	9,000
Rice–fish	Having an irrigated field for integrated rice–fish		
Orchard	Cropping fruit-orchard,	250,000	4,500
Ditch-dike	A system enabling to raise fish under the fruit trees		
Pig	Breeding and/or fattening pigs	20,000	20,000
Pig-fish	Raising pigs above the fish to recycle the pig wastes		
Cattle	Raising cattle on the rice-field (in million VND/head).	2,5	5,0

* The cost of rice-bran, basic constituent of feed for fish and pig, was set at 2500 VND/kg

To include social and family related motives, we included two farmers' reference frames in the model. The FIS of the farmers' reference frame for diversification, capturing the social motives for diversifying the farming activities, was composed of three variables: the number of children and young in the household, the age of the household head, and the phase in the household life cycle [8]. The economic drive for diversification of farm household activities was captured through the market prices (Fig. 3). The farmers' reference frame for integration including the factors decisive for the integration of various farm components inferred six variables: the distance between the fields and the homestead, the area of the homestead and irrigated land, on the farmers' education level, and the rank of importance the farmer gives to integration.

RESULTS

Though the total land size of farms with rice–fish systems was slightly higher, only the pond area was significantly larger (Table 3). The net income of farms that were transformed partly from rice-field into grassland was as low as that of farmers with no rice–fish-system. Intensive rice–fish-systems using manufactured feeds had a higher net income, but the income/ha was lower compared to that of rice–fish-systems recycling the waste of mono-gastric livestock. The rice–fish farmers had a higher income from fish, fruit, vegetable and duck, and rated their know-how on fish higher than those not practicing rice–fish: 4 and 3.4; respectively ($p<0.1$).

Table 3 The mean (± SE) of pond and total land area (ha), and the net income of different production systems with or without fish integration (million VND).

	n	Pond area*	Land (ha)	Income/person	Income/ha
no rice–fish	46	0.09 ± 0.17^{a}	1.93 ± 0.26	6.9 ± 1.2^{a}	23.6 ± 16.3^{ab}
extensive rice–fish system	25	0.29 ± 0.04^{b}	2.44 ± 0.44	13.5 ± 1.4^{ab}	38.3 ± 5.7^{ab}
intensive rice–fish system	13	0.29 ± 0.05^{b}	2.60 ± 0.40	17.8 ± 3.2^{b}	50.0 ± 8.4^{abc}
Animal waste rice–fish	6	0.21 ± 0.05^{ab}	1.50 ± 0.42	13.6 ± 3.9^{ab}	58.3 ± 15.8^{bc}
Grass-pond-dike system	4	0.11 ± 0.03^{ab}	2.12 ± 0.78	6.9 ± 2.5^{a}	15.8 ± 2.7^{a}

* The pond area includes the surface of ditches in the rice-field and in the orchard.

*Numbers with different superscripts (a, b or c) are statistically different for $P < 0.05$

The districts of Long Ho and Tan Hiep had relatively more intensive rice–fish and animal waste rice–fish systems (8/14 and 8/16 compared to 2/24 and 1/21 for Cao Lanh and Vung Liem; respectively). Soil quality of Vung Liem was significantly lower, and for Cao Lanh non-significantly lower compared to that of the other 2 districts. In the district where the distance between lowland and homestead was longest, the farmers gave significantly less importance to integration and slightly less to having land to crop rice for food security (Table 1). Data on land size for Tan Hiep were somewhat skewed because five farms were much larger. In this district, the land area and the size of the household and thus household labor availability were larger (Table 4). In Tan Hiep also cropping frequency was lower, flood period longer, and flood-depth among the highest. The interaction between district and village was significant for cost of inputs; for gross income, the difference between the villages within a district was significant. Cost of inputs and gross income were higher in the district with larger land size, but net income per person was not significantly higher; net income per hectare was even among the lowest in this district. In general the total cost of input was highly correlated to total income (r = 0.9), net income (r=0.5) and net income per person (r=0.8), but negatively to the net income per ha (r=-0.07, non significant).

Table 4 Economic parameters of the interviewed farm households (HH) in the districts (in million VND, except for household labor see text).

	Number of crops	Flood		HH	Gross	Cost	Net income	
District	on lowland	period	height	labor	income	input	/person	/ha
Long Ho	2.6 ^{b}	2.4	0.7	4.2 ^{ab}	63.3 ^{a}	24.5 ^{a}	11.2 ± 1.4	49.0 ± 5.8 ^{b}
Tan Hiep	2.1 ^{a}	3.3	0.8	5.2 ^{b}	176.8 ^{b}	111.5 ^{b}	13.5 ± 1.8	25.8 ± 4.3 ^{a}
Cao Lanh	2.8 ^{ab}	3.1	0.9	3.1 ^{a}	49.0 ^{a}	25.7 ^{a}	7.1 ± 1.0	24.0 ± 3.9 ^{a}
Vung Liem	3.0 ^{b}	2.1	0.6	3.8 ^{a}	57.7 ^{a}	39.1 ^{a}	11.0 ± 2.9	35.6 ± 8.5 ^{ab}

*Numbers with different superscripts (a, b or c) are statistically different for $P < 0.05$

The factor analysis did not distinguish between farms practicing rice–fish systems in 2006, those practicing in 2000, or those considering it for the future. Though rain characteristics were identified as attributes in, as well as, the factor as the principle component analysis, they are similar for all farmers in one village and cannot distinguish between farmers having or not a rice–fish system in the same village. Flood characteristics however varied within one district and one village. Results showed that the main factors contributing to non-adoption of the rice–fish system were: capital and labor availability, and to a lesser extent, the market-price of fish, the distance to the field and the know-how on the technology, and for those having stopped since 2000 the availability of water. The advocacy for the rice–fish system by the Government services was not an important factor for practicing farmers in 2006 or for those that consider practicing a rice–fish system in the future. Factors driving the adoption, among others, included the need to increase income, rice-yield, soil-quality, and fish availability and to reduce pests (Table 5). Creating space for more upland crops like fruits, vegetables and grass were important arguments for the construction of a rice–fish system. For those not-considering the rice–fish system the risk of poaching and the low price of fish weighted heavier.

Table 5 Main factors affecting the adoption of rice–fish systems by farmers practicing rice–fish systems in 2006 (RF-system 2006), in 2000 (RF-system 2000), or those considering it for the future (RF-future)

	RF-system 2006**				**RF-system 2000**			**RF-future**				
	1	2	3	4	1	2	3	1	2	3	4	5
RF-system	**0.75**	0.13	0.19	0.10	**0.75**	0.15	0.03	0.12	0.18	0.18	0.25	**0.76**
Rank of wealth	0.12	0.15	0.15	**0.80**	0.17	0.25	**0.56**	0.03	0.18	**0.80**	0.16	0.16
Farm-size	0.06	0.05	0.29	**0.74**	0.06	0.01	**0.83**	0.25	0.06	**0.71**	0.28	0.25
Recycle by-products	0.41	0.03	0.39	0.01	**0.56**	0.07	0.18	0.21	0.01	0.03	0.48	0.13
Improve income	**0.79**	0.14	0.27	0.02	**0.84**	0.12	0.05	0.48	0.19	0.02	0.37	0.41
Produce food	**0.70**	0.22	0.24	0.00	**0.78**	0.23	0.04	**0.51**	0.27	0.02	0.36	0.23
Higher rice-yield	**0.58**	0.12	0.44	0.27	0.39	0.19	**0.60**	**0.74**	0.07	0.24	0.26	0.03
Better for soil	**0.83**	0.08	0.17	0.01	**0.71**	0.16	0.27	**0.83**	0.01	0.01	0.07	0.09
Reduction of pests	**0.86**	0.15	0.02	0.04	**0.80**	0.21	0.22	**0.83**	0.05	0.01	0.18	0.21
Efficient labor use	0.15	0.04	**0.79**	0.00	0.25	0.00	0.28	0.00	0.05	0.01	**0.81**	0.11
Less wild fish	0.01	**0.82**	0.03	0.03	0.04	**0.81**	0.05	0.18	**0.69**	0.05	0.07	0.01
Space for upland crops	0.05	**0.89**	0.02	0.05	0.04	**0.85**	0.02	0.05	**0.87**	0.02	0.00	0.02

* Only factors having Eigenvalue > 1 and explaining >5% of the total variance are presented

** The variables *age of the household head* and *education level* had a high Eigen -values for RF2006 but were not mentioned to reduce table size.

The greedy stepwise procedure selected also different attributes for the decision-making when including either RF2000, RF2006 or RFuture (Table 6). However, some of the selected factors are not different for farmers with or without a rice–fish system. The size of the homestead and the fishpond, the level of know-how on fish, the rank of wealth and the rating of integration and recycling, distinguish farmers with and without a rice–fish system, all were higher for the farmers practicing a rice–fish system.

Table 6 The selected attributes* of decision making related to practicing a rice–fish system at present (RF2006) in the past (RF2000) or in the future (RFuture), and P-value of the attributes for RF2006 (if different);

P-value	**RF 2006**	**RF2000**	**RFuture**
0.00	Area pond	Area pond	Area pond
0.00	Know-how fish	Know-how fish	Know-how fish
0.01	Area homestead	Area homestead	
0.08	Distance to lowland	Distance to lowland	
-	Household-lifecycle		Household-lifecycle
-	Number of children		Number of children
-	Know-how rice		Know-how rice
0.00	HH consumption produce**	HH consumption produce**	
0.02	Rating recycling***		
0.06	Wealth rank		
	Flood level	Know-how cattle	Flood period
	Area with owner certificate	Soil quality homestead	HH-size
	Rice-field food security		Area upland
			Know-how fruit, pig breeding, cattle
Merit of			Distance to bank, market, road
best subset	0.494	0.6	0.405

* To ease the interpretation the order of the variables was changed, leaving above the line those that are common for two or all three of the subsets;

** This is most probably a consequence and not a cause of having a rice–fish system;

***A similar rating on the importance of integration scored $p<0.001$.

Modelling decision making with fuzzy logic

The fuzzy logic simulation approached quite well the actual distribution of the number of components practiced (Figure 4). Calibration did not reach a maximum fit; main problems were the simulation of the number of farmers cropping fruit and those practicing the systems by mixing fruit and pigs with fish. The validation on the separated dataset confirmed this tendency.

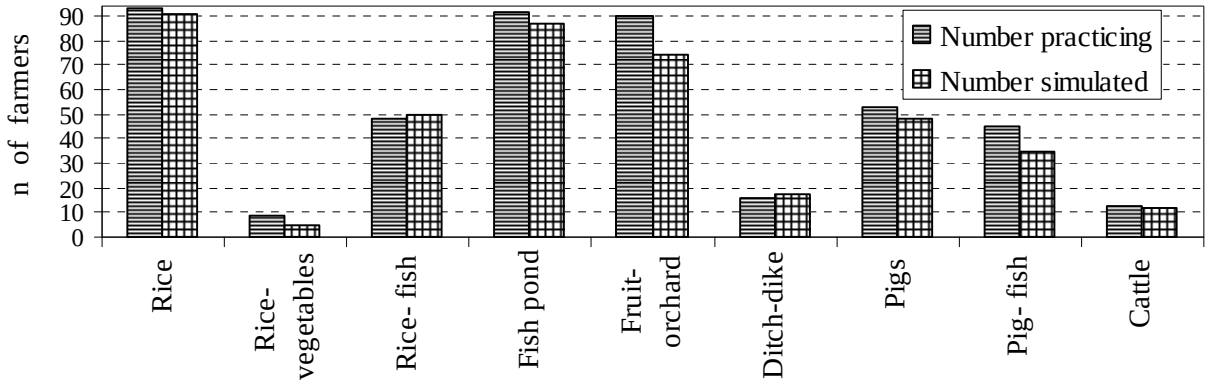


Figure 4: The cumulated number of components practiced by the 94 farmers, and the number according to the fuzzy logic simulation.

After calibration the individual fit of farmers having the rice–fish system was acceptable, but it was unsatisfactory for those practicing the pig-fish system and those raising cattle, and even zero for the rice-vegetable and fruit-fish systems (Table 7). An elaborate fine-tuning might improve the results of the individual classifications.

Table 7 The classification rate of the simulation for the calibration dataset and for the validation dataset.

	Rice only	**Rice-vegetables**	**Rice-fish**	**Fish-pond**	**Orchard**	**Ditch-dike**	**Pigs**	**Pig-fish**	**Cattle**
Calibration	0.98	0.00	0.69	0.68	0.72	0.00	0.62	0.45	0.57
Validation	1.00	0.00	0.60	0.97	0.91	0.00	0.50	0.50	0.44

The result of the models' sensitivity analysis confirms the importance of the area of pond and homestead and the rate of know-how on fish, but stresses also labor availability, and market prices of rice and fish as factors influencing the decision to practice a rice–fish system (Table 8). The sensitivity for the distance to the lowland level and the variables related to the capital availability such as the area of owned land and the rank of wealth were low. The flood depth affected the uptake in two ways: it reduced the number of rice-fish farmers for low flood-depths, but increased the number for high flood-depths by 10%.

Table 8 The fuzzy logic models' sensitivity (%) of the number of farmers practicing a rice–fish system to a range of values of some attributes.

Total area of owned land	2	Number of children	21	Cost of NPK fertilizer	17
Area of lowland	7	HH labor	34	Cost of rice-bran	–1
Area homestead	45	Know-how fish	14	Cost of fry/fingerlings	–9
Area pond	27	Know-how rice	–5	Market price of rice	–27
Flood depth	4	Rate of Integration/recycling	24	Market price of fish	16
Flood period (length)	–22	Distance homestead to lowland	–4	Rank of Wealth	2

DISCUSSION

The present study confirms that farm income depended on agro-ecological sites (flood-depth, soil type), and integration with livestock production within the farm rather than fish farming practices only, as concluded in 2000 [6]. The advocacy for the rice–fish system by the Government services was an important factor for those having a RF in 2000, but less important for still practicing farmers in 2006. Though not mentioned in 2006 among the determinants for adoption, family-labor availability was mentioned by farmers in 2000 and affected strongly the sensitivity of the fuzzy logic model. The present study confirmed most other factors found in 2000: land-size, distance between field and homestead, water management, and access to knowledge system (know-how on fish). Market prices of fish and to a lesser extent of rice also influence the decision to practice a rice–fish system. The various determinants represent aspects of the five different livelihood capitals as used by Ellis [12]. An important farmer's argument for constructing a rice–fish system was to create space for a more diverse farming system (both aquatic and upland crops) and to take advantage of the synergy among farming enterprises through nutrient recycling within the farm.

The low sensitivity of the fuzzy logic model to changes in the financial capital availability, made operational through the total area of land owned and the rank of wealth, might show that these attributes are less crucial for take-up than considered, but this might also be a consequence of their place in the hierarchical structure of the model. In the hierarchical model these attributes are considered only to determine the opportunity for the individual activity in the second level, but not the decision on the integration in the third level. To test their importance in the decision-making, future studies need to implement some of these attributes at the third level also. Using fuzzy logic modeling, the present study confirms earlier findings [11] that the number of young children, the phase in the household life-course, and the level of know-how affect decisions on farm composition at least as strong as market prices. Also the availability of household labor, the area of homestead and pond, and the farmers' rating of the importance of component integration affect the take-up of a rice–fish system. The above mentioned family-related motives (number of children and household's life-course) are mostly not considered in farm models, and we agree with other authors that social factors, other than leisure, need to be considered in farm economic models [13-15].

We found the farmers' ranking of soil quality and water availability not satisfying without using a standard. For example, in one village the rating of water availability could range from 4 to 6, while on the scale of 10 classes used in earlier studies [16] they fall all within the best two. Therefore, we advise to submit a range of fixed well-described categories of quality for the farmers to choose from.

The results confirm that intensification by using more financial capital goes often at the expense of efficiency of labor and land utilization. The income per person is only slightly affected by the total cost of inputs. This pleads once more for evaluation of innovations on both economic and social efficiency as well as on ecological impact.

CONCLUSIONS

Concurrent rice–fish systems doubled the average net income per person and improved the income per ha between 60 and 120 %. Farm households integrating pigs in the system earned the highest net income, while those using the dikes only to graze cattle made the lowest net income.

The main constraints for adoption of the rice–fish system were an insufficient availability of capital and of appropriate land. Fuzzy modeling shows that a good market-price of fish and an acceptable price of rice may convince farmers to build a rice–fish system, while a very high price for one and a very low for the other product might push farmers into specialization. The extension services can promote rice–fish farming by improving the know-how on fish and on integration of system components of farmers with fields close to the homestead and good access to water, in the agro-ecological zones with good soil quality, short to average flood-period and low to average flood-depth.

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REFERENCES

1. R. H. Bosma, N. Q. Cao, H. M. J. Udo and J. A. J. Verreth, 2007. Assessing farmers' motives for livelihood diversification in the Mekong Delta: household life cycle, virtual farm size, and index of integration, *in* "Fish Ponds in Farming Systems" (A. J. v. d. Zijpp, J. A. J. Verreth, L. Q. Tri, M. E. F. v. Mensvoort, R. H. Bosma and M. C. M. Beveridge, Eds.), Wageningen Academic Publishers, Can Tho 261-269.
2. A. G. Gagauan and R. G. Arce, 1992. Overview of pesticide use in rice-fish farming in Southeast Asia, *in* "Rice-fish research and development in Asia" (C. R. dela-Cruz, C. Lightfoot, B. A. Costa-Pierce, v. R. Carangal and M. P. Bimbao, Eds.), ICLARM, Manilla 217-233.
3. N. Vromant, 2007. Combining fish and rice production. *CAB Reviews: Perspectives in Agriculture, Veterinary Sciences, Nutrition and Natural Resources*, 2, 1-9.
4. A. J. Rothuis, D. K. Nhan, C. J. J. Richter and F. Ollevier, 1998. 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. *Aquaculture Research*, 29, 59-66.
5. H. Berg, 2002. Rice monoculture and integrated rice-fish farming in the Mekong Delta, Vietnam—economic and ecological considerations. *Ecological Economics*, 41, 95-107.
6. D. K. Nhan, L. T. Duong and N. Vromant, 2002. Intensive rice production and integrated rice-fish farming systems in the freshwater Mekong delta: Farm resource uses and economics *Scientific Journal of Can Tho University (in Vietnamese with English abstract)*, 3, 567-585.
7. I. H. Witten and E. Frank, 2005, 2nd Edition. Data Mining: Practical machine learning tools and techniques Morgan Kaufmann San Francisco.
8. R. H. Bosma, C. Q. Nam, H. M. Udo, J. A. Verreth and L. Visser, 2006. Agriculture diversification in the Mekong Delta: farmers' motives and contribution to livelihoods. *Asian Journal of Agricultural Development*, 2, 49-66.
9. Mathworks, 2004. Fuzzy logic toolbox (version 2) for use with Matlab The Mathworks Inc. Natick, USA.
10. R. H. Bosma, U. Kaymak, J. v. d. Berg and H. M. J. Udo, 2005. Fuzzy modelling of farmer motivations for integrated farming in the Vietnamese Mekong Delta Reno (Nevada, USA), 827-832.
11. R. H. Bosma, 2007. Using fuzzy logic models to reveal farmers' motives to integrate livestock, fish and crops PhD-thesis, Wageningen University Wageningen.
12. F. Ellis, 1998. Household Strategies and Rural Livelihood Diversification. *The Journal of Development Studies*, 35, 1-38.
13. R. H. M. Bergevoet, C. J. M. Ondersteijn, H. W. Saatkamp, C. M. J. v. Woerkum and R. B. M. Huirne, 2004. Entrepreneurial behaviour of dutch dairy farmers under a milk quota system: goals, objectives and attitudes. *Agricultural Systems*, 80, 1-21.
14. C. M. Coughenour and L. E. Swanson, 1988. Rewards, values and satisfaction with farm work. *Rural Sociology*, 53, 442-459.
15. J. R. Fairweather and N. C. Keating, 1994. Goals and management styles of New Zealand farmers. *Agricultural systems*, 44, 181-200.
16. R. H. Bosma, L. T. Phong, U. Kaymak, J. v. d. Berg, H. M. Udo, M. E. F. v. Mensvoort and L. Q. Tri, 2006. Assessing and modelling farmers' decision-making on integrating aquaculture into agriculture in the Mekong Delta Farmer. *Netherlands Journal of Agricultural Sciences*, 53, 281-300.