Assessing and modelling farmers' decision-making on integrating aquaculture into agriculture in the Mekong Delta

R.H. Bosma[1, *], Le Thanh Phong[2], Uzay Kaymak[3], J. Van Den Berg[3], H.M.J. Udo[4], M.E.F. Van Mensvoort[5] and Le Quang Tri[2]

[1] Fish Culture and Fisheries Group, Wageningen University, P.O. Box 338, NL-6700 AH Wageningen, The Netherlands
[2] College of Agriculture and Applied Biology, Can Tho University, Can Tho, Vietnam
[3] Department of Computer Science, Erasmus University, Rotterdam, The Netherlands
[4] Animal Production Systems Group, Wageningen University, Wageningen, The Netherlands
[5] Laboratory for Soil Science and Geology, Wageningen University, Wageningen, The Netherlands
* Corresponding author (fax: +31 317 483937; e-mail: roel.bosma@wur.nl)

Received 8 July 2005; accepted 6 January 2006

Abstract

Contrary to the global trend of specialization within agriculture, the rice-based Vietnamese production systems have diversified into integrated agriculture–aquaculture systems. Economic liberalization in 1986 resulted in an explosive increase in rice production and a rapid diversification. This paper describes the history and dynamics of these systems in the Mekong Delta, and the farmers' decision-making in this process. Subsequently, we use fuzzy logic to simulate farmers' decisions to opt for no aquaculture or one of four fish-production systems: waste-fed, pellet-fed, rice–fish, and ditch–dike, i.e., fish–fruit. In a reaction to changing market opportunities the farmers developed these systems either from the depressions left after building a homestead or after raising dikes to improve irrigation and drainage for rice and fruit trees. The decision-making was simulated in a two-level hierarchy decision-tree. The first layer handles the farmer's production preferences for rice, fruit or fish, with composed variables for land, water, labour, capital and market. The second layer simulates the choice between five options: no fish, and the four alternative fish-production systems. The model allowed a farmer to practise different aquaculture systems at the same time. The fuzzy model simulation predicted the frequency distribution of fish production systems fairly accurately, but performed poorly when classifying individual farmers. To improve the accuracy of the simulation, additional rules can be specified and more factors considered for each product by adding a third layer to the decision-tree and replacing the composed variables with fuzzy rules.

Additional keywords: fish, fuzzy logic, motives, change, diversification

Introduction

Farming systems integrating agriculture with aquaculture (IAAS) are expected to make farmers' livelihoods more sustainable. With such systems the components in the farm's nutrient cycle are used more efficiently (Prein *et al.*, 1998; Jamu, 2003). Nutrient losses are reduced, as manure and other farm waste are used to fertilize the fish pond; the pond sediments are subsequently used to fertilize the crops of which the residues can in turn be used as fodder for the livestock. Globally, agricultural research and development focus primarily on high-input technologies requiring high capital investment; e.g. most new crop varieties and animal breeds only perform well under high-input conditions. However, the financial capital available to small-scale farmers is often insufficient to enable them to adopt such technologies. And if the farm components are not in equilibrium, even if farmers do adopt the technology, there may be significant nutrient losses, thus reducing ecological and financial sustainability (Prein *et al.*, 1998). To enlarge the potential of IAAS's contribution to sustainable livelihoods the INREF[1] Programme for Optimisation of Nutrient Dynamics and Animals for Integrated Farming (POND) studied: (1) breeding of fish that perform well in low-cost production environments, and (2) optimizing the nutrient recycling at farm level. The results of the first POND experiments on the interaction between genotype and environment suggest that the context in which the fish are raised does indeed dictate their growth performance (Charo-Karisa *et al.*, 2004). Moreover, the growth rates of fish in the low-cost environment (ponds fertilized with poultry manure) nearly matched those of fish fed with high-cost pellets (Muendo *et al.*, 2004).

The two innovations mentioned above can increase IAAS's potential contribution to sustainable farmer livelihoods. Whether this potential is achieved depends on what options are available for farmers and what decisions individual farmers make. In order to analyse farmers' decisions about changing and adopting technologies it may be necessary not only to assess the resource utilization context (Hebinck, 2001) but also to run model simulations (e.g. Batz *et al.*, 1999; Caswell *et al.*, 2001). If used individually neither method can entirely elucidate and quantify the process. Most current modelling methods are unsatisfactory because they assume that farmers' decisions are based solely upon utility (Scoones & Toulmin, 1998). These models do not match the new constructivist sociological approach towards rural development, which places the individual farmer at the centre of agricultural innovations (Long, 2001). To go beyond utility and to respect other farmers' motives we propose an alternative approach based on fuzzy logic modelling that can deal with subjective farmer statements, through 'if then' statements. Fuzzy models can also cope with non-probabilistic forms of uncertainty and incorporate expert (i.e., farmer's) knowledge (Zadeh, 1965, cited in Jang *et al.*, 1997). Moreover, they can generate a range of solutions (Silvert, 1997) similar to the process by which farmers shape one technology into various techniques (Hebinck, 2001). In this paper we describe how we tested the applicability of the approach using fuzzy systems for simulating farmers' decision-making.

The Vietnamese Mekong Delta (MD) is a good example of a region where many

[1] Interdisciplinary Research and Education Fund of Wageningen University.

farmers have diversified their production systems into IAAS. Within the past 30 years, many farming systems in Vietnam have emerged from the state-controlled monoculture of rice for the market and other complementary produce destined for subsistence use. A range of new rice-based integrated systems has evolved, with many variations in terms of crop/fish/livestock integration and market orientation (Sanh *et al.*, 1998; Prein, 2002). Because increased diversification in Vietnam has happened relatively recently, we collected the data to build a decision-making model by asking farmers to recount the evolution of their practices (Bosma *et al.,* submitted). In this paper we attempt to elucidate farmers' motives for diversifying into IAAS by (1) describing the history and changes of the IAAS in the MD, (2) establishing which factors account for farmers' decisions to integrate aquaculture with agriculture in the delta and surrounding hills, and (3) applying fuzzy logic modelling to simulate farmer decision-making about fish production systems.

Methodology

Choosing the case study sites

The Vietnamese Mekong Delta can be divided into seven agro-ecological zones (Figure 1). In order to assess the factors influencing the increased integration of farming components, we identified the zones where IAASs were appropriate. Livestock–fish–crop systems are found mostly in the freshwater alluvial zone (delta) and to a lesser extent in the upland and hill zones, where rain-fed agriculture predominates over irrigated cropping. In the other zones, crop and/or livestock farming is governed mainly by periodic flooding.

The predominant ethnic group in the delta lowlands is the Kinh, who practise Buddhism. In this area, the official land-use policy promotes the integration of fruit, fish, pigs and poultry into farming systems dominated by rice. The uplands are inhabited by the Kinh and a Khmer group of Cambodian origin. Some of the upland people practise a particular form of Buddhism prohibiting them from feeding faeces to farm animals and fish. The official land-use policy for the upland region focuses on the production of fruit, timber and cattle and this has led to the neglect of aquaculture's potential. Recently, however, in response to the increasing number of farmers starting fish production, the 'People's Committee' has started support programmes on aquaculture.

Data collection and processing

In 2004, farmers' motives for implementing IAAS were assessed through semi-open interviews in the delta (February) and uplands (March). The reason for including the uplands was to capture the differences between the two farming systems. In the upland districts, three hamlets with predominantly rain-fed farms were selected: Le Tri, Phu Hiep, and Phu Hoa. In the delta, three hamlets in the villages studied by Phong *et al.* (2004) were selected: My Hung, Phu Dien and Thoi My. In that study,

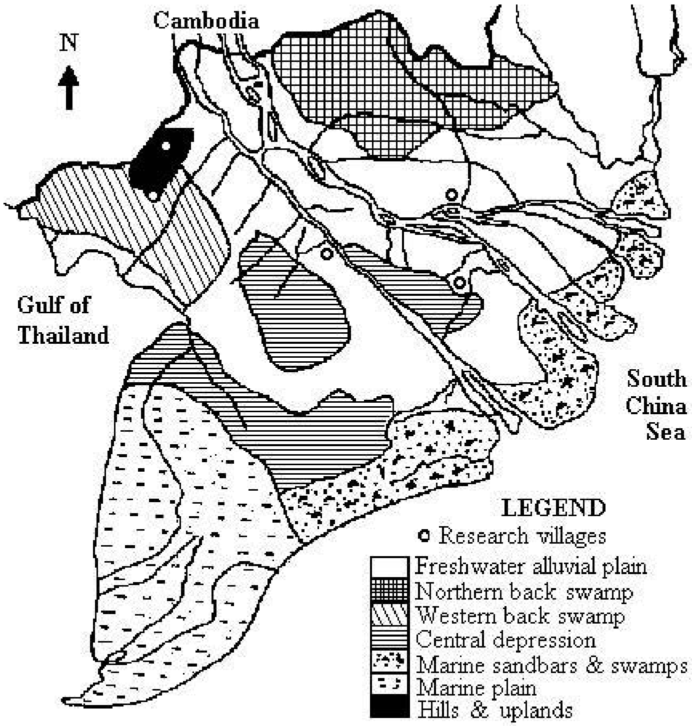

Figure 1. The agro-ecological zones of Vietnam's Mekong Delta. Adapted after Sanh *et al.* (1998).

participatory community appraisal (PCA) tools and structured questionnaires were used for recording an oral history and analysing the IAAS situation. The PCA involved timelines, seasonal calendars, food consumption patterns, village transects, bio-resource flows and production activities. To compose the timelines, farmers were asked about events that had occurred since 1970.

For the present study we interviewed 144 farmers in 6 hamlets. In each hamlet 24 farmers were selected through stratified random sampling based on wealth rankings of poor, intermediate and well-off households. The classification was abstracted from existing lists or rankings provided by three knowledgeable local experts (Bosma *et al.*, submitted). In the interviews data were collected on family and farm characteristics, present farming systems, past changes and the causes or reasons for changing or not changing. The data consisted of quantitative data on the household and farm, descriptive information, and 'if then' statements. We classified children contributing to farm activities as youngsters (10–18 years) and their grandparents still working on the farm as elders. For the calculation of labour availability, elders not participating in work and young children were both classified as non-working. The 'if then' statements describing in linguistic terms the conditions under which farmers implement a change or innovation, were based upon farmers' motives for modifying their farming system and practices. These data and statements were used to build the fuzzy model. Applying the

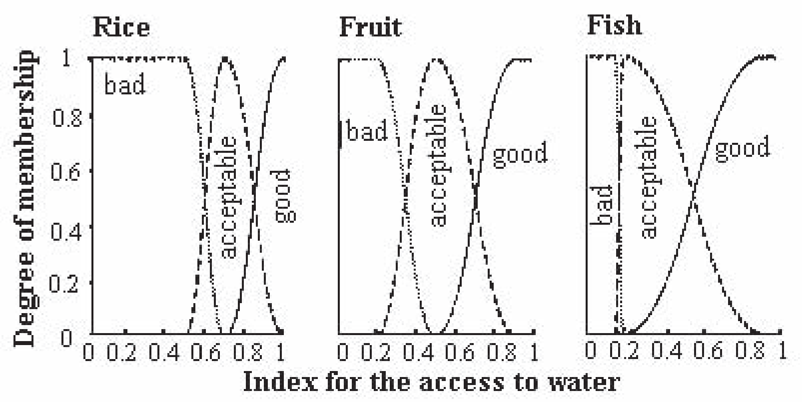

Figure 2. The adjusted membership functions of the input variable water for the Fuzzy Inference Systems of rice, fish and fruit. The vertical axis represents the degree of membership, and the horizontal axis represents water availability.

fuzzy logic toolbox of the software package Matlab 6.1, release 13.1 (Anon., 2001) we simulated farmers' decision-making about integrating a fish component into the farming system.

Fuzzy inference system

The core of a fuzzy system (also called a fuzzy inference system, abbreviated FIS) consists of a number of 'if then' rules, the membership functions (MFs) of the linguistic values, and a reasoning engine. A typical fuzzy 'if then' rule is composed as follows: 'If x is A and y is B then z is C'. In such a rule 'x is A' and 'y is B' are antecedents, 'and' is a connective, and 'z is C' is called the consequence. The antecedent 'x is A' is composed of the variable (x) having a linguistic value (A) taken from a 'term set' of linguistic values (e.g. bad, average, good). The linguistic values associated with each variable are defined by overlapping MFs that cover the universe of discourse (see Figure 2 for an example). MFs can be defined as singletons, triangles, trapezoids, bell-shapes, etc. using various functions or their combinations. Unlike sets for conventional models that have a hard threshold, it can be seen from the MFs in Figure 2 that fuzzy sets can take account of gradual changes and have fuzzy boundaries.

The reasoning engine of the FIS proceeds in 5 steps (Figure 3, in which the numbers in the black dots refer to the steps below):

1. The fuzzifier, or the fuzzification module, determines the degree of membership of the data (x and y) input to the MFs.
2. The degree of fulfilment (m) of each rule is computed from the degree of membership using fuzzy logic operators; in this case the minimum operator was used.
3. The combined degree of fulfilment is calculated using a t-norm (b) which, if the min-operator is used (this is the commonest approach), recapitulates in truncating the smallest section of the graph.

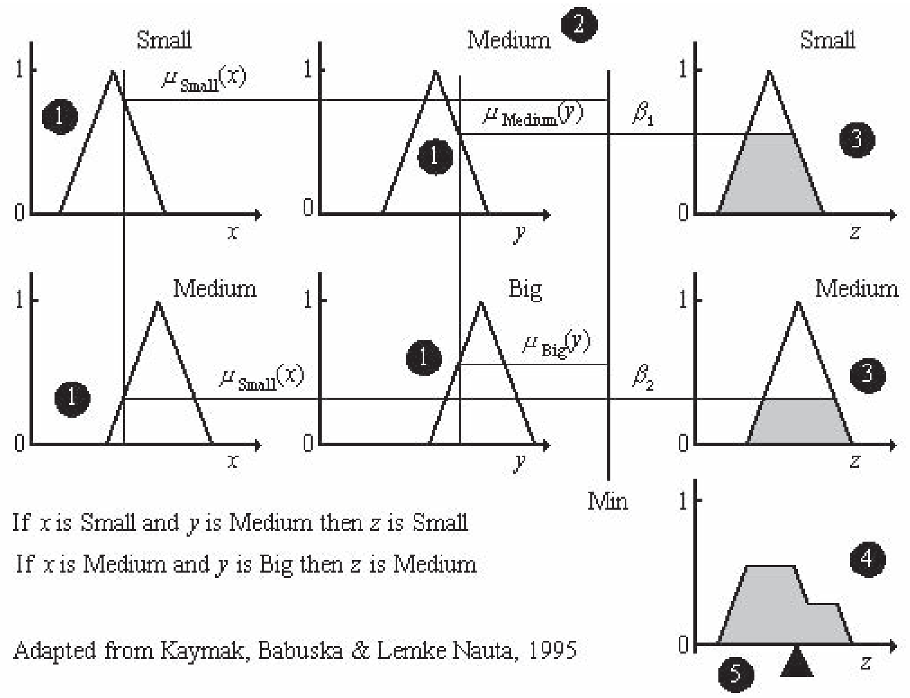

Figure 3. The fuzzy inference of two rules (see text for explanation). Adapted after Kaymak *et al.*, 1995.

4. The degrees to which the rules are fulfilled are aggregated, using the max-min reasoning.
5. The defuzzification module (or defuzzifier) calculates a 'centre of gravity' or 'centroid of area' to change the fuzzy solution into a crisp decision.

Constructing the fuzzy model

The FIS of the simulation model was built in the following six steps (adapted after Jang *et al.*, 1997):

1. The decision-making process was represented in a two-level decision-tree (Figure 4) in which the first layer consisted of three FISs for estimating the probabilities of a given farmer producing rice, fruit or fish. The outputs of this layer, together with another variable termed the 'farmer's reference frame' (see Results), were fed into the fourth FIS, which formed the second layer of the hierarchy.
2. When defining the input variables, we used the criteria the farmers considered to be central to the decisions they made (see Results section Dynamics of IAAS).
3. Data from the structured part of the semi-open interviews generated inputs for the fuzzification and supported the formulation of the linguistic value sets and the associated MFs for each variable.

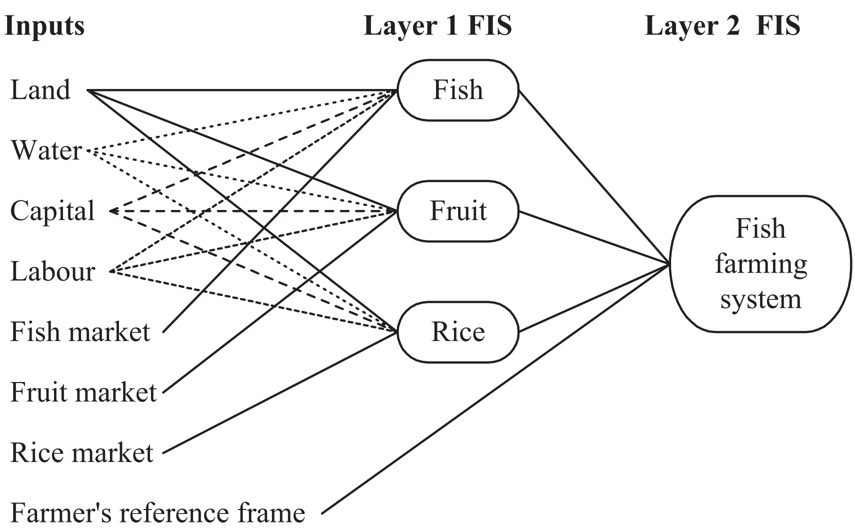

Figure 4. Simulation framework for farmer's decision-making. On the left: the inputs for the first layer of three Fuzzy Inference Systems (FIS). In the centre: their respective outputs, i.e., the inputs for the second-layer FIS. On the right: the output from the second-layer FIS.

4. The farmer's motives and statements collected during the interviews guided the composition of the fuzzy 'if then' rules. We began by composing an extensive rule base for each FIS, including all possible combinations of the variables and linguistic values (e.g. 5 variables, each with 3 values, yielding $5^3 = 125$ rules). Taking 'don't care' rules into account reduced the rule explosion. An example of a 'don't care' rule is 'If *Water* is bad then *No fish*'. So if the value of the variable *Water* is bad the values of the other variables do not affect the decision, and therefore it is permissible to reduce the rule base.
5. The second layer rule base of the decision-tree contained multiple rules with the same antecedent and different consequences, which implies that farmers could adopt different fish production systems simultaneously. The consequences were represented as set of non-overlapping output functions to account for the multiple outcomes, i.e., one farmer practising several systems. The farmer was assumed to adopt a particular production system if the membership for that output was larger than 0.5, i.e., larger than 50% of the surface area of the output function (Bosma *et al.*, 2005).
6. The model was fine-tuned and calibrated by comparing the preliminary outputs with the real situation, and by manually adjusting the rules and the MF parameters to obtain optimal fit between the observed systems and the model estimates.

Initially, the parameters for the MFs of the linguistic values for the input variables were set at quartile values calculated from the dataset, e.g. 1st quartile = low; 2nd and 3rd quartiles = acceptable, and 4th quartile = good. For the fine-tuning, the magnitude of the five output variables was compared with the individual cases with the fish production system as practised on-farm. After identifying inconsistencies, the fine-tuning was done by shifting the thresholds of bad, acceptable and good for the MFs of the first-layer FIS input variables for the products (Figure 2). This change resulted in a larger or smaller centre value in the output, thereby increasing or reducing the probability of a specific system being implemented.

We report the details of the membership functions for the input variables in the second part of the Results section, after presenting the dynamics of the IAAS. The model was validated through a comparative simulation of the fish production systems practised in the MD uplands and delta. We then analysed the resulting set of rules.

Results

Dynamics of IAAS in the Mekong Delta

Historical background

Recent human settlement in the Mekong Delta was favoured by the construction of a network of waterways from 1840 onwards. Later, the French colonial administration improved road access into the delta and people constructed linear settlements on the raised borders of the waterways (Sanh *et al.*, 1998). Rural life on and around the waterways is still dominated by the diurnal tides from the South China Sea (Bosma *et al.*, submitted). The annual monsoon flood lasts between 2 and 6 months and may inundate the land by up to 3 m, depending on the particular year and location (Xuan & Matsui, 1998).

The livelihood of the people living in the delta centred on fishing and irrigated, rainfed and/or floating rice crops. In the second half of the 20th century the economic development and livelihood patterns of the local people were strongly affected by wars and a centralized economic system. Between 1945 and 1976 the rural population followed a survival strategy, but the construction and dredging of waterways continued, laying the foundations for new development.

Changes since 1976

In all three delta districts studied the timeline showed the same major events (Figure 5). However, chronological differences in the key events caused technologies to have different impacts in districts and their hamlets (Phong *et al.*, 2004). In some areas, major state investments in dikes and dams preceded the application of double or triple rice-cropping.

Household production activities were strongly affected by the introduction of new technologies, the construction of canals and dikes, the 'Doi Moi' market reforms, and wide commodity price fluctuations. From 1976 to 1992, farm households were stimulated to achieve self-sufficiency within co-operative units comprising 10 to 12 family farms. The marketing of most products was either restricted to the local area (e.g. perishables, such as vegetables) or regulated by the state (e.g. pork, rice and clothing). The 'Doi Moi' was a legal reform of the centrally planned economy, liberating trade, industry and services. It laid the foundations for land reform in which collective agri-

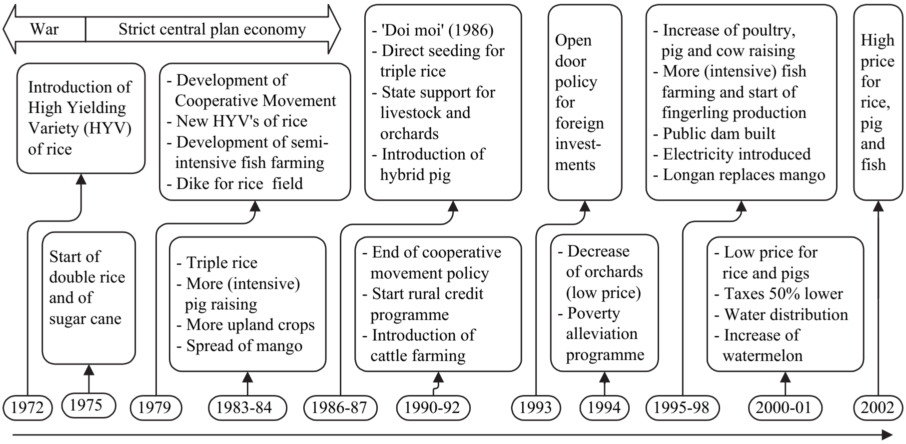

Figure 5. Trends in agriculture during the period 1972–2002 for Cai Bè, Tam Binh and O-Mon districts in Vietnam's Mekong Delta.

culture was abandoned. After 1992, land tenure was individualized and the land was designated either for agriculture by awarding a 'red certificate' or for forestry by a 'green certificate'. These certificates not only conferred on the user the right to use the land as collateral, but also aimed to bring land use within a regulatory framework governed by land use policies. Farmers with a green certificate for forest plots had the obligation to bring their land use practices in line with regulations. Gradually, as the land market liberalized, land prices rose and access to land became dependent on the market.

Farmers' reference frame

Rice is the main staple crop in Vietnam and in the Mekong Delta in particular. Surplus production is sold to pay for farm inputs and support household needs. Elsewhere (Bosma *et al.*, submitted) we report how the adoption of water management practices, rice varieties, and rice technologies that allowed two – and later three – crops per year, improved the household's food security, affected the market price of rice, and made land available for other uses. The improved food security achieved through rice production plus the low but stable prices and liberalized market for rice influenced the farmers' decision-making. Some farmers became less fixated on growing rice to ensure household food security. The motives for making changes to the farming system were also related to the farm household labour cycle and availability of labour. The desire to improve income and/or the availability of food for the household, especially to ensure the well-being of the children, was important. Older couples with no offspring to take over the farm tended to produce labour-saving fruit and fish instead of rice. Most farmers were aware of the potential benefits of IAAS: risk spreading, a more even distribution of cash-generating opportunities, and more efficient resource use (Figure 6).

A low level of know-how sometimes hampered the inclusion of a new component

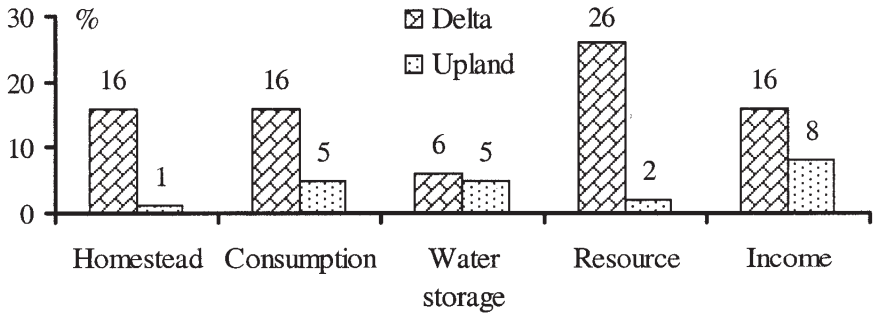

Figure 6. Frequency distribution of the first two reasons farmers in the delta and upland areas of Viet-nam's Mekong Delta gave for installing a fish pond.

in the farm, as shown in the fish-raising example (Figure 7). In our survey, the only way we scored farmers' knowledge was by recording the formal education they had completed. However, we found that the farmers' propensity to try new technologies did not correlate solely with education level (Bosma *et al.*, submitted; Nhan *et al.*, submitted). In the villages, most of the transfer of know-how on feeding fish and on new fish species for aquaculture was through the extension services and television. Poorer farmers' access to media was limited, but those who travelled – sometimes for government (military) service – picked up ideas, could visit friends and acquired specific knowledge. Farmers rarely said that 'lack of knowledge' was one of the top two major constraints to the adoption of a fish-farming system.

Farm characteristics

The village transects in the delta mostly showed homesteads with a pigsty and poultry pen, surrounded by fish ponds, orchards, a vegetable garden and a rice field (Phong *et al.*, 2004). The average farm area was 1.0 ha in the delta (SD 1.8) and 2.1 ha in the uplands (SD 2.3). Most of the rice fields were at some distance from the homestead. The rice field was a source of food and cash for the family and of crop residues that could be used as livestock fodder. Other feed sources for pigs, poultry and fish came

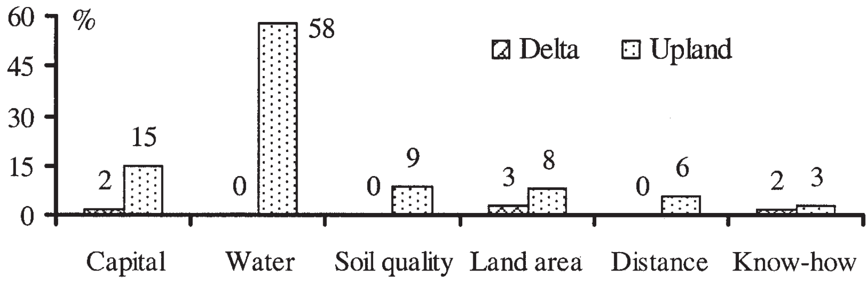

Figure 7. First and second constraints to the integration of a fish pond in the farming systems of Viet-nam's Mekong Delta, as mentioned by farmers (Bosma *et al.*, 2004). Distance refers to the distance between the probable location of the fish pond and the homestead.

from the garden: weeds, and vegetable and fruit waste. After the fish had been harvested, the enriched sediment was removed from the pond bottom and applied as topdressing around the trees in the orchard. In addition, the fish pond could supply water to irrigate the fruit trees and feed for pigs and poultry, such as water spinach, snails, or crabs. Most wastes and excreta were recycled on-farm (Phong *et al.*, 2004). Farmers optimized the use of their resources by using the pig manure to fertilize the fish pond. In the uplands the homesteads tended to be further away from the fields, paddies, forests and orchards, making it more difficult to integrate the farm components effectively (Bosma *et al.*, submitted).

In the delta, aquaculture started off with existing ponds, canals and ditches and the self-recruited natural fish left after floods had receded. These fish were abundant until about a decade ago and were mostly raised without any inputs, but now almost all farmers have enhanced production by stocking with cultured fish and giving supplementary feeding. In the delta, 97% of the farmers interviewed raised fish, compared with only 25% in the uplands. The pond or ditch area varied from 6 m^2 to 3000 m^2 with an average of nearly 350 m^2. In the delta, at least 30% of the farms had more than one pond. The sample did not include farmers raising fish in netted enclosures or on boats in canals. In the delta about 40% of the farms were raising fish in ponds originally not meant for that purpose; in the uplands this figure was 25%. In the uplands some ponds were used mainly to store water for livestock and orchards. In the lowlands of the delta the ponds were the depressions left after soil was removed to raise the ground level for a house or for farming. In swampy areas it was traditional to build homesteads on raised mounds, not only to avoid flooding but also because of the scarcity of wood needed for houses with a raised floor. Fruit trees also need to be grown on raised land, to avoid waterlogging.

Development of IAAS

When rice cropping was no longer remunerative, the farmers turned to substitution and/or complementary activities, i.e., fish farming, fruit orchards, vegetable growing and livestock rearing. They increased the number of farm components to optimize the use of their limited resources and diversify production for the market. Phong *et al.* (2004) recorded 16 different rice-based systems in combination with horticulture, upland crops, livestock, fish pond, or biogas. Almost 60% of the farms in the delta comprised the four main components: garden, livestock, fish and rice; over 90% comprised at least two (Figure 8). Some of the rice fields were converted directly into fish ponds; sometimes farmers gradually built a network of dikes and ditches, using the dikes for upland crops or trees and the ditches for raising fish (Sanh *et al.*, 1998; Linh, 2001; Prein, 2002).

In the delta, over half of the farmers who started to raise fish concurrently developed land for fruit orchards; one third of them did so using ditch–dike or 'raised bed' systems. In some cases the transition was related to neighbours' land-use practices, not only because of the diffusion pattern of the innovation, but also because of the changes in water management resulting from local decisions to abandon paddy rice. In the uplands, the major reason for not having a fish pond was related to the unavailability of water during the dry season and/or inappropriate conditions: sandy or shal-

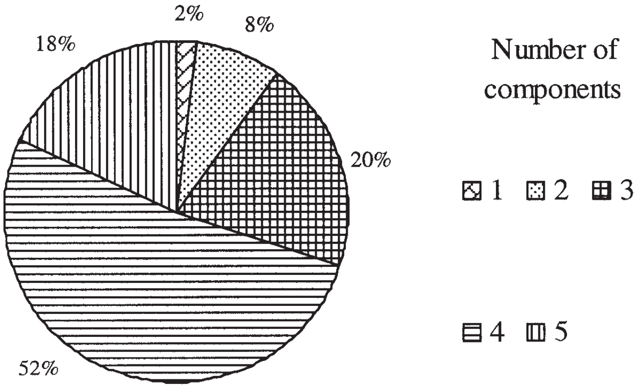

Figure 8. Frequency distribution of farms according to the number of components in the farming system, in 3 districts of the fresh water alluvial zone in Vietnam's Mekong Delta in 2002. Based on data from Le Thanh Phong (in preparation).

low soils (Figure 7). Other main reasons for not having a fish pond were insufficient assets, e.g. capital, and insufficient access to the land (the risk of theft and bird predation increased with the distance between homestead and fish pond).

The vast majority of fish ponds recycled farm waste: household and market waste, rice bran and excreta from humans, pigs, chickens and ducks. In the delta, 77% of the fish ponds recycled residues, compared with 65% in the uplands (Figure 9). Four major types of fish-feeding systems were distinguished: (1) extensive low-input systems, (2) farm-waste feeding systems, (3) systems supplemented by external inputs of feed (e.g. pellets or market waste), and (4) rice–fish systems. Feed regimes were not mutually exclusive: for example, fish waste could be used in conjunction with pellets. Latrine ponds and manure-fertilized ponds were more popular in the delta, not only because of the water level in the delta but also because of a religious taboo in the uplands (Bosma *et al.*, submitted). In all three districts, fish farming could be based on high, moderate or low input levels, depending on market demand and level of technology. The practice was related to land use differences but distance to market was also important: 6.6 km for O Mon, 13.8 km for Tam Binh and 15.6 km for Cai Beh (Phong

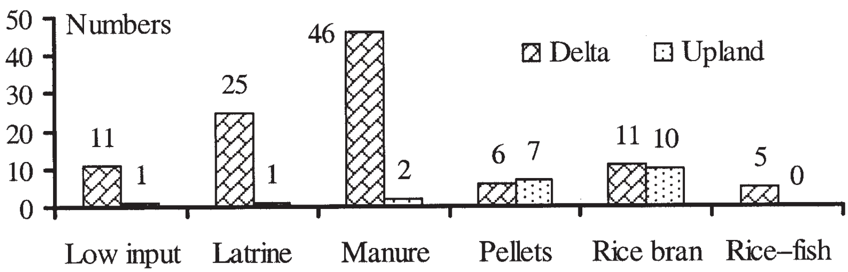

Figure 9. Main feed resources of fish production systems in the alluvial fresh water delta and the uplands of the Vietnamese Mekong Delta (Bosma *et al.*, 2004).

et al. 2004). For the model we retained 4 main fish-production systems: (1) ponds with waste-fed fish, (2) ponds with (partially) pellet-fed fish, (3) fish raised in the ditches of fruit-oriented IAAS (ditch–dike), and (4) rice–fish systems.

Fuzzy logic modelling

The first step in the fuzzy logic modelling of farmers' decision-making was to build a fuzzy simulation model based on a set of input variables that reflected farmers' reasoning and output variables representing the causality of farmers' decisions. This preliminary model was limited to simulating the frequency distribution of fish production systems in the delta and the uplands of the MD. Five alternative modelled outputs were considered: no fish, and the four fish-production systems mentioned above.

The input variables

The potential constraints to the expansion of aquaculture mentioned by the farmers were know-how, water, capital, labour and three land-related factors (Figure 7). In the model, these constraints were represented by one parameter calculated from several variables. Next to these constraints the model considered the effect of market prices and of the farmers' willingness to change.

The farmers' reference frame (Van Paassen, 2004) was used as a proxy for the farmers' willingness to change and for the know-how of farmers. This reference frame was based on four variables that we assumed determined farmers' decisions: (1) the psychological attachment to the rice field, (2) educational level, (3) number of children, and (4) age. The psychological attachment to *rice as a key to food security* was represented by a value of –1 if the farmers had increased rice production for domestic consumption or expressed an interest in doing so, and by +1 if they had not. *Education* was ranked from 0 to 5, where 0 represented no schooling and 5 a college education. The two variables most determining changes in the IAAS during the four stages of the household life-cycle were the *number of children* and *age*. The *number of children* was counted as real numbers and *age* implemented as: (10/age).

The availability of water for a pond depends on proximity to a waterway or source of surface water or groundwater, the soil water retention quality, and water level management options. These factors were also reflected in farmers' land use, as improved water management possibilities enhanced multi-cropping and high-value fruit orchards (Bosma *et al.*, submitted). The index for water was therefore derived from a land quality index (LQI). The land suitability was classified into a LQI of nine classes, with land suitable for the most intensive production being assigned to class 1 and the extremely acid sulphate soils being assigned to class 9. (Acid sulphate soils also make fish production difficult if drainage possibilities are limited.) Homesteads consisting solely of an area with a house and farm buildings were classed as 10. In practice it meant that the linguistic values for *water* were: *good* if water was easily available all year after pond excavation, *acceptable* if water was available most of the year, and *poor* if access to water was difficult even in the wet season.

The availability of land for a fish pond was related to the homestead area and upland fields where LQI < 6, and to the number of lowland irrigated rice crops per year near the homestead. Irrigated land was taken into account only if the distance to the homestead was less than 400 m and if LQI < 3.

Regarding labour, farmers most frequently mentioned the availability of family labour in a specific age category as the factor that determined production changes or innovations (Bosma *et al.*, submitted). The index for labour was derived from the weighted number of family members in the age categories: *adult* –0.25 × *non-working* + 0.5 × *youngster* + 0.75 × *elder*. In the model the availability of capital was assumed to depend on the capacity to save and on the access to credit. The capacity to accumulate savings depends partly on income, which was related to the total area of land (R = 0.43; see Bosma *et al.*, submitted). Access to bank credit depends on the area of land with a red or green certificate, and on family-owned equipment or on other assets. Combining these considerations, the index for capital availability was derived from the area of land with red and green certificates, with the area with a green certificate counting for half. (It should be noted that this ignored the frequent accessing of credit from relatives – for which no collateral was required – and from traders for inputs like fertilizer and feed.)

The farm-gate prices of fish, fruit and rice were expressed as price indices with values ranging from 0 to 1. A value of 0.1 was assigned when a low relative price was an argument for changing the farming system, 0.9 when a high price level was an argument for changing practices and 0.5 when the price was stable during the period of the change. When the product price was not important enough to induce changes in the farming system, a neutral value in the fuzzy inference system was used; 1 was applied as the minimum operator to calculate the degree of fulfilment.

Performance and analysis of the fuzzy model

The preliminary fuzzy model for farmers' decision-making predicted the number of farmers raising fish reasonably accurately, but the simulation of the frequency distribution of fish production systems in the MD was less satisfactory (Figure 10). The fuzzy simulation predicted that 62 of the 144 farmers would not raise fish. The actual number was 57, an accuracy of 91% for predicting whether a farmer does or does not raise fish.

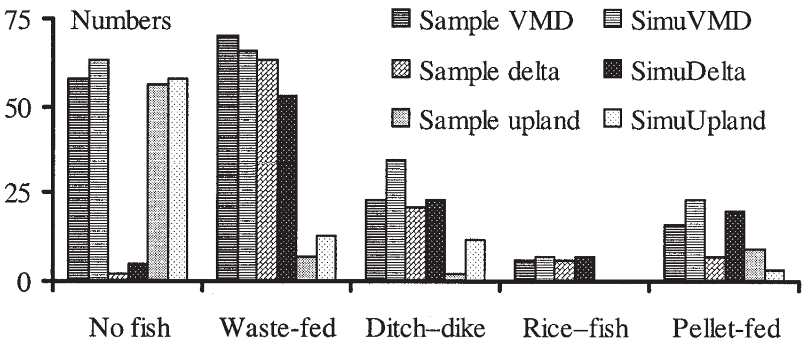

Figure 10. Actual and simulated numbers of farmers with various fish production systems in the Mekong Delta (VMD). Sample size: 144 of whom 57 produced no fish and the rest had 115 ponds.

Table 1. Cross-tabulation rates (%) for individual cases of observed and estimated fish production systems.

Observed cases		Estimated cases		Total
		No fish	Other	
No fish		37	3	40
Other		7	53	60
	Total	44	56	100
		Waste-fed	Other	
Waste-fed		32	16	48
Other		10	42	52
	Total	42	58	100
		Ditch–dike	Other	
Ditch–dike		6	10	16
Other		12	72	84
	Total	18	82	100
		Rice–fish	Other	
Rice–fish		0	4	4
Other		5	91	96
	Total	5	95	100
		Intensive	Other	
Intensive		1	10	11
Other		15	74	89
	Total	16	84	100

In calculating the error, 4% were missed positives, i.e., farmers who had implemented the system but were not as such identified, and 5% were missed negatives, i.e., farmers who were not implementers but could have been according to the rules of the model.

The prediction of the choice for a specific fish production system was less accurate. The simulation underestimated the number of waste-fed ponds in the delta by about 15% and overestimated their number in the uplands by about 40%. The number of ponds in ditch–dike systems was overestimated in general by about 50%, mostly due to a large overestimation for uplands. The frequency of pellet-fed ponds was generally overestimated by 40%; the underestimation for the upland was smaller than the overestimation for the delta.

Table 2. The list of the applied rules for the Fuzzy Inference Systems in the first layer of the decision model determining the likelihood of fish farming.

‘if W is bad, then fish farming is bad’;
‘if W is fine and L is fine and C is low, then fish farming is bad’;
‘if W is fine and L is fine and C is fine and M is fine and P is fine, then fish farming is fine’;
‘if W is fine and L is fine and C is fine and M is fine and P is good, then fish farming is good’;
‘if W is fine and L is fine and C is fine and M is good and P is fine, then fish farming is fine’;
‘if W is fine and L is fine and C is fine and M is good and P is good, then fish farming is good’;
‘if W is fine and L is fine and C is good and M is fine and P is fine, then fish farming is fine’;
‘if W is fine and L is fine and C is good and M is fine and P is good, then fish farming is good’;
‘if W is fine and L is fine and C is good and M is good and P is fine, then fish farming is fine’;
‘if W is fine and L is fine and C is good and M is good and P is good, then fish farming is good’;
‘if W is fine and L is bad and C is good, then fish farming is fine’;
‘if W is good and L is bad, then fish farming is good’;
‘if W is good and L is fine and C is fine, then fish farming is good’;
‘if W is good and L is fine and C is good, then fish farming is good’;
‘if W is good and L is good, then fish farming is good’.

Key: *W = water*; *L = land*; *C = capital*; *M = labour*; *P = fish market*; fine = acceptable.

The model’s success rate in classifying individual farmers according to their fish production system was below 50% (Table 1). The model specifically failed to predict the few individual farmers who adopted rice–fish or intensive pellet-fed fish production systems. This indicates that the rules predicting these systems should be evaluated further in order to improve the model’s performance.

The numbers of rules in the FISs for estimating the production levels of fish, fruit and rice were 27, 21 and 34, respectively, and the rule base for the fish production system contained 384 rules (see e.g. the rule base for fish in Table 2). An analysis of the rules that were most decisive for the classification revealed that for raising fish or planting fruit trees, low capital availability was a constraint and an acceptable market price a condition. However, these factors did not prove important for decisions to grow rice. Poor availability of water was a constraint to starting fish or fruit activities, but poor access to land did not restrict fish farming, though it did limit the growing of rice or fruit trees.

In order to elicit the farmers’ reasons for integrating complementary production components into their farming system and further develop IAAS, the model needs to be extended. We think of at least four adjustments:

1. The number of waste-fed ponds in the uplands was overestimated because the religious taboo on using manure as feed was not considered. Besides, both the underestimation of waste-fed ponds in the delta and the overestimation of pellet-fed ponds might be explained by farmer preference for pig-fattening concentrates and subsequent use of the manure to fertilize the ponds. These aspects can probably be accounted for by inserting the variable *Farmers’ reference frame* in the FIS for each product separately.

2. The use of a three-level scale for subsistence rice production preferences hardly affected the variable for the farmers' reference frame. It would be better to rank farmers' preferences on a scale of 1–5: very high, high, medium, low, and very low.
3. The price index for changes in the fish production system apparently performed well. However, it strongly directed the simulation results and did not capture commodity market price fluctuations. To address this, the model simulations could be repeated with different price levels.
4. The fuzzy model overestimated the likelihood of ditch–dike systems in the uplands, possibly because of the favourable conditions there for fruit production. In fact, most farmers raising fish in the uplands have insufficient water to create ditch–dike systems and do not need drainage canals or dikes to avoid waterlogging of the land on which fruit trees are grown. The fruit trees varied between the uplands and the delta: mango trees predominated in the uplands, but longan (*Euphoria longan*) and citrus were common in the delta (Phong, in preparation). To address this discrepancy, different factor demands related to the type of product should be included in the model.

Discussion and conclusions

In Vietnam, small-scale IAAS seem a logical starting point for the development of a socially, ecologically and financially sustainable agriculture on family farms lacking resources or with few opportunities outside agriculture. In view of the abundant rice production, with low and stable prices, and guaranteed family food security, rural households engaged in other farm activities to earn cash. Most farmers in the MD produce fish to improve their livelihoods and to diversify their sources of food and cash income. In the delta, where ponds were often available for other reasons and ditches became available when farmers started growing fruit trees, fish make efficient use of resources and waste from other land-use components of the family farm. This is reflected in the high frequency of waste-fed systems. Those promoting aquaculture improvements in Vietnam through the widespread adoption of innovations need to appreciate the role of fish in recycling waste (Brummett & Haight, 1996). The overestimation of the frequency for the ditch–dike and waste-fed systems in the hills might also indicate that aquaculture has the potential for further expansion. While farmers in the uplands of North Vietnam cope with temporal water shortages by producing fish in short seasonal rain-fed cycles (Bosma *et al.*, 2003), many of the upland farmers in our sample still believe that aquaculture is only feasible in the delta, where water is available all year round.

Fuzzy logic modelling enabled us to satisfactorily simulate the decision whether a farmer does raise fish or not. However, for some systems the individual classification rate of farmers and the frequency distribution in the delta or uplands were unsatisfactory. The simulation of the spatial dynamics of land use (see Verburg *et al.*, 2002) yielded a satisfactory fit, varying between 65% and 85%. We obtained an average fit of 91% for the decision to raise or not to raise fish, but an error of about 400% for the ditch–dike system in the hills. The error is relative, given that Nhan *et al.* (submitted) have estimated that only one quarter of the available ditch–dike systems in the delta are effectively used for raising fish for market purposes, i.e., the ditch–dike systems are available but farmers do not stock fish. Psychologists consider that people's decisions are the outcome of complex and unobservable mental processes that researchers are still trying to elucidate (Johnson-Laird & Shafir, 1993). This is probably also reflected in the low individual classification rate for e.g. the infrequent rice–fish system: many farmers may have conditions suitable for the rice–fish system but only a few are actually using it, and we were unable to simulate their reasoning with the present rule-base and decision model. The rule base and the data sets used were rudimentary and have scope for improvement in terms of individual farmer knowledge and experience; this should reduce errors and increase the classification rate. Moreover, though using composed variables allowed a simple simulation model to be developed, this may have dramatically decreased the fuzzy character of the reasoning.

We made this fuzzy model to simulate farmer decision-making about adopting four aquaculture systems in the Vietnamese part of the Mekong Delta. Whether a fuzzy logic model can be used to explore the possibilities of fish production in other regions can be discussed only after the simulation has been refined by replacing the composed variables with a third level of FISs, including more factors for each product, and specifying additional rules for the farmers' reference frame.

Acknowledgements

We wish to thank the farmers, Can Tho University and the Village People Committees of An Phu, An Thanh, Cai Be, O Mon and Tam Binh for their kind collaboration, and last but not least, Messrs Cao Quoc Nam and Phan Minh Duc for assisting in the fieldwork and interviewing the farmers. We gratefully acknowledge the contribution of Dr H.K. Komen, initiator of the INREF-POND Programme. The study was funded by the Interdisciplinary Research and Education Fund (INREF) of Wageningen University.

References

Anonymous, 2001. Fuzzy Logic Toolbox Guide for Use with Matlab. The MathWorks, Natick, Massachusetts.

Batz, F.J., K. Peters & W. Janssen, 1999. The influence of technology characteristics on the rate and speed of adoption. *Agricultural Economics* 21: 121–130.

Bosma, R.H., R.L. Roothaert, P. Asis, J. Saguinhon, L.H. Binh & V.H. Yen, 2003. Economic and Social Benefits of New Forage Technologies in Mindanao, Philippines and Tuyen Quang, Vietnam. CIAT Working Document No 191. Centro Internacional de Agricultura Tropical (CIAT), Los Baños, 92 pp.

Bosma, R.H, Cao Quoc Nam, Pham Minh Duc, H.M.J. Udo & J.A.J. Verreth, 2004. Motivation of farmers in the Vietnamese Mekong Delta to integrate aquaculture in their production system. In: H.K. Wong, J.B. Liang, Z.A. Jelan, Y.W. Ho, Y.M. Goh, Jothi M. Panandam & W.Z. Mohamad (Eds), New Dimensions and Challenges for Sustainable Livestock Farming. Proceedings of the 11th Animal Science Congress of the Asian-Australian Association of Animal Production Societies, 5–9 September 2004, Kuala Lumpur. Volume III, Persatuan Produksi Haiwan Malaysia, pp. 419–422.

Bosma, R.H., U. Kaymak, J. Van Den Berg & H.M.J. Udo, 2005. Fuzzy Modelling of Farmer Motivations for Integrated Farming in the Vietnamese Mekong Delta. In: Proceedings of the 14th IEEE (Institute of Electrical and Electronics Engineers) International Conference on Fuzzy Systems, 22–25 May 2005, Reno, Nevada. IEEE Publications Office, Los Alamitos, pp. 827–32.

Bosma, R.H., Cao Quoc Nam, H.M.J. Udo & J.A.J. Verreth, 2006. Farmers motives and drives for agriculture diversification in the Mekong Delta. *Asian Journal of Agriculture and Development.* (accepted for publication)

Brummett, R.E. & B.A. Haight, 1996. Research-Development Linkages. Report of the Expert Consultation on Small-scale Rural Aquaculture. Fisheries Report No 548 (FIRI/R548). Food and Agriculture Organization of the United Nations (FAO), Rome, pp. 147–169.

Caswell, M., K. Fuglie, C. Ingram, S. Jans & C. Kascal, 2001. Adoption of Agricultural Practices: Lessons Learned from the United States Department of Agriculture (USDA). Area Studies Project 792. Resource Economic Division, Economic Research Service, USDA, Washington, D.C., 111 pp.

Charo-Karisa, H., M.A. Rezk, H. Bovenhuis & H. Komen, 2004. Effects of rearing conditions on low-temperature tolerance of Nile Tilapia juveniles. In: Proceedings 6th International Symposium on Tilapia in Aquaculture, 12–16 September 2004, Manilla. The American Tilapia Association, Charles Town, pp. 30–41.

Hebinck, P., 2001. Maize and socio-technical regimes. In: P. Hebinck & G. Verschoor (Eds), Resonances and Dissonances in Development. Van Gorcum, Assen, pp. 119–128.

Jamu, D.M., 2003. Identification of Sediment Processes Regulating Nitrogen Use Efficiency and Retention in Integrated Aquaculture/Agriculture Systems. Worldfish Centre, Zomba, 43 pp.

Jang, J.-S.R., C. Sun & E. Mizutani, 1997. Neuro-Fuzzy and Soft Computing. A Computional Approach to Learning and Machine Intelligence. Prentice Hall, Upper Saddle River, New Jersey, 614 pp.

Johnson-Laird, P.N. & E. Shafir, 1993. The interaction between reasoning and decision making: an introduction. *Cognition: International Journal of Cognitive Science* 49: 1–10.

Kaymak, U., R. Babuska & H.R. Van Nauta Lemke, 1995. Fuzzy control - theory and design. *Journal A* 36(3): 4–12.

Linh, N.V., 2001. Agricultural innovation: multiple grounds for technology policies in the Red River delta of Vietnam. PhD thesis Wageningen Agricultural University, Wageningen, 200 pp.

Long, N., 2001. Development Sociology: Actor Perspectives. Routledge, London, 394 pp.

Muendo, P.N., J.J. Stoorvogel, G.E. Naggar, A. Milstein, A.A. Van Dam & M.C.J. Verdegem, 2004. Sediment accumulation in fish ponds: its quantity and quality as a crop fertilizer. In: Abstract of the 7th Asian Fisheries Forum, 30 November – 4 December 2004, Penang. Universiti Sains Malaysia, Kuala Lumpur, p. 297.

Nhan, D.K., L.T. Phong, M.J.C. Verdegem, Le Thanh Duong, R.H. Bosma & D.C. Little. Integrated freshwater aquaculture, crop and animal production in the Mekong Delta, Vietnam: participatory assessment of current situation and opportunities for sustainable development. *Agricultural Systems* (submitted for publication)

Phong, L.T., H.M. Udo, M.E.F. Van Mensvoort, L.Q. Tri, R.H. Bosma & D.K. Nhan, 2004. Understanding integrated agriculture-aquaculture systems in the Mekong Delta, Vietnam. In: H.K. Wong, J.B. Liang, Z.A. Jelan, Y.W. Ho, Y.M. Goh, Jothi M. Panandam & W.Z. Mohamad (Eds), New Dimensions and Challenges for Sustainable Livestock Farming, Proceedings of the 11th Animal Science

Congress of the Asian-Australian Association of Animal Production Societies, 5–9 September 2004, Kuala Lumpur. Volume III, Persatuan Produksi Haiwan Malaysia, pp. 423–425.

Phong, L.T. Changes in integrated agriculture aquaculture systems: what is the balance in sustainability? PhD thesis Wageningen University, Wageningen. (in preparation)

Prein, M., 2002. Integration of aquaculture into crop-animal systems in Asia. *Agricultural Systems* 71: 127–146.

Prein, M., R. Oficial, M. Bimao & T. Lopez, 1998. Aquaculture for diversification of small farms within forest buffer zone management: an example from the uplands of Quirino Province, Philippines. In: Edwards P., D.C. Little & H. Demaine, 2002 (Eds), Rural Aquaculture. CABI Publishing, Wallingford, pp. 97–110.

Sanh, N.V., V.T. Xuan & T.A. Phong, 1998. History and future of farming systems in the Mekong Delta. In: V.T. Xuan & S.E. Matsui (Eds), Development of Farming systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Can Tho, pp. 16–80.

Scoones, I. & C. Toulmin, 1998. Soil nutrient balances: what use for policy? *Agriculture, Ecosystems and Environment* 71: 255–267.

Silvert, W., 1997. Ecological impact classification with fuzzy sets. *Ecological Modelling* 96: 1–10.

Van Paassen, A., 2004. Bridging the gap: computer model enhanced learning for natural resource management in Burkina Faso. PhD thesis Wageningen University, Wageningen, 219 pp.

Verburg, P.H., W. Soepboer, A. Veldkamp, R. Limpiada, V.Espaldon & S.S.A. Mastura, 2002. Modelling the spatial dynamics of regional land use: the CLUE-S model. *Environmental Management* 30: 391–405.

Xuan, V.T. & S. Matsui, 1998. Development of farming systems in the Mekong Delta of Vietnam. Saigon Times Group, Vietnam Asia Pacific Economic Center. Ho Chi Min City Publishing House, Can Tho, 318 pp.