Fish WorldFish Centre. Impact of the Development and Dissemination of Integrated Aquaculture–Agriculture Technologies in Malawi

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7 WorldFish Centre. Impact of the Development and Dissemination of Integrated Aquaculture–Agriculture Technologies in Malawi

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Fish is an important part of the nutrition of Malawians, providing essential protein and micronutrients. However, due to declining catches from the lakes and a doubling of the population since the 1970s, per capita annual fish consumption decreased from 14 kg in the 1970s to 4.2 kg in 2005, with a corresponding increase in fish prices. This has further worsened food insecurity, especially of the rural population in a country (Fig. 7.1) where an estimated 66% of the population does not consume the minimum daily energy requirement (Jamu and Chimatiro, 2004).

The Fisheries Department of Malawi designated aquaculture to play a complementary role to the capture fisheries sub-sector (ICLARM and GTZ, 1991). Aquaculture increases fish supply and therefore releases the pressure on capture fisheries. Various projects focusing on introducing small-scale fish farming to rural farmers were implemented from the 1970s to the mid-1990s by the United Nations Development Programme, the Oxford Committee for Famine Relief (OXFAM), the United Nations Children's Fund, Landell Mills Associates/European Economic Community, Official Development Aid and the German Agency for Technical Cooperation (GTZ) (ICLARM and GTZ, 1991). In essence, these initiatives upgraded the national extension and research infrastructure, conducted capacity-building activities of Fisheries Department staff, and implemented farmer training and technology support activities. However, the extended technology 'packages' required considerable investments on the side of the farmer, which they could not afford without project support (Banda, 1987; Brummett and Noble, 1995a,b). With the

Fig. 7.1. Map of Malawi.

termination of externally funded extension and research projects, the support subsidies to farmers were discontinued. In many cases this resulted in a considerable decline in production levels in farmers' ponds, frequently leading to disadoption of aquaculture (Brummett and Noble, 1995a,b). Furthermore, there was no diffusion of the technologies from adopters to subsequent new adopters. The total estimated aquaculture production in Malawi in 1985 was only 173 t from 170 ha of ponds.

Responding to the challenge of introducing aquaculture into small-scale farming in sub-Saharan Africa, the WorldFish Centre[1] started aquaculture research in Malawi in 1985 with funding from the German Federal Ministry for Economic Cooperation and Development/GTZ. The objective of the project was to develop appropriate and sustainable aquaculture technologies for smallholder rural farmers. Box 7.1 provides an overview of the major milestones and key research outputs.

[1]Prior to 2002, the Centre's name was International Centre for Living Aquatic Resources Management (ICLARM).

Box 7.1. Major milestones of research by the WorldFish Centre and its partners that led to the development of integrated aquaculture–agriculture in Malawi.

1988	Understanding of agroecological and socio-economic environments in which Malawian small-scale farmers live.
1988–1990	Development of the integrated resource management concept, which refers to the synergistic movement and utilization of resources between and among farm and household enterprises.
	Assessment of local availability of potentially useful bio-resources and their efficiency as pond inputs.
	On-station testing of integrated aquaculture–agriculture (IAA) technologies. Demonstration of the impact of IAA through farmer-managed on-farm trials.
1991	Wide adoption of integrated rice-fish technology in Zomba district.
1991–1994	On-farm testing of IAA technologies.
	Development of the farmer–scientist research partnership (FSRP) approach to aquaculture technology development and dissemination utilizing RESTORE (Resource Tools for Natural Resource Management, Monitoring and Evaluation) through research extension teams.
2000	Incorporation of FSRP approach into the national Fisheries and Agriculture Policy.
2003–2004	The aquaculture sector has benefited from the Highly Indebted Poor Countries (HIPC) initiative funds that were allocated for the construction of fishponds for poor female-headed households. The funds paid for locally supplied labour. About 751 fishponds were constructed in 2003 with individual areas from 300 to 400 m^2.

The WorldFish Centre applied a new farmer participatory research approach in which the potential for farmers to add fish farming as an additional enterprise to their farms was assessed. This approach, termed RESTORE (Research Tools for Natural Resource Management, Monitoring and Evaluation), is a combination of farmer participatory field procedures and an analytical database (Lightfoot *et al.*, 1994, 2000). The approach focuses on the development and diffusion of integrated aquaculture–agriculture (IAA), in which existing resources (in the form of organic wastes and by-products) on and around the farm are utilized as much as possible as nutrient inputs to the pond and also to other agricultural enterprises.[2] The organic wastes and by-products do not flow exclusively to the pond, but from the ponds (in the form of pond mud and nutrient-rich water) to other enterprises such as vegetable production around the pond. Fishponds require fertilization, and because they also function as a bio-digester (or an 'aquatic rumen') lend themselves ideally to be the central catalytic component of IAA systems. The most common pond inputs are plant-based residues and processing wastes such as leaves, straw, peels,

[2]For a detailed discussion on IAA systems, readers are referred to Edwards *et al*. (1988), Edwards (1998), Prein (2002) and Pant *et al*. (2005).

husks, bran and pulp. Livestock manures are used mainly if these are penned and no other use exists, or if these can be obtained in bulk from other sources away from the farm (e.g. chicken farms). Other on-farm wastes are kitchen scraps and slaughter wastes. Prior to engagement with the concept of recycling through IAA, farmers are often unaware of the nutrient management opportunities.

The IAA system leads to improved environmental soundness (Lightfoot *et al.*, 1993a; Lightfoot and Noble, 2001) and synergisms among various subsystems (e.g. crop production, aquaculture, etc.), resulting in a higher output of desired products from natural resources under farmers' control (Edwards *et al.*, 1988; Edwards, 1998). The farmer participatory research approach was implemented in Malawi by research extension teams (RETs) under the farmer–scientist research partnership (FSRP) concept (Chikafumbwa, 1994; Brummett and Noble, 1995a; Brummett and Haight, 1996; Brummett, 1999, 2002).

This chapter presents an *ex post* impact assessment of the development and dissemination of small-scale IAA technologies in Malawi over more than 15 years by the WorldFish Centre and its national and international partners.

Impact pathways

The project has developed two broad categories of outputs.

1. IAA technologies → new technologies.
2. Development and transfer of aquaculture technology → new approach.

The impact pathway for the new technologies starts with the development of IAA by the WorldFish Centre and its partners, followed by dissemination via extension agents and farmers. Finally, after adaptation and adoption by farmers, IAA technologies have (market and non-market) impact on adopting households as well as at the national level. The new FSRP approach that was developed by the WorldFish Centre has been subsequently adopted by national agencies. This adoption resulted in the development and dissemination of IAA technologies, which have been adapted and adopted by farmers. Once adopted, IAA generated impact both at the household and national level.

The IAA technologies are being disseminated to farmers by: (i) government extension agencies, such as the Department of Fisheries through its various projects; (ii) various non-governmental organizations (NGOs); and (iii) farmer cooperators who have been involved during the development of technologies. By 1994, 86% of Malawian farmers who had been exposed to IAA technology through the FSRP had adopted at least one of the demonstrated technologies, 76% adopted at least two and 24% had adopted four (Brummett and Noble, 1995a). Currently, at least 50% of the over 5000 fish farmers in Malawi have adopted some form of IAA technology developed through this project (Brummett and Chikafumbwa, 1999). This project has increased the number of farmers incorporating fish farming into their existing farming systems. Once in the rural community, the IAA technologies have spread and often evolved without further extension support (Baker, 2003).

Methodology and Data Used

Conceptual framework

The case study rests on the overall hypothesis that IAA leads to improved farm productivity. This arises first because IAA offers a set of technologies in which conventional inputs such as labour, organic fertilizer and capital can be used more effectively. Second, IAA improves human and social capital, thus increasing farmers' efficiency and improving efficiency in the use and conservation of natural resource capital, such as soil, water and biodiversity. Improvements in human and social capital result from learning new input-use techniques via extension or technology transfer between farmers and from formation of social institutions such as fish farmers' clubs. Finally, IAA offers an opportunity to increase utilization of biodiversity. In this way, through the improved use of natural capital and other inputs, farmers are likely to increase their productivity (Fig. 7.2).

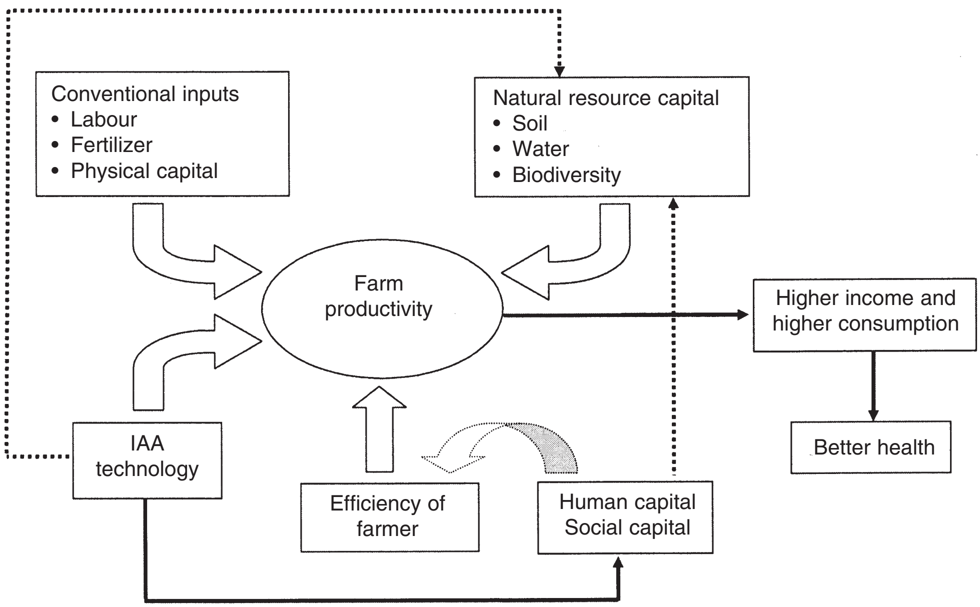

Fig. 7.2. Schematic diagram of farm productivity and household welfare (IAA, integrated aquaculture–agriculture).

This results in households realizing higher incomes and higher consumption, which lead to better health. From this, the following hypotheses can be drawn.

1. Compared with a non-IAA household, an IAA household is likely to have: (i) higher farm productivity; (ii) larger technical efficiency; and (iii) greater human and social capital (i.e. increased capacity of farmers and farmers' organizations).
2. Higher human capital and social capital result in higher efficiency of farmers.
3. Increased farm productivity leads to higher household income and higher consumption.
4. Higher income and higher consumption lead to better household health.

Thus, it is of interest to determine which factors facilitate the adoption of the technology, and which factors bring about productivity and therefore lead to an improved health status. A two-stage framework was used for this *ex post* impact assessment of IAA research in Malawi. Stage one identified which technical, socio-economic, institutional and policy factors influence IAA adoption. In stage two, the effect of IAA adoption on efficiency, food security, employment and sustainability was assessed. The respective impact indicators are listed in Table 7.1.

The welfare impact of IAA technologies on producers and consumers at the national level was estimated using standard economic surplus techniques. In addition, the internal rate of return (IRR) of investment in IAA research and development was estimated.

Table 7.1. Impact themes and related indicators used in the *ex post* impact assessment.

Theme	Indicator
Efficiency	• Fish production (kg/ha/year) • Total farm productivity (total factor productivity score) • Profitability (US$/ha) • Total farm income (US$/ha/year) • Technical efficiency (score)
Food security and health	• Fish consumption (kg/capita/month, frequency) • Food security of household • Animal protein consumption (kg/capita/month) • Nutritional status of children under 5 years of age
Sustainability	• Diversity (number of managed enterprises) • Recycling and integration with other farm enterprises (number of bio-resource flows) • Soil fertility (farmers' perception, nitrogen loss)
Employment	• Employment opportunity generated (person-days/ha)
Institutional capacity	• Increased capacity of farmers and farmers' organizations

Survey framework

The case study applied *ex post* impact assessment based on a 'with and without' scenario. A survey of IAA-adopting and non-adopting farmers was conducted in early 2004 at six sites in Malawi representing various agroecological and socio-economic conditions (Table 7.2). All sites have high water resources, therefore having a good potential for fish farming, and are dominated by small landholding sizes with the opportunity to intensify production. With small numbers of livestock, fish are an important source of protein.

Table 7.2. Distribution of household respondents included in the analysis.

District	Number of IAA respondents	Number of non-IAA respondents	Total
Zomba West	28	26	54
Zomba East	22	12	34
Mwanza	30	25	55
Mulanje	29	26	55
Thyolo	28	30	58
Mangochi	29	30	59
Total	166	149	315

IAA, integrated aquaculture–agriculture.

In each study site, 30 IAA and 30 non-IAA (i.e. 'control') respondents were selected for the survey. NGO or government extension workers provided sampling frames for the respondents. In cases where the aquaculture farmers operated in groups, only a sample of farmers was selected randomly per group. Out of 360 sample farmers, 315 were interviewed; the remaining 45 farmers were not available for interview. The survey covered information for the 2003/04 season on: (i) socio-economic profile of farmers; (ii) farming environment; (iii) sources of income and wealth status; (iv) production systems; (v) input, output and profitability of various farming enterprises; (vi) social and institutional environments; and (vii) food and fish consumption. In addition, available information collected by the WorldFish Centre was used (baseline survey data, survey on health status of IAA and control farmers, on-farm trial data).

Adoption of Integrated Aquaculture–Agriculture

Characteristics of adopters (versus control farmers)

An IAA adopter is defined as a farmer who has a fishpond as part of his/her farming operations and who recycles resources among various enterprises. The average age of the household head was 45 years among the IAA respondents and about 40 years among the non-IAA respondents (Table 7.3). The age difference between the two groups was significant. This suggests that as households become older they tend to acquire more farming skills, resources and experiences that enable them to undertake fish farming. The average family size of the IAA respondents was 5.2 family members and that of the control group was 4.9 persons (Table 7.3) although this difference was not statistically significant. Also, there were no significant differences between the two groups with regard to the number of male and female adults. The number of male farmers was higher among the IAA respondents (1.12) compared with the non-IAA respondents (0.97). This has implications on the type and quantity of labour available to undertake aquaculture farming. Aquaculture is generally undertaken by male-headed households individually or by female-headed households in groups. However, there were a few cases of individual female-headed households having fishponds.

Table 7.3. Key characteristics of respondents who did and did not adopt integrated aquaculture–agriculture (IAA).

Variable	IAA respondents (*n* = 166)	Non-IAA respondents (*n* = 149)
Average age of respondents (years)	45.36	39.88
Average household size	5.19	4.9
Average number of male farmers	1.12	0.97
Average number of female farmers	1.25	1.20
Average farm size (ha)	1.98	1.49
Land type (%)		
Homestead	22	30
Lowland	37	28
Upland	32	31
Wetland (*dimba*)	10	10
Topography (% of parcels)		
Flat	27	21
Gentle slope	57	62
Others	16	17
Source of water (%)		
Rainfall	75	78
Water course (natural)	9	8
Well	6	4
Others	10	10

The IAA respondents had a significantly larger average farm area than the non-IAA respondents (Table 7.3). The total farm area can include different natural resource types that can be considered as separate management units with distinct usage. Farmers distinguish such management units (homestead, lowland, upland and wetland) based on tenure, topography, soil type and water supply (Lightfoot *et al.*, 1993b). The IAA respondents had more land in the lowland than the non-IAA respondents (Table 7.3). Access to low-lying areas enables the households to participate in fish farming. The difference in access to flat land (gentle slopes) between IAA and non-IAA respondents was statistically significant in absolute terms. Such flat land is usually suitable for fishpond construction and operation as it is usually associated with clay soils. A majority of respondents indicated that they had exclusive access to the parcels that were being farmed (96% and 94% for IAA and non-IAA respondents, respectively).

For both groups of respondents, rainfall was the primary source of water for farming enterprises (Table 7.3). Even in areas such as Chingale, where gravity and furrow irrigation is fairly widespread and is a recent development, respondents stated that the principal source of water is rain. At least for farming, rainfall is important even when people irrigate during the dry season. The majority of the water sources was seasonal in nature (reported by 70% of IAA respondents and 74% of non-IAA respondents). A majority of the respondents indicated that the water they use is not polluted (96% of IAA and 99% of non-IAA farmers).

Adoption model

The main assumption is that critical factors such as human, social and natural resource capital facilitate the adoption of the IAA technology. The hypothesized related variables X_i that might affect IAA adoption are as follows.

Human and physical capital

- Age or level of education (years in school) of household head and household members.
- Gender of household head (male = 1, female = 0).
- Number of household members who are trained in IAA.
- Person:land ratio (*n*/ha).
- Land area as proxy to income (ha).

Social capital

- Access to credit programmes (access = 1, no access = 0).
- Access to extension activities (access = 1, no access = 0).

Natural resource capital

- Access to irrigation (access = 1, no access = 0).
- Biodiversity (number of species on the farm) or number of enterprises.
- Presence of wetland area (*dimba*) on the farm (present=1, not present = 0).

It is also hypothesized that adoption is a continuum process, as the intensity of technology use varies among the adopters (Rauniyar and Goode, 1996). Thus, a two-stage framework was applied to model the adoption process. In the first stage, a Logit model was estimated to determine the significance of factors on the adoption of IAA:

$$P[Y_1 = 1] = \log\left(\frac{P}{1-P}\right) + = \beta_0 + \sum_i \beta_i X_i = \varepsilon \qquad (7.1)$$

where Y_1 is a binary variable representing adoption with a value of 1 if the respondent is an IAA adopter and 0 if otherwise; P is the probability of adopting IAA; X_i are the explanatory variables as defined above; β_i are the corresponding coefficients to be estimated and ε denotes the error term. In the second stage, a Logit model was estimated among the adopters to determine the significance of the same factors with regard to the intensity of adopting IAA (defined as the fraction of the number of bio-resource flows over the total number of enterprises per farm, henceforth termed level of integration):

$$P[Y_2 = 1|Y_1 = 1] = \log\left(\frac{P}{1-P}\right) + = \beta_0 + \sum_i \beta_i X_i = \varepsilon \qquad (7.2)$$

where Y_2 is a binary variable representing the level of integration with a value of 1 for higher integration (defined as integration of 0.75 or above) and 0 if otherwise; and the other variables are as defined above.

Results indicate that farmers who have access to extension services are more likely to adopt IAA than farmers who have no access to extension services, *ceteris paribus*. Also, the likelihood of adopting IAA is higher for older farmers with a larger farm area and a greater number of enterprises than for younger farmers with a smaller farm area. Contrary to expectations, the coefficient of education shows that higher education did not lead to higher adoption. However, the level of education increased the level of integration of IAA practices. At the same time, access to irrigation enabled a higher intensity of adoption (Table 7.4).

Socio-economic Impact of Integrated Aquaculture–Agriculture at Household Level

Impact on land use, farm income, productivity and profitability

Within an IAA system, the availability of pond water and nutrients allows intensifyied land use and enables farmers to grow additional crops.[3] Farmers in the sample who adopted IAA practices have a larger area for vegetable cultivation specifically around their homestead and in the uplands (Table 7.5).

The encouragement to increase cropped area to grow higher-value

[3]In Malawi, marginal areas such as waterlogged depressions (*dambo*) have been utilized for IAA technologies, i.e. without sacrificing existing farmland (Brummett and Noble, 1995a; Noble, 1996).

Table 7.4. Determinants of integrated aquaculture–agriculture adoption (*n*=270)[a].

	Stage 1: Adoption		Stage 2: Level of integration	
	Estimate	SE	Estimate	SE
Intercept	2.66***	0.74	–0.19	0.75
Age (years)	0.07**	0.03	<0.01	0.01
Age?Age (quadratic term)	<0.01*	<0.01		
Education of household head (years)	–0.06	0.06	0.14*	0.08
Gender of household head (male = 1)	0.23	0.30	–0.87*	0.53
Persons in household trained in IAA (*n*)	0.46***	0.16	–0.03	0.16
Extension dummy (access = 1)	0.62***	0.18	–0.17	0.28
Credit dummy (access = 1)	0.14	0.25	0.01	0.27
Land area (ha)	0.15**	0.07	0.02***	0.01
Person:land ratio (*n*/ha)	<0.01	<0.01	–0.01	0.01
Dimba area dummy (present = 1)	0.02	0.21	0.19	0.32
Irrigation dummy (access = 1)	0.10	0.18	0.58**	0.25

SE, standard error.
[a]Dependent variable: Stage 1 – 1 if integrated aquaculture–agriculture is adopted, 0 if otherwise; Stage 2 – 1 if high integration, 0 if otherwise.
*Significant at ·= 0.10; **significant at ·= 0.05; ***significant at ·= 0.01.

crops (i.e. vegetables) in combination with pond activities was also reported by other studies (e.g. Brummett and Noble, 1995a; Chimatiro and Scholz, 1995). The technical reasons for the very high cropping intensities realized by IAA respondents and additional impact on the farming system are explained further below.

The most conventional measures of productivity and profitability are

Table 7.5. Impact of integrated aquaculture–agriculture (IAA) adoption on land use.

		Area			
		IAA respondents		Non-IAA respondents	
Land type	Crop	ha	%	ha	%
Homestead	Maize	0.35	5.56	0.49	9.23
	Vegetables	0.60	9.52	0.20	3.77
	Other crops	0.29	4.60	0.62	11.68
Lowland	Maize	0.86	13.65	0.71	13.37
	Vegetables	0.92	14.60	1.00	18.83
Upland	Maize	1.20	19.05	0.52	9.79
	Vegetables	0.56	8.89	0.20	3.77
	Other crops	0.44	6.98	0.60	11.30
Wetland (*dimba*)	Maize	0.38	6.03	0.27	5.08
	Vegetables	0.70	11.11	0.70	13.18

production (yield) and return (gross margin) per unit area. Such measures, however, fail to account for differences in input and output prices across farmer groups and sites. More importantly, partial productivity measures such as yield are not appropriate in a multiple output–multiple input setting (such as the IAA system with strong linkages between the enterprises). To overcome such limitations, the concept of interspatial total factor productivity (TFP)[4] was used to measure the farm productivity of each farmer and compare the productivity of IAA and non-IAA farmers. TFP values were further analysed using the interspatial Tornqvist index (TI).

Following Dey *et al*. (unpublished),[5] the interspatial TI is defined as:

$$TI_i = \frac{\sum_l \ln[Y_{il}/Y_l][(s_{yil} + s_{yl})}{2} - \frac{\sum_k \ln[X_{ik}/X_k](s_{xik} + s_{xk})}{2} \qquad (7.3)$$

where the subscript i refers to the ith farmer, l refers to the lth output (maize, vegetables, other), k refers to the kth input (seed, fertilizer, labour), Y_{il} is the quantity of output (kg/ha), Y_l is the average across farmers, X_{ik} is the quantity of input, s_{yil} is the share of the lth output to the total gross return, s_{xik} is the share of the kth input to the total cost input, and s_{yl} and s_{xk} are the average shares of the lth output and kth input, respectively. TI_i is the interspatial Tornqvist index. The exponentiation of TI_i gives the productivity difference between the ith farmer and the average farmer (TFP_i), indicating how much more or less it would cost a particular farmer (say farmer i) than the average farmer to produce the same quantity of output per unit area using the same technology.

Table 7.6 presents the results of the comparison of TFP, profitability and input use. Results show that, on average, IAA farmers in the southern region of Malawi are 11% more productive than non-IAA farmers. IAA farmers had 133% more income per hectare than non-IAA farmers. One of the reasons for the higher income is the increased cropping intensity (due to increased cultivation of vegetables and other crops, Table 7.5).

Of interest is the difference in productivity and profitability as the level of integration increases. As shown in Table 7.6, there is a positive association between productivity and profitability with the level of integration, i.e. productivity and profitability increase as the level of integration increases. Previous studies have also found a positive effect of the adoption of IAA on pond productivity and farm income (Brummett and Noble, 1995a; Chimatiro and Scholz, 1995).

Total household income was almost 1.5 times higher for the IAA households (US$254) compared with the non-IAA respondents' average

[4]Total factor productivity refers to the ratio of total farm production given all inputs used on the farm.

[5]Dey, M.M., Prein, M., Paraguas, F., Lopez, T., Shah, W.A. and Grover, J. (2001) Integrated agriculture–aquaculture, natural resources and overall farm productivity. International Centre for Living Aquatic Resources Management/WorldFish Centre, Penang, Malaysia, unpublished manuscript.

Table 7.6. Comparison of farm profitability (US$/ha/year) and productivity.

	By household type			Level of integration	
	IAA	Non-IAA	Difference (%)	Low	High
Gross income	163	93	76	101	205
Total cost	67	51	30	54	74
Seed	14	10	32	11	16
Fertilizer	22	16	35	18	22
Manure	3	2	38	2	5
Labour[a]	28	22	25	23	32
Net income	96	41	133	47	131
TFP	1.33	1.20	11	1.18	1.52

IAA, integrated aquaculture–agriculture; TFP, total factor productivity.
[a]Labour was valued based on ruling wage rates.

income of US$174 (Table 7.7). This huge difference is mainly due to the difference in farm income (income earned from farming activities), whereby IAA farmers had a farm income of US$185, which is 1.8 times as much as the non-IAA farmers' average of US$115. Around 80% of the total income of the IAA respondents was derived from farming compared with only 66% of the total income of the non-IAA respondents (difference is statistically significant at the 5% level). Out of the farm income of IAA farmers, an average of US$21 (about 10%) is directly contributed by fish culture (Table 7.7). Also, the IAA farmers had a higher average income from remittances. The results are in line with previous studies that have shown that IAA adoption increased farm income substantially (Brummett and Noble, 1995a,b; Chimatiro and Scholz, 1995; Petry, 1996; Scholz and Chimatiro, 1996).

Table 7.7. Household income of farmers who did and did not adopt integrated aquaculture–agriculture (IAA), by source (US$/year).

	IAA farmers	Non-IAA farmers	Difference (%)
Total income	254	174	46
Farm income	185	115	60
Income from fish	21	–	–
Non-farm income	26	36	–27
Off-farm income	15	18	–17
Remittances	7	4	67

While farm productivity and profitability as well as farm income were higher for IAA farmers, non-IAA respondents had a higher off-farm income (earned from outside the homestead, e.g. employment or piecework) and more income from non-farm activities (e.g. business within the homestead), although the difference is not statistically significant. IAA farmers spent an average of 72% of their time farming compared with 66% of the time spent by non-IAA respondents. On average, IAA farms spent 24 person-days per hectare a year more than non-IAA farms.

IAA farmers generally recycled their produce or by-products among the various enterprises. This requires additional labour; for example, to move by-products between enterprises and the pond, to manage the pond dykes, and stock, harvest and sell the fish. However, pond maintenance activities are normally scheduled in times of low labour demand from agricultural activities, thus smoothing the labour demand over the year and providing an alternative to off-farm employment during slack times for agricultural labour (February–March, May–September).

As the productivity of family labour in IAA activities is higher than that through alternative opportunities of selling family labour for off-farm activities, the overall return to labour from IAA is higher. Therefore, although non-IAA farmers can generate a higher income from non-farm activities (through sale of family labour), IAA farmers will have higher overall income by using their family labour in IAA practices instead of selling it.

To control the effect of other factors on income, a regression analysis was run on farm income. It was assumed that farmers are profit maximizers facing production constraints such as farm size, access to irrigation and credit, and the level of education of the household head. In the regression, the technology (IAA) was introduced to measure the shift in farm income, controlling for the effect of other variables or production constraints. Since farm income, which is the dependent variable, was expressed in the form of its natural logarithm, the coefficient can be considered as elasticity, i.e. percentage change in farm income due to adoption of the technology. However, IAA adopters differ from non-adopters in characteristics that cannot be observed and affect both the decision to adopt the technology and its outcome (e.g. ability or motivation). To correct for this possible selection bias, the instrumental variable technique was employed using predicted probability of adoption as an instrument (Heckman *et al.*, 1998).

The probability of adoption was estimated using the adoption model as defined in Eqn (7.1). The positive sign of the coefficient for the predicted probability indicates that, on average, IAA adopters have a higher net farm income than non-adopters (Table 7.8).

Moreover, access to irrigation increases per hectare farm income by 35%, *ceteris paribus*, while an increase of farm size by 1 ha will decrease the per hectare farm income by 75%. This can be explained by a shortage of labour, so that large areas are not cultivated intensively.

Table 7.8. Farm income function[a].

	Estimate	SE
Intercept	8.58***	0.16
Probability of IAA adoption[b]	0.91***	0.27
Ln farm size (ha)	–0.75***	0.07
Irrigation dummy (access = 1)	0.35***	0.10
Credit dummy (access = 1)	0.13	0.14
Education of household head (years)	0.03	0.03
F value	23.05***	
R^2	0.27	

IAA, integrated aquaculture–agriculture; SE, standard error.
[a]Dependent variable: ln farm income per hectare.
[b]Probability of IAA adoption of model = probability that was estimated using Eqn (7.1).
***Significant at $\cdot\alpha$ =0.01.

Impact on technical efficiency

The impact of IAA on overall farm technical efficiency was evaluated using the stochastic frontier approach (Battese and Coelli, 1995). The level of technical efficiency was computed for each farmer to identify the causes of (in)efficiency and to analyse whether IAA farmers have increased efficiency.[6]

Following Battese and Coelli (1995), the stochastic production frontier is defined as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{6} \beta_j \ln(X_{ij}) + U_i \tag{7.4}$$

where subscript i refers to the ith farmer; Y is the observed farm output (US$/ha); X_1 is the total seeding rate of all crop seeds combined (US$/ha); X_2 is the fertilizer rate (kg/ha); X_3 refers to the amount of organic fertilizer applied (kg/ha); X_4 is the pre-harvest labour use (family and hired person-days/ha); and X_5 and X_6 are dummy variables for inorganic and organic fertilizer applications, respectively, which hold values of 1 if fertilizer is applied and 0 if otherwise. These dummy variables were introduced because X_2 and X_3 had numerous zero values, which introduce statistical bias. This can be corrected through the introduction of dummy variables (Battese, 1996).

Following Battese and Coelli (1995), the mean of farm-specific technical inefficiency (U_i), μ_i, is defined as:

$$U_i = \delta_0 + \sum_{i=1}^{7} \delta_i Z_i \tag{7.5}$$

where Z_1 is a dummy variable for the type of respondents which takes a value of 1 if the farmer is practising IAA and 0 otherwise; Z_2 represents age as a proxy for experience of the operator expressed in number of

[6]An alternative would have been the Multi Production Distance Function approach, which we did not use due to zero values in some of the outputs (i.e. not all farmers used all enterprises).

years; Z_3 represents the education of the farmer collaborator expressed in number of years of formal schooling; Z_4 represents the farm area (in hectares) as a proxy for income; Z_5 is a dummy variable for gender of household head that holds a value of 1 if the head is male and 0 otherwise; Z_6 is a credit dummy variable which holds a value of 1 if the farmer has access to credit and 0 otherwise; and Z_7 is an extension dummy variable that holds a value of 1 if the farmer has access to extension services and 0 otherwise.

All but one variable in the stochastic production function are highly significant, indicating their importance in determining yield levels (Table 7.9). In the technical inefficiency function, the dummy variable for IAA being practised is significant, indicating that on average IAA farmers are more technically efficient than non-IAA farmers. Results also indicate that older farmers are more technically inefficient than younger farmers.

Table 7.9. Stochastic production and technical inefficiency function.

	Estimate	SE
Stochastic production function		
Constant	3.187***	0.515
Ln seed (US$/ha)	0.419***	0.047
Ln fertilizer (US$/ha)	0.131***	0.055
Ln manure (US$/ha)	1.555***	0.726
Ln labour (US$/ha)	0.510***	0.108
Fertilizer dummy	–0.230	0.242
Manure dummy	–1.406***	0.597
Technical inefficiency function		
Constant	0.291	0.537
IAA practice dummy	–0.310**	0.162
Age (years)	–0.007*	0.001
Education (years)	–0.022	0.066
Farm area (ha)	0.033	0.025
Male household head dummy	–0.534	0.472
Access to credit dummy	0.089	0.277
Extension dummy	–0.224	0.167
Variance parameters		
Σ^2	0.422***	0.056
δ	0.813***	0.067

IAA, integrated aquaculture–agriculture.
*Significant at ·= α0.10; **significant at ·= α0.05; ***significant at ·= α0.01.

Figure 7.3 shows the distribution of technical efficiency of IAA and non-IAA farmers. On average, the technical efficiency score of IAA farmers is 90%, while it is only 65% for non-IAA farmers. None of the IAA farmers has a technical efficiency score of less than 50%, while around 40% of the non-IAA farmers have a technical efficiency score lower than that.

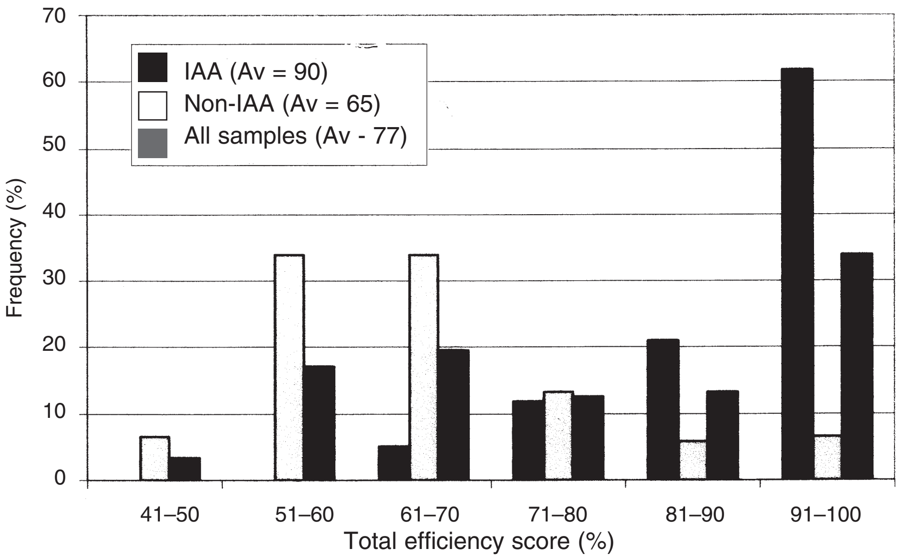

Fig. 7.3. Distribution of technical efficiency score of farmers who adopt (IAA) and do not adopt (non-IAA) integrated aquaculture–agriculture.

Impact on consumption of fish and other protein food

The respondents were requested to indicate the number of times their household had eaten a given type of protein food (beans, meat, dried fish, fresh fish and chicken) during the previous month. Figure 7.4 shows the frequency with which the various foods were consumed in the month prior to the interview.

Overall, dried fish was the protein food most frequently consumed during the previous month, followed by beans and fresh fish. IAA respondents consumed fresh fish more frequently than non-IAA respondents and also on average stated higher frequency for all other animal protein foods. Non-IAA farmers on average consumed slightly more beans than IAA respondents. The quantity of protein food (by type) consumed by IAA and non-IAA farmers was recorded (Table 7.10). As expected, IAA respondents consumed more fresh fish, dried fish, chicken and meat compared with non-IAA respondents. While there were no significant differences between the two groups in the average consumption of beans, meat and dried fish, there was a significant difference between the two groups in the consumption of fresh fish and chicken. It can be assumed that the consumption of fresh fish (which is more expensive than dried fish) is higher for fish-growing households that do not have to purchase this food. The higher consumption of chicken, however, can be explained by the higher household income of IAA farmers that leads to an increase in purchased animal protein on top of increased on-farm production. Still, beans were the major protein source in terms of the amount consumed for

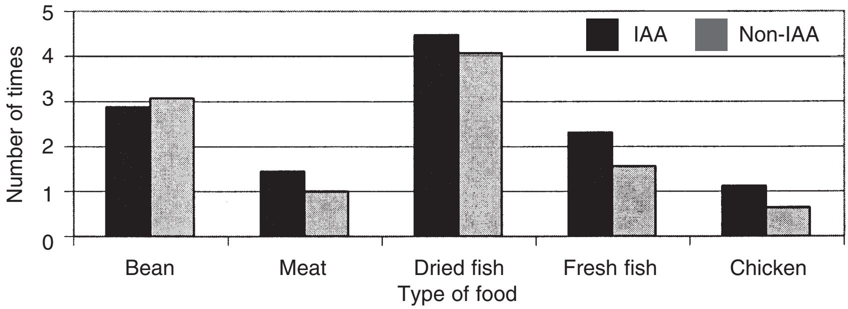

Fig. 7.4. Frequency of protein food consumption over the previous month among farmers who adopt (IAA) and do not adopt (non-IAA) integrated aquaculture–agriculture.

both groups. However, non-IAA respondents consumed more beans, the cheapest source of protein, while IAA respondents consumed higher value protein sources such as meat and fresh fish.. Table 7.10 clearly shows that adoption of IAA practices leads to an overall increase in protein food consumption and to a more varied food consumption pattern.

Table 7.10. Protein sources (kg/capita/month) of respondents who did and did not adopt integrated aquaculture–agriculture (IAA).

Type of protein food	IAA respondents (n = 167)	Non-IAA respondents (n = 149)	P value for difference of means
Beans	2.20	3.69	0.370
Meat	1.52	1.03	0.122
Dried fish	1.95	1.61	0.274
Fresh fish	1.91	0.62	0.000
Chicken	1.08	0.48	0.000

Based on data collected in a nutrition survey, no significant impact of IAA adoption on the nutritional status of children below 5 years of age could be demonstrated. The results of the analysis of consumption patterns and amounts, however, allow the conclusion that in the long term such an improved diet will ultimately have a positive impact on the nutritional status of household members, and especially children. For an econometric analysis of this issue, a larger data set would be required and additional health data need to be collected. Finally, such long-term impacts may only be measurable several years after technology adoption.

Impact of Integrated Aquaculture–Agriculture at the National Level

Apart from farm-level impacts, the use of IAA as a strategy to promote the development of aquaculture in Malawi has resulted in sustained increases in fish production from small farms. When the WorldFish Centre started its operations in Malawi in 1986, the total annual fish production from all fishponds combined was around 90 t/year. The total fish production from fishponds has currently increased to around 1000 t/year.

Aquaculture production in Malawi increased at an annual rate of 7.36% during the period 1970 to 2001. Much of the increase can be attributed to the dissemination of IAA since 1995. During the phase from 1985 to 1995, i.e. the period when basic research and on-farm trials on IAA technologies were conducted, the annual growth rate was 2.4%. However, after the dissemination of the technology (i.e. the years from 1996 to 2001), the annual rate of production increased exponentially to 22% (Fig. 7.5).

The IAA technology was developed and introduced by a WorldFish Centre project that ran from 1986 to 1994. The total cost of the project research activities during this period was around US$1.5 million. A substantial amount of resources spent from 1986 to 1990 (about US$0.6 million) was for collecting baseline information, which has been utilized not only by the WorldFish Centre and its direct partners, but also by various R&D agencies in Malawi. From 1994 onwards, dissemination was undertaken by the WorldFish Centre, NGOs and the Government of Malawi. The following impact assessment uses *ex post* economic surplus

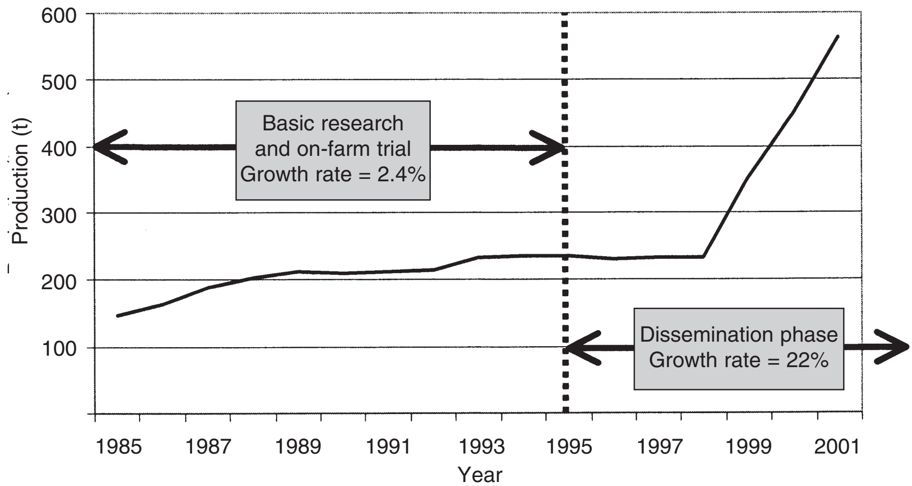

Fig. 7.5. Aquaculture production (t) in Malawi during the research and dissemination phases of the WorldFish Centre's integrated aquaculture–agriculture project.

analysis from 1986 to 2001, the last year from which data are available (through the FishStat database of the Food and Agriculture Organization of the United Nations; FAO, 2004). From 2001 onwards, *ex ante* analysis was applied up to 2016 (30-year time horizon of evaluation). Calculations of present value use a discount rate of 10% and all economic values are stated in US dollars.

Project benefits and costs are calculated based on a number of assumptions. The WorldFish project costs were divided annually. Other IAA activities were valued at US$100,000 per year during the project period to reflect the cost of the collaborating MAGFAD (Malawi–German Fisheries and Aquaculture Development) project (Scholz, U. and Gloerfelt-Tarp, T., personal communications, 2004). From 1994 onwards, a constant cost of US$100,000 annually was applied for further dissemination work by the government of Malawi and various NGOs (Chimatiro, S., personal communication, 2004).

The measure of gross project benefits is the change in economic surplus. To calculate economic surplus, a multi-commodity model was constructed following the framework of Dey *et al*. (2005). Benefits accrue only from 1994 onwards (a conservative assumption). For 1994 to 2001, the model is calibrated to 1994 baseline data. For 2001 to 2016, the model is calibrated to 2001 data. The FAO data were corrected for reclassification of miscellaneous freshwater fish to tilapia in 1998.

The supply impact of R&D on IAA in Malawi is estimated as follows:

- Increases in aquaculture production are attributed to growth in the production area (price-response independent), yield and demand.
- A quarter of the growth is attributed to demand, consistent with population and income trends.
- The remainder is divided equally between yield and area growth.
- The actual annual growth of culture production during the period 1994–2001 is 24.7%. This is rounded off to 20%; hence, the area expansion is set to 7.5% per year, the same figure applied for productivity growth.

Two different scenarios were simulated. In the first, the counterfactual (without-project) scenario assumes 0% growth (counterfactual I) in area and productivity without the project throughout the evaluation period. In the second scenario 2.4% growth (counterfactual II) in area and productivity throughout the evaluation period were assumed to allow for the impact of other projects.

The present value of project costs is US$2.23 million and the present value of benefits is US$0.15 million for the *ex post* evaluation, and US$2.9 million for the *ex ante* evaluation (under counterfactual I). Over the entire evaluation period, the bulk of the project benefits are enjoyed by the consumers (estimated as 69% and 63% for counterfactual I and II, respectively). Consumers benefit due to lower prices, which tend to depress the benefits received by producers from adopting the improved technology (this is also why consumer surplus is higher in the 0% growth scenario). The benefit:cost ratio is well beyond 1 for both simulations (Table 7.11). The IRR for scenarios I and II, respectively, are reasonably high by World Bank standards.

Table 7.11. Economic surplus analysis of the integrated aquaculture–agriculture technology.

	Value ('000 US$)	
	Counterfactual I (0% growth)	Counterfactual II (2.4% growth)
Producer surplus	1087	1120
Consumer surplus	2396	1936
Net present value of benefits	3483	3056
Benefit:cost ratio	1.56	1.37
Internal rate of return	13.2	12.2

The assumptions for the welfare analysis are conservative estimates for the following main reasons: first, the IAA technology that was developed during the basic research phase can be considered a public good that is used by other organizations and in other countries as well. However, the benefits from such additional use or spillover effects are not included in the simulation and research costs are fully charged to the project. Second, the positive non-market impact (e.g. environmental effects) that is described below were not included in the computation, hence assumed benefits are rather at the low end. Finally, the calculation incorporates additional costs of the collaborating MAGFAD project, so cost assumptions are rather at the high end.

Non-market Impact of Integrated Aquaculture–Agriculture

Impact on sustainability

To assess whether IAA technologies improve the sustainability of natural resource use, four sustainability indicators computed by an analytical procedure in RESTORE are monitored over time (annual cycles). These indicators are:

- Diversity – number of species/enterprises maintained and utilized in the farming systems, i.e. managed biodiversity or agrodiversity.
- Recycling – number of movements of biological output or by-product/waste from one natural resource enterprise to another within the farming system.

- Capacity – product biomass yield in t/ha.
- Economic performance – profit:cost ratio.

The findings can be presented in a ‘kite’ diagram such as the ones shown in Fig. 7.6. The values are specific to each farm and the season analysed, and can vary considerably between years due to changes in the climatic conditions or other shocks (death or illness of a family member, marriages or other social events, or disturbances such as theft).

In Malawi, some 40 farms were monitored using the RESTORE approach. Since not all cases can be presented here and average values are not meaningful for the interpretation, two farms were selected as examples. Increases in the ‘kite’ size reflect improvements in farm sustainability, including the farm’s endowment of natural resources (Fig. 7.2, ‘Natural resource capital’). However, all sustainability indicators need to be considered simultaneously, and annual comparisons and other information about the household and its context factors have to be included.

Results from RESTORE analyses indicate that farmers who have integrated their farms with fish farming increased enterprise diversity, recycling flows among enterprises, the overall biomass production and improved economic performance, even though results might vary over time (Lightfoot and Noble, 2001). It is further hypothesized that farmers increase their aquaculture knowledge and integrated pond management skills, selecting what fits best in the often variable agroecological and socio-economic context.

The case study farm of Mr Ismael Amadu experienced typical variability over the 6 years shown here. Two years were affected by drought (1991/92, 1994/95) and in 1993/94 the farm was stressed by a severe

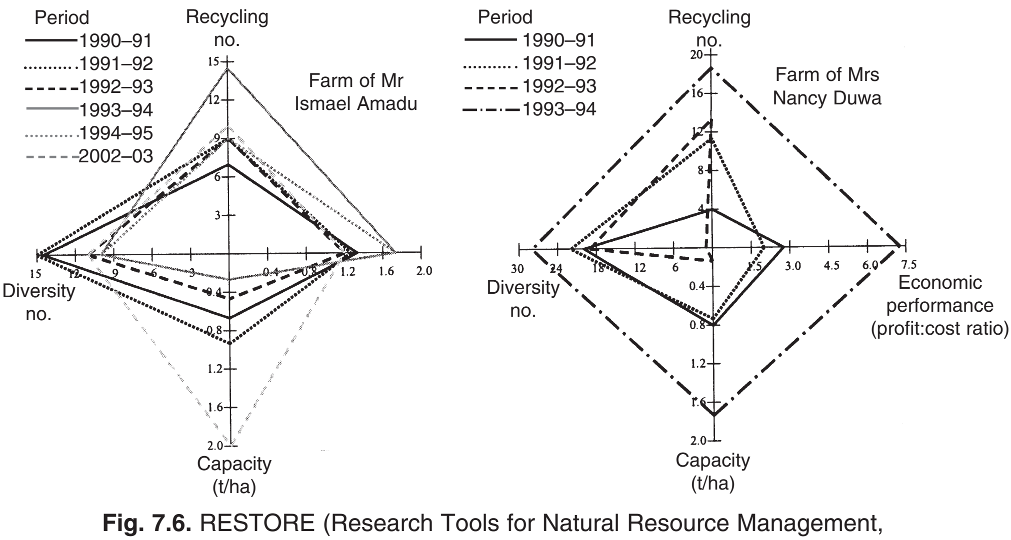

Fig. 7.6. RESTORE (Research Tools for Natural Resource Management, Monitoring and Evaluation) ‘kites’ of sustainability indicators – integrated farms of Mr Ismael Amadu (left) and Mrs Nancy Duwa (right).

drought. Although enterprises were affected (reflected in reduced production), the farmer managed to achieve high profit:cost ratios during the two latter drought years through IAA-enabled strategies such as growing additional varieties of vegetables around ponds in residual moisture of dried-out ponds.

In the early years of the Centre's IAA research in Malawi (1987–1988) five out of six smallholder farms were not recycling any materials at all. With the adoption of IAA, the number of bio-resource flows increased to an average of eight (Brummett and Noble, 1995b). The same authors reported that integrated fish farms recycle four times as much material (in terms of flow counts) as non-integrated fish farms and retain nitrogen and phosphorus better. These results are a reflection of the potential improvement of soil characteristics arising from IAA farming.

Fishponds act as on-farm mini-reservoirs that store nutrient-loaded water, enabling the cultivation of vegetables on the pond dykes or in the pond vicinity (see results on land-use change above). Often, ponds are constructed in locations adjacent to streams, or farmer groups organize small and simple irrigation/conveyance systems to have year-round access to water. Although the primary motivation for establishing the water supply and holding facilities was that of fish culture, the complementary production of fish and vegetables or use of the water for other (agricultural) activities can increase household income and overall sustainability of the farming system. However, issues of finiteness and fragility of the water sources need to be considered in scaling up and adopting irrigation by larger numbers of farmers.

Other studies have documented that the adoption of IAA technologies has reduced nitrogen loss and has made farming systems more durable (Jamu, 2003; Brummett and Noble, 1995b; Chimatiro and Scholz, 1995). By practising IAA, farmers are reducing the loss of nitrogen by 50%. Specifically, it was shown that nitrogen loss in maize plots where fishpond sediments are applied as a basal fertilizer is half (5 mg/m^2/day) that of maize plots where inorganic fertilizer is applied as basal fertilizer. This finding has important implications, since nitrogen is the most limiting soil nutrient in Malawi. Furthermore, the same study showed that IAA tended to improve nitrogen use efficiencies, defined as the quantity of nitrogen produced per kilogram of nitrogen applied. IAA farmers had nitrogen use efficiency of about 0.4–0.6 compared with only 0.2–0.3 among the non-IAA farmers. Brummett and Costa-Pierce (2002) also found that adoption of IAA has a positive impact on the sustainability of farming systems through resource recycling and use of pond water and nutrients for growing agricultural crops.

Impact on institutions

The impact of IAA dissemination and adoption on institutions is presented as thematic summaries of impact categories, based on information collected through case studies conducted in five locations (Zomba West, Zomba East, Mulanje, Thyolo, Mangochi) representing different geographic and social–political–institutional settings (e.g. presence/absence of NGOs, proximity to aquaculture research station, presence/absence of externally funded aquaculture projects).

The first impact resulting from IAA dissemination and adoption is a change in human capital (Fig. 7.2, 'Human capital'). Knowledge of farmers is enhanced through interaction with or training provided by extensionists from sources such as the Department of Fisheries, NGOs, scientists or fellow farmers. The very nature of the IAA technology is a farming systems approach that is tailored to the specific location and prevailing on-farm conditions (Molnar *et al.*, 1987). This means that training is mainly concerned with imparting underlying principles and concepts to farmers. At the same time, the FSRP approach explicitly includes farmers in the technology development and encourages adopters to experiment and adapt the technology to suit their individual situation and needs. This enhanced knowledge enables them to take a leading role in community organizations (e.g. the establishment of fish farmers' clubs), and in teaching other interested farmers and neighbours about integrated aquaculture. For example, Mr Nikoloma (of Thyolo District), Mr Chitonya and Mrs Kuunde (of Zomba District) are helping other farmers set up their ponds, advising them in pond management and in some cases providing fingerlings. Their success in IAA-based fish farming has influenced numerous other farmers in their villages to adopt IAA.

The second observed institutional impact is a change in the social structures and improvement in social capital (Fig. 7.2, 'Social capital'). IAA introduction strengthens social institutions such as fish farmers' clubs. In fish farmers' clubs farmers jointly establish and operate infrastructure such as small irrigation schemes, purchase inputs or sell produce together, and exchange knowledge and experiences. Such clubs were established in a number of villages, for example in Zomba East and Zomba West, Mawira and Kunenekude. These clubs are key mechanisms for spread-over and sustainability of newly adopted technologies. In many cases, NGOs support these groups by providing inputs or microcredits and technical expertise, but in other cases successful individual farmers voluntarily assume the role of an extension worker and advise other farmers in pond management. Progressive farmers usually gain social recognition, which is manifested by becoming the chairperson of the fish farmers' club for example, or an otherwise locally recognized authority and source of technical information. Such lead farmers are often already among the better-off farmers in the community. However, in some cases farmers of 'lesser social rank' can gain social stature within a community through displays of technical accomplishment and socially beneficial involvement, in particular when an 'exciting' innovation such as a cluster of fishponds is introduced.

Another change in institutions as a consequence of IAA introduction is the development of markets for fingerlings and fish as well as marketing or production cooperatives. In Mawira for example, 30 farmers who received training in IAA from the NGO World Vision produced and sold fingerlings in 2003. In Mulanja, OXFAM is promoting IAA technologies and purchases fingerlings from farmers that are then provided as inputs for new entrants from established fish farmers.

Finally, the FSRP approach applied for development and dissemination of IAA also had an impact on local governments and strengthened national institutions. The FSRP approach was incorporated into the Malawi Fisheries and Aquaculture Policy in 2000 and a Presidential Initiative on Aquaculture Development in Malawi was issued and signed by the President in early 2006 (DOF, 2006). RETs have been formed in all five fish-farming stations in southern Malawi and implementation of the policy is underway in other parts of the country. The RETs and fish farmers jointly design and test IAA technologies so that farmers become good 'extensionists' who encourage and advise other farmers in their communities on IAA.

Summary of Findings and Lessons Learned

This chapter examines the *ex post* impact of the development and dissemination of small-scale IAA technologies by the WorldFish Centre and its national and international partners in Malawi over more than 15 years. The results indicate that the adoption of IAA technology in Malawi has improved total farm productivity by 10%, increased per hectare farm income by 134% and total farm income by 61%, and improved the technical efficiency of farming by almost 40%. In addition, the increased per capita consumption of fresh fish by about 208% and per capita consumption of dried fish by 21% have resulted in an enhanced consumption of protein-rich food. IAA has improved the sustainability and environment of the adopters' farms, reduced nitrogen loss by half and improved nitrogen use efficiency. The development and dissemination of IAA technologies in Malawi have also institutionalized the natural resource management approach within the Malawi Department of Fisheries, strengthened local institutions and improved the overall welfare of both producers and consumers. The IRR from research and dissemination of IAA technologies in Malawi is at least 12.2%. This estimated rate of return is a very conservative estimate and does not include many of the positive non-market benefits of IAA technology such as impact on ecosystem health and local institutions.

Regression analyses show that better extension, higher amounts of training opportunities in IAA, better access to water, higher number of farm enterprises and bigger farm size have positively affected the adoption of IAA technologies in Malawi. While the results imply that it is the somewhat larger farmers (i.e. average farm area of 2 ha) that tended to adopt IAA technology, it does not necessarily mean that the technology is unsuitable for farmers with smaller landholdings. In fact, such farmers would be best suited since IAA would offer a safety-net effect in which farmers would improve their access to food in general and protein intake in particular. Moreover, the smallholder farmers would use the water to grow high-value crops, which would increase their on-farm income. The adoption by larger farmers suggests what has been observed in many other farming communities: small-scale farmers tend to be more averse to taking risks and are therefore not likely to be among the first to adopt new technology; instead, they follow a wait-and-see approach. Group- or community-based approaches and farmers' training help small-scale farmers to adopt IAA technologies more easily.

Through the development of IAA technologies, the WorldFish Centre has been able to clearly demonstrate the viability of aquaculture not only for the benefit of targeted communities, but also for whole countries. In fact, the results in Malawi have also provided a blueprint for the development and dissemination of IAA technologies elsewhere. Other African countries such as Zambia, Mozambique and Cameroon are currently adopting the IAA technology. At the same time, the FSRP approach to aquaculture technology development and transfer is also used in Cameroon and Zambia. This international spillover effect has not been quantified in this study.

One major reason for the Malawi project's success has been its inclusive nature. Instead of using a 'top-down' approach to technology dissemination, the WorldFish Centre has engaged directly with farmers, utilizing their resource base and recognizing the various constraints they face. One major institutional challenge to the implementation of the IAA approach has been the inadequate human and institutional capacity of the government institutes (e.g. Department of Fisheries, Malawi). It is therefore important to establish and strengthen partnerships with community-based organizations (such as NGOs and farmers' groups) to effectively develop and disseminate innovations such as IAA.

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References

Baker, J.D. (2003) Preliminary study on the spread of aquaculture technologies between farmers in Southern Malawi. In: *Aqua-Fish Technical Report 2*. Bunda College of Agriculture, Lilongwe, Malawi, pp. 42–45.

Banda, G.A. (1987) *Smallholder Aquaculture Development in Malawi: A Preliminary Socio-economic Study of Smallholder Fish Farming in Mwanza and Zomba Districts*. International Centre for Living Aquatic Resources Management Africa Office, Zomba, Malawi.

Battese, G.E. (1996) A note on the estimation of the Cobb–Douglas production function when some explanatory variables have zero values. *Journal of Agricultural Economics* 4892), 250–252.

Battese, G.E. and Coelli, T.J. (1995) A model for technical efficiency effects in a stochastic frontier production function for panel data. *Empirical Economics* 20(2), 325–332.

Brummett, R.E. (1999) Integrated aquaculture in sub-Saharan Africa. *Environment, Development and Sustainability* 1(3–4), 315–321.

Brummett, R. (2002) Realizing the potential of integrated aquaculture: evidence from Malawi. In: Uphoff, N. (ed.) *Agroecological Innovations: Increasing Food Production with Participatory Development*. Earthscan, London, pp. 115–124.

Brummett, R.E. and Chikafumbwa, F.J.K. (1999) An incremental farmer-participatory approach to the development of aquaculture technology in Malawi. *FAO Aquaculture Newsletter* (FAN) 23, 26–31.

Brummett, R.E. and Costa-Pierce, B.A. (2002) Village-based aquaculture ecosystems as a model for sustainable aquaculture development in sub-Saharan Africa. In: Costa-Pierce, B.A. (ed.) *Ecological Aquaculture: The Evolution of the Blue Revolution*. Blackwell Science, Oxford, UK, pp. 145–160.

Brummett, R.E. and Haight, B.A. (1996) Research–development linkages. In: Martinez-Espinosa, M. (comp.) *Report of the Expert Consultation on Small Scale Rural Aquaculture*. FAO Fisheries Report No. 548. Food and Agriculture Organization of the United Nations, Rome, pp. 145–169.

Brummett, R.E. and Noble, R.P. (1995a) Farmer–scientist research partnerships and smallholder integrated aquaculture in Malawi. In: Symoens, J.-J. and Micha, J.-C. (eds) *The Management of Integrated Freshwater Agro-piscicultural Ecosystems in Tropical Areas*. Technical Centre for Agricultural and Rural Cooperation, Wageningen, The Netherlands, pp. 443–454.

Brummett, R.E. and Noble, R.P. (1995b) *Aquaculture for African Smallholders*. ICLARM Technical Report 46. International Centre for Living Aquatic Resources Management, Manila and German Agency for Technical Cooperation, Eschborn, Germany.

Chikafumbwa, F.J.K. (1994) Farmer participation in technology development and transfer in Malawi. In: Brummett, R.E. (ed.) *Aquaculture Policy Options for Integrated Resource Management in Sub-Saharan Africa*. ICLARM Conference Proceedings 46. International Centre for Living Aquatic Resources Management, Manila, pp. 30–34.

Chimatiro, S.K. and Scholz, U.F. (1995) Integrated aquaculture–agriculture farming systems: a sustainable response towards food security for small-scale poor farmers in Malawi. Presented to the *Bunda College Aquaculture Symposium*, Lilongwe, Malawi, 11 February.

Dey, M.M., Briones, R. and Ahmed, M. (2005) Disaggregated analysis of fish supply, demand and trade: baseline model and estimation strategy. In: *Aquaculture Economics and Management 9*. 9(1–2), pp. 113–139.

DOF (2006) *Presidential Initiative on Aquaculture Development in Malawi*. Department of

Fisheries, Ministry of Mines, Natural Resources, and the Environment, Lilongwe, Malawi, February.

Edwards, P. (1998) A systems approach for the promotion of integrated aquaculture. *Aquaculture Economics & Management* 2(1), 1–12.

Edwards, P., Pullin, R.S.V. and Gartner, J.A. (1988) *Research & Education for the Development of Integrated Crop–Livestock–Fish Farming Systems in the Tropics*. ICLARM Studies & Reviews 16. International Centre for Living Aquatic Resources Management, Manila.

FAO (2004) *FishStat Plus – Universal Software for Fishery Statistical Time Series, Version 2.3*. Food and Agriculture Organization of the United Nations, Rome; available at http://www.fao.org/fi/statist/Fisoft/FishPlus (accessed August 2004).

Heckman, J.J., Ichimura, H., Smith, J. and Todd, P.E. (1998) Characterizing selection bias using experimental data. *Econometrica* 66(5), 1017–1098.

ICLARM and GTZ (1991) *The Context of Small-scale Integrated Agriculture–Aquaculture Systems in Africa: A Case Study of Malawi*. International Centre for Living Aquatic Resources Management, Manila and German Agency for Technical Cooperation, Eschborn, Germany.

Jamu, D.M. (2003) *Identification of Sediment Processes Regulating Nitrogen Use Efficiency and Retention in Integrated Aquaculture/Agriculture Systems*. Final report submitted to the African Career Awards, The Rockefeller Foundation, Nairobi.

Jamu, D.M. and Chimatiro, S. (2004) Sustainable agro-pisciculture in Malawi. *Entwicklung und Ländlicher Raum* 38(6), 27–28.

Lightfoot, C. and Noble, R.P. (2001) Tracking the ecological soundness of farming systems: instruments and indicators. *Journal of Sustainable Agriculture* 19(1), 9–29.

Lightfoot, C., Bimbao, M.P., Dalsgaard, J.P.T. and Pullin, R.S.V. (1993a) Aquaculture and sustainability through integrated resources management. *Outlook on Agriculture* 22(3), 143–150.

Lightfoot, C., Dalsgaard, J.P.T., Bimbao, M.P. and Fermin, F. (1993b) Farmer participatory procedures for managing and monitoring sustainable farming systems. *Journal of the Asian Farming Systems Association* 2(2), 67–87.

Lightfoot, C., Prein, M. and Lopez, T. (1994) Bioresource flow modelling with farmers. *ILEIA Newsletter* 10(3), 22–23.

Lightfoot, C., Bimbao, M.A.P., Lopez, T.S., Villanueva, F.F.D., Orencia, E.L.A., Dalsgaard, J.P.T., Gayanilao, F.C., Prein, M. and McArthur, H.J. (2000) *Research Tool for Natural Resource Management, Monitoring and Evaluation (RESTORE)*. Vol. 1. *Field Guide*. ICLARM Software Series 9 (Vol. 1). International Centre for Living Aquatic Resources Management, Manila.

Molnar, J.J., Duncan, B.L. and Hatch, L.U. (1987) Fish in the farming system: applying the FSR approach to aquaculture. *Research in Rural Sociology and Development* 3, AI Press, Greenwich, 169–193.

Noble, R. (1996) Wetland management in Malawi: a focal point for ecologically sound agriculture. *ILEIA Newsletter* 12(2), 9–11.

Pant, J., Demaine, H. and Edwards, P. (2005) Bio-resource flow in integrated agriculture–aquaculture systems in a tropical monsoonal climate: a case study in northeast Thailand. *Agricultural Systems* 83(2), 203–219.

Petry, A. (1996) *Status of Small-scale Aquaculture in the Southern Region of Malawi*. Malawi–German Fisheries and Aquaculture Development Project, Zomba, Malawi.

Prein, M. (2002) Integration of aquaculture into crop–animal systems in Asia. *Agricultural Systems* 71(1–2), 127–146.

Rauniyar, G.P. and Goode, F.M. (1996) Managing green revolution technology: an analysis of a differentiated practice combination in Swaziland. *Economic Development and Cultural Change* 44(2), 413–437.

Scholz, U. and Chimatiro, S. (1996) *The Promotion of Small-scale Aquaculture in the Southern Region of Malawi, a Reflection of Extension Approaches and Technology Packages used by the Malawi–German Fisheries and Aquaculture Development Project (MAGFAD)*. Vieh & Fisch, Abteilung 422. German Agency for Technical Cooperation, Eschborn, Germany.