ECONOMIC AND SOCIAL RETURNS TO TECHNOLOGY AND INVESTMENT IN THAILAND

Ninth Work Plan, Marketing and Economic Analysis Research 4 (9MEAR4)
Final Report

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ABSTRACT

Thailand has a long and rich history of aquaculture production. The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) has been involved in fish production research in Thailand since 1983. The economic impact of new technologies will depend upon farm-level benefits of the new technologies. However, if the new technologies require resources at a level not readily available to farmers, then the overall adoption rates and economic impacts will be lower. This study compares three aquaculture production technologies in Thailand with a fertilization technology developed by the PD/A CRSP to evaluate the farm-level economic impacts. Enterprise budgets were developed for each production technology. Price and cost data used in the analysis were pre-1998 data. These were used to formulate a whole-farm mathematical programming model. Farm resource levels specified in the model were based on survey data of small-scale fish farmers in northeastern Thailand. The production technologies evaluated included an extensive polyculture system that included tilapia, a more intensive polyculture of herbivorous fish including tilapia, monoculture of sex-reversed tilapia, and production of hybrid catfish. The enterprise budget analysis indicated that profits were highest for the tilapia monoculture system, second highest for the hybrid catfish production system, third highest for the more intensive polyculture system, and lowest for the extensive polyculture system. However, total annual costs were highest for hybrid catfish production, followed in descending order by tilapia monoculture and more intensive polyculture, and were lowest for the extensive polyculture system. The majority of the costs of catfish production were for the feed, whereas feed, fry, and fertilizer costs were the most important cost categories for tilapia monoculture production. Urea and triple superphosphate (TSP) costs were most important for the more intensive polyculture system, whereas manure was the greatest cost for extensive polyculture production. Results of the whole-farm mathematical programming analysis showed that if adequate resources exist on the farm, the optimal production mix is to stock all ponds in tilapia monoculture in order to maximize profits. However, when the model was constrained to the level of resources typically available on farms in northeastern Thailand, four of five ponds would be stocked in the extensive polyculture system with only one pond stocked in tilapia monoculture. Parametric analyses indicated that operating capital was the key limiting factor and constraint. Net returns increased dramatically as operating capital levels increased and the mix of production technologies moved more towards the more profitable tilapia monoculture production. The technologies were not labor intensive and the availability of labor did not change the mix of production activities, even at very low levels of labor. Yield of monosex tilapia production was also a key factor. The analysis indicated that a yield of 4,000 kg ha^{-1} constituted a threshold below which the production mix excluded tilapia monoculture and substituted the more intensive polyculture system. The price analysis showed that, if tilapia prices fell to Baht 27 kg^{-1}, the production mix would switch to the more intensive polyculture from tilapia monoculture. Feed and fertilizer prices, even at four times the level identified from the survey, did not affect the choice of production technology. Hybrid catfish production would only enter the mix if extremely high levels of operating capital were available and if the price of catfish were at least Baht 29 kg^{-1}.

INTRODUCTION

Farmers have raised aquaculture crops in northeastern Thailand for a number of years. The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) has conducted aquaculture research in Thailand since 1983. Much of the effort of the PD/A CRSP research program in Thailand has been on tilapia production technologies, with a specific emphasis on fertilization types and strategies. Studies have evaluated both organic and inorganic fertilizers including chicken manure (Knud-Hansen et al., 1993), urea (Knud-Hansen and Pautong, 1993), and triple superphosphate (TSP).

Organic pond fertilization with chicken manure requires more dissolved oxygen and was shown to produce a significantly higher fish yield when compared to inorganic fertilization alone (Diana et al., 1990). However, inorganic pond fertilization has a lower oxygen demand but adds high nutrient content (Yamada, 1986). PD/A CRSP researchers developed a fertilization strategy that has been referred to as high-input green water (HIGW) technology. HIGW production uses relatively intensive applications of urea and TSP. Shrestha et al. (1997) showed that HIGW technology using sex-reversed tilapia has produced yields of over 5,000 kg ha^{-1} yr^{-1}.

Engle and Skladany (1992) evaluated PD/A CRSP technologies utilizing chicken manure. Results showed that net returns increased by 85 and 98% for chicken manure collected for use on fish ponds and for chicken manure applied directly from integrated systems, respectively. Returns on average investment on ponds and equipment increased by 60 to 70%, while returns on average total investment (including land) increased by 5% by adopting CRSP technologies of chicken manure fertilization regimes.

The predominant type of fish culture system in northeastern Thailand can be classified as semi-intensive herbivorous fish culture (Phromthong and Demaine, undated). Within this general category, three different levels of intensification can be identified: extensive polyculture, a more intensive polyculture, and monoculture of sex-reversed tilapia. The extensive polyculture practiced in northeastern Thailand is used to culture fish primarily for household consumption. Small fingerlings (1 to 2 cm) of tilapia and other herbivorous species are stocked. Fish are fed only occasionally with agricultural by-products, and the ponds are fertilized on a limited basis with livestock manure. Production levels range from 375 to 500 kg ha^{-1} yr^{-1}.

The more intensive polyculture production system is used to produce fish for household consumption with some surplus for sale. Farmers using this type of production system release a larger size of fingerling (6 to 8 cm) or nurse small fry to fingerlings in net cages before releasing fingerlings into the grow-out pond. Inorganic fertilizers and manures are used to fertilize the pond, and some supplementary feed from agricultural by-products is fed. Production levels typically range from 1,562 to 2,188 kg ha^{-1} yr^{-1}.

Monoculture production of sex-reversed tilapia is destined primarily for sale. Combined with the PD/A CRSP fertilization strategies of intensive fertilization and management, yields can exceed 5,000 kg ha^{-1} yr^{-1}.

Hybrid catfish production can produce approximately 10 tons $farm^{-1}$ yr^{-1}. Most hybrid catfish is sold to provincial markets in the region. A farmer can produce as much as three crops a year of catfish.

METHODS

Enterprise budgets were developed for the four aquaculture production technologies (extensive polyculture, more intensive polyculture, hybrid catfish culture, and high-input monoculture of sex-reversed tilapia) based on standard techniques (Kay and Edwards, 1994). Production, cost, and price information were taken from Phromthong and Demaine (undated), Edwards et al. (1986), Engle and Skladany (1992), and Shrestha et al. (1997). Data used were pre-1998 data.

The enterprise budgets formed the basis for constructing a whole-farm mathematical programming model for a representative fish farm in northeastern Thailand. The objective of the model was to maximize annual net returns subject to a series of constraints. Each production technology constituted a potential production activity. An additional activity modeled is a fish sales submodel. Fish of different sizes sold in different types of markets will sell for different prices. The fish sales submodel accounts for these marketing differences. Other activities modeled include purchases of feed (for nursing fry and for grow-out), purchases of fertilizers (urea, TSP, and lime), and application of manure.

Constraints included the availability of land and labor. Appropriate balance constraints were included as needed. The availability of sex-reversed and catfish fingerlings were modeled as constraints in the model. Financial constraints included the availability of both operating and investment capital.

Each submodel was tested and validated independently and then in conjunction with the other submodels. The model was run with unconstrained levels of right-hand side variables. Once the consistency tests were completed, the right-hand side variables were adjusted to represent typical farms as defined by means encountered in the survey data reported by Phromthong and Demaine (undated).

The effect of varying levels of operating capital on the optimal mix of production activities was modeled by parameterizing the levels of operating capital in the model. Similar parameterizations were conducted for varying levels of investment capital, land, and labor.

Fish yield is frequently a key determinant of fish farm profitability. The effect of yield level of tilapia in the high-input monoculture of sex-reversed tilapia was evaluated by testing model results at ± 25, 50, and 75% of the mean yields reported in the literature. The availability of sex-reversed tilapia fry, a previously constraining factor in monosex tilapia production in Thailand, was evaluated by varying the right-hand side values in increments of 25,000 fry.

Fish prices, prices of the different fertilizers, and feed prices were subjected to sensitivity tests to evaluate the effect on optimal production mix of varying levels. Input prices were increased by as much as four times the average price, while fish prices were decreased incrementally to price levels that represented half of the average price.

RESULTS

The extensive polyculture production system utilized a very low level of inputs (Table 1). The primary input was animal manure in addition to some feed fed in the grow-out phase of production. In addition to these inputs, there was some amount of pond maintenance. In all, total annual variable costs were Baht (Bt) 1,550 per year. Of these, manure represented the largest resource utilized and represented the greatest cost. In these budgets, these costs represent opportunity costs of resource utilization because most of these inputs were obtained from the farm itself. An average of 437.5 kg of fish were produced per year. Given the relatively small size of fish, the market price, if sold locally, would be Bt 30 kg^{-1}. In reality most of these fish are consumed by the household. The estimated revenue represents an opportunity cost of the consumption of these fish and allows for a comparison of resource utilization with other, market-oriented fish production activities. The fish production then was estimated to have a value of Bt 13,125. After accounting for total annual costs, the net returns to operator's labor, management, land, and risk were Bt 12,335 ha^{-1}.

The more intensive polyculture system utilized higher levels of inputs and produced higher yields of fish (Table 2). In addition to higher levels of feed for both the nursery and grow-out phases of production and much higher levels of fertilizer, additional marketing costs were associated with marketing fish

Table 1. Annual costs and returns of extensive polyculture system utilized on small-scale fish farms in northeastern Thailand (1 ha pond).

Budget Items	Quantity (kg)	Price (Bt kg^{-1})	Value (Bt)	Percent of Total Variable Cost (%)
GROSS RETURNS	437.5	30.00	13,125	
VARIABLE COSTS				
Fry	0		0	0
Fingerlings	0		0	0
Fertilizer				
Urea	0		0	0
TSP	0		0	0
Lime	0		0	0
Manure	960.0	0.75	720	46
Feed				
Nursery	0	0	0	0
Grow-out	25.4	9.44	240	16
Labor				
Harvesting (Bt)	0		0	0
Pond Maintenance (Bt)	0		550	36
Marketing			0	0
TOTAL ANNUAL VARIABLE COSTS			1,550	
TOTAL ANNUAL COSTS			1,550	
NET RETURNS TO OPERATOR'S LABOR, MANAGEMENT, LAND, AND RISK (Bt ha^{-1})			12,335	

Table 2. Annual costs and returns of a more intensive polyculture system utilized on small-scale fish farms in northeastern Thailand (1 ha pond).

Budget Items	Quantity (kg)	Price (Bt kg^{-1})	Value (Bt)	Percent of Total Variable Cost (%)
GROSS RETURNS	1,875.0	40.00	75,000	
VARIABLE COSTS				
Fry	0		0	
Fingerlings	0		0	
Fertilizer				
Urea	1,332.0	5.00	6,660	30
TSP	872.0	8.00	6,976	31
Lime	766.0	1.00	766	3
Manure	1,920.0	0.75	1,440	6
Feed				
Nursery	297.6	11.80	3,512	16
Grow-out	25.4	9.44	240	1
Labor				
Harvesting (Bt)	0			0
Pond Maintenance (Bt)			2,550	11
Marketing	469.0	.08	38	0
TOTAL ANNUAL VARIABLE COSTS			22,181	
TOTAL ANNUAL COSTS			22,181	
NET RETURNS TO OPERATOR'S LABOR, MANAGEMENT, LAND, AND RISK (Bt ha^{-1})			52,819	

in nearby villages. Urea and TSP represented the greatest levels of inputs used, constituting 30 and 31%, respectively, of total variable costs. Total annual costs of production were Bt 22,181. The value of fish produced in this technology was Bt 75,000 yr^{-1}, generating annual net returns to operator's labor, management, land, and risk of Bt 52,819 ha^{-1}.

Hybrid catfish production required the highest level and usage of inputs (Table 3). Catfish ponds were fed intensively, and feed constituted 92% of all total variable costs of production. High numbers of fingerlings were stocked into the pond. Fertilizer application rates were moderate, but there were additional costs associated with harvesting the high weight of fish produced in the system. Total annual costs of production were Bt 2,172,612. However, given the 82,794 kg ha^{-1} of catfish produced, the gross returns were Bt 2,235,438, even at the relatively low price of Bt 27 kg^{-1} for catfish. Thus, hybrid catfish appears to be profitable, and it generated net returns to operator's labor, management, land, and risk of Bt 62,826 ha^{-1}.

Monoculture of sex-reversed tilapia with high-input inorganic fertilization strategies utilized more moderate levels of input resources when compared with that of hybrid catfish (Table 4). Fry stocked into nursery phases were less than the number of catfish fingerlings stocked. However, fertilizer rates and costs were higher, especially the manure application rates. Feed levels were lower than those for hybrid catfish production, but higher than those for the more intensive polyculture production. Total annual variable costs were Bt 61,032 yr^{-1}. With the 6,022 kg ha^{-1} of tilapia produced, gross revenues were Bt 240,880 yr^{-1}, generating net returns to operator's labor, management, land, and risk of Bt 179,848 ha^{-1}.

Thus, the enterprise budget analysis indicated that profits were highest for the tilapia monoculture system, second highest for the hybrid catfish production system, third highest for the more intensive polyculture system, and lowest for the extensive polyculture system. However, total annual costs were highest for hybrid catfish production, followed in descending order by tilapia monoculture and the more intensive polyculture, and were lowest for the extensive polyculture system. The majority of the costs of catfish production were for the feed, whereas feed, fry, and fertilizer costs were the most important cost categories for tilapia monoculture production. Urea and TSP costs were most important for the more intensive polyculture system, whereas manure was the greatest cost for extensive polyculture production.

Table 5 presents results of the whole-farm mathematical programming analysis when resources are not constrained. In this case the optimal production mix is to stock all ponds in tilapia monoculture in order to maximize profits. Net returns in this scenario are Bt 540,988 yr^{-1}.

However, in reality, farms do not have access to unlimited resource levels. When the model was constrained to those levels of resources identified by survey data of farms in northeastern Thailand, the solution changed (Table 6). Only one pond was put into tilapia monoculture with high-input inorganic fertilization methods, and the remaining four were stocked in the extensive polyculture production system. Net returns decreased to Bt 245,810 yr^{-1}. The key constraint to production in this scenario was the level of operating capital. In other words, the farm did not have adequate operating capital to put more than one pond into the more profitable tilapia monoculture system and substituted the extensive polyculture system that required only very low levels of operating capital.

Varying the amounts of operating capital available resulted in the selection of different mixes of optimal production tech-

Table 3. Annual costs and returns of hybrid catfish production for small-scale fish farms in northeastern Thailand (1 ha pond).

Budget Items	Quantity (kg)	Price (Bt kg^{-1})	Value (Bt)	Percent of Total Variable Cost (%)
GROSS RETURNS	82,794	27.000	2,235,438	
VARIABLE COSTS				
Fry	0			
Fingerlings	1,324,700	0.100	132,470	6
Fertilizer				
Urea	859	5.000	4,295	0
TSP	562	8.000	4,496	0
Lime	494	1.000	494	0
Manure	828	0.750	621	0
Feed				
Nursery	0	11.800	0	0
Grow-out	211,061	9.440	1,992,416	92
Labor				
Harvesting (Bt)	82,794	0.270	22,354	1
Pond Maintenance (Bt)			2,550	0
Marketing	82,794	0.156	12,916	1
TOTAL ANNUAL VARIABLE COSTS			2,172,612	
TOTAL ANNUAL COSTS			2,172,612	
NET RETURNS TO OPERATOR'S LABOR, MANAGEMENT, LAND, AND RISK (Bt ha^{-1})			62,826	

Table 4. Annual costs and returns of the high-input inorganic fertilization tilapia production system for small-scale fish farms in northeastern Thailand (1 ha pond).

Budget Items	**Quantity** (kg)	**Price** (Bt kg^{-1})	**Value** (Bt)	**Percent of Total Variable Cost** (%)
GROSS RETURNS	6,022	40.00	240,880	
VARIABLE COSTS				
Fry	25,000	0.50	12,500	20
Fingerlings	0		0	0
Fertilizer				
Urea	1,719	5.00	8,595	14
TSP	1,125	8.00	9,000	15
Lime	988	1.00	988	2
Manure	12,431	0.75	9,323.25	15
Feed				
Nursery	297.6	11.80	3,511.68	6
Grow-out	1,476.5	9.44	13,938.16	23
Labor				
Harvesting (Bt)	0		0	0
Pond Maintenance (Bt)			2,550	4
Marketing	6,022	0.104	626	1
TOTAL ANNUAL VARIABLE COSTS			61,032	
TOTAL ANNUAL COSTS			61,032	
NET RETURNS TO OPERATOR'S LABOR, MANAGEMENT, LAND, AND RISK (Bt ha^{-1})			179,848	

Table 5. Mathematical programming results when resources are not constrained.

Item	**Value**
Net Returns (Bt yr^{-1})	540,988
Number of Ponds Used (n)	5
Production System Selected	High-Input Inorganic Fertilization
Monosex Tilapia Fry Purchased (n)	116,822
Urea Purchased (kg)	8,033
TSP Purchased (kg)	5,257
Lime Purchased (kg)	4,617
Animal Manure Used (kg)	58,005
Tilapia Sold (kg)	28,140
Fry Feed Purchased (kg)	1,391
Grow-out Feed Purchased (kg)	6,900
Grow-out Labor Used (h)	234
Harvesting Labor Used (h)	56
Pond Maintenance Cost (Bt)	11,916
Investment Capital (Bt)	30,000

Table 6. Results of mathematical programming analysis of model with resources limited to mean values as identified in Phromthong and Demaine (undated).

Item	**Value**
RESOURCE AVAILABILITY LIMITS	
Land (ha)	5
Labor (h)	7,488
Operating Capital (Bt)	75,000
Investment Capital (Bt)	30,000
MODEL SOLUTION	
Net Returns (Bt yr^{-1})	245,810
Ponds Used (n)	
High-Input Inorganic Fertilization	1
Extensive Polyculture	4
Tilapia Sales (kg)	
Locally	1,672
District	7,102
Key Constraint: Operating Capital	

nologies (Figure 1). Decreasing operating capital to Bt 25,000 resulted in stocking all five ponds in the extensive polyculture system. Increasing available operating capital above the Bt 75,000 mean value resulted in additional ponds stocked with tilapia monoculture. At the highest rates analyzed (Bt 250,000), four ponds were stocked in tilapia monoculture and only one stocked in the extensive polyculture system. Net returns also increased with increasing levels of operating capital available (Figure 2).

Varying the level of investment capital available to the farmer between Bt 14,000 and Bt 50,000 did not affect the choice of optimal production mix. However, at investment capital levels of Bt 13,000, the production mix switched to only three ponds in extensive polyculture while still keeping one pond in tilapia monoculture. As investment capital levels were lowered even farther, additional ponds were taken out of production. At investment capital levels of Bt 5,000 to 8,000, only one pond was put into production and that one was stocked in tilapia monoculture. These results indicate that it was more profitable to use the limited investment capital resources to produce the more profitable tilapia monoculture than to have more ponds in extensive polyculture. In this parameterization analysis, operating capital was held constant at Bt 75,000, so there was adequate operating capital to manage the one pond in tilapia monoculture throughout this analysis.

Figure 3 shows the results of the analysis parameterizing the level of land available to the farmer while holding all other values constant. With increasing amounts of land, additional ponds were put into extensive polyculture because, with the mean value of operating capital available, there was insufficient operating capital to add more tilapia monoculture ponds.

The technologies modeled in this analysis were not labor intensive. The parameterization analyses of land availability did not change the mix of production activities, even at very low levels of labor.

Yield of tilapia in the high-input monoculture system was a determining factor in its selection in the profit-maximizing mix of production activities (Figure 4). The analysis indicated that a yield of 4,000 kg ha^{-1} constituted a threshold below which the production mix excluded tilapia monoculture and substituted the more intensive polyculture system. The 4,000 kg ha^{-1} yr^{-1} production level represented a reduction of more than 25% from the average yield reported from survey data. This threshold also represented a sharp decrease in net returns from this production activity.

Reductions in the availability of sex-reversed tilapia fry did not have a dramatic impact until the low level of 25,000 fry per farm. At this level some hectareage began to switch to the more intensive polyculture system from the high-input tilapia monoculture production system (Table 7).

The price analysis showed that, if all tilapia prices were the same for local, village, and provincial markets, tilapia monoculture would still be the profit-maximizing option. However, if tilapia prices fell to Bt 27 kg^{-1}, the production mix would switch to the more intensive polyculture from tilapia monoculture. Feed and fertilizer prices, even at four times the level identified from the survey, did not affect the choice of production technology.

Hybrid catfish production never entered the profit-maximizing mix of production activities in this analysis. Catfish production is resource-intensive but not as profitable as tilapia monocul-

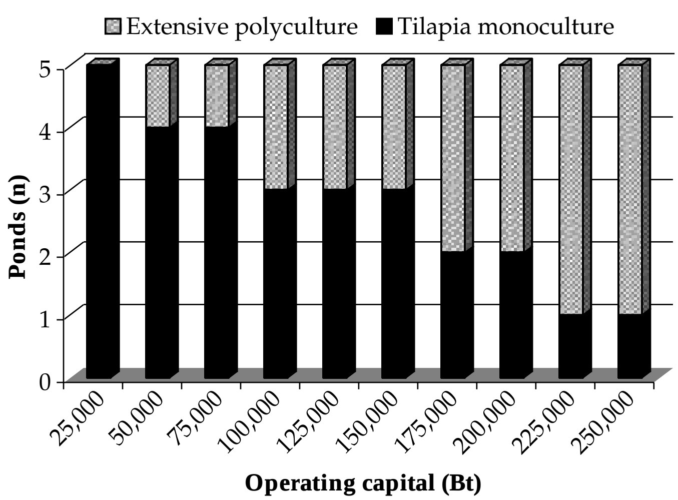

Figure 1. Optimal mix of tilapia production technologies at varying levels of operating capital availability.

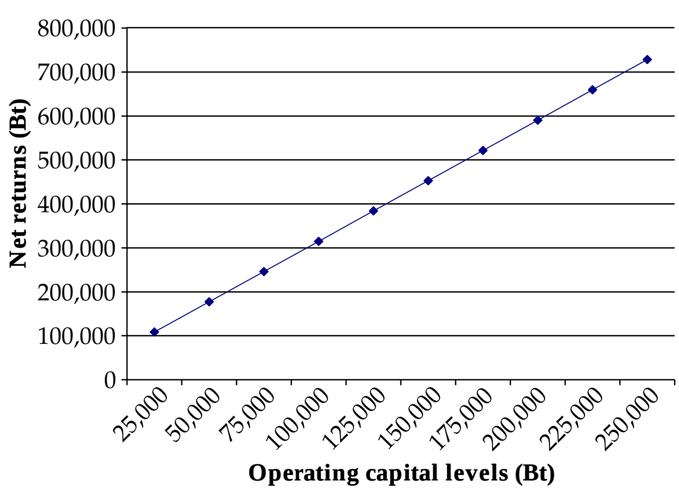

Figure 2. Net returns at different levels of operating capital availability.

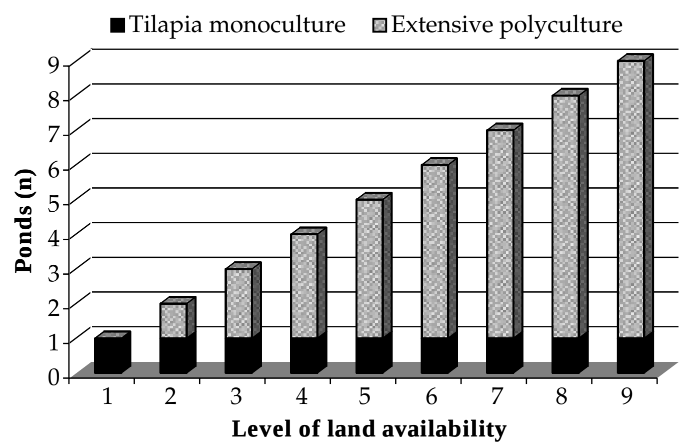

Figure 3. Optimal mix of tilapia production technologies at varying levels of land availability.

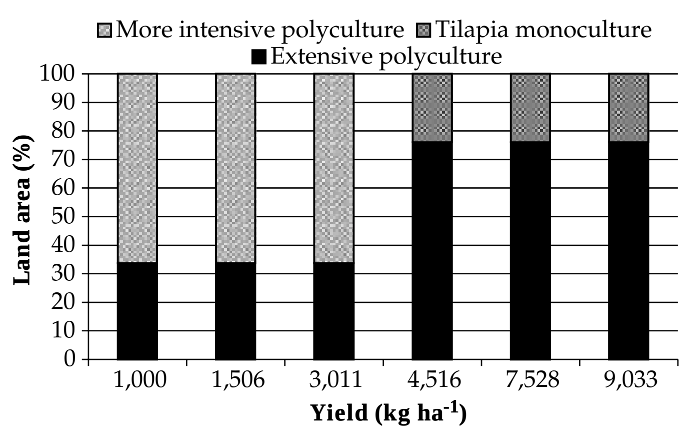

Figure 4. Optimal mix of tilapia production technologies with varying yields of monosex tilapia.

Table 7. Optimal mix of tilapia production technologies with varying levels of availability of sex-reversed tilapia.

Level of Availability of Sex-Reversed Tilapia Fry	**Net Returns** (Bt ha^{-1} yr^{-1})	**Production Technology** (ha of ponds)		
		Extensive Polyculture	*More Intensive Polyculture*	*High-Input Inorganic Fertilization*
25,000	236,039	3.5	0.5	1.0
50,000	245,810	3.8	0	1.2
75,000	245,810	3.8	0	1.2
100,000	245,810	3.8	0	1.2
125,000	822,390	3.8	0	1.2

ture. It may be that market demand for more diverse types of fish would limit the quantities of tilapia sold such catfish would begin to enter the mix of activities. In additional simulations, hybrid catfish production would enter the mix only if extremely high levels of operating capital were available and if the price of catfish were at least Bt 29 kg^{-1}.

DISCUSSION

The PD/A CRSP technologies developed to improve fertilization techniques and to produce sex-reversed tilapia fry result in strong economic incentives for adoption of this technology. Nevertheless, this analysis is based upon pre-1998 data in Thailand. Additional analysis is needed to evaluate the impacts of the 1998 economic change on cost and price relationships.

CONCLUSIONS

The combination of more intensive fertilization practices with monoculture of sex-reversed tilapia resulted in the most profitable production technology of those evaluated. Thus, the impact of the PD/A CRSP technologies is likely to be quite high. Nevertheless, this technology is strongly constrained by the availability of operating capital. In the absence of adequate levels of operating capital, the farmers revert to the very extensive type of traditional types of aquaculture. At the mean levels of operating capital from the survey data, the farm was restricted to putting only one pond into the more profitable tilapia monoculture system. Thus, financial conditions in the country will likely restrict the adoption, implementation, and impact of this technology.

ANTICIPATED BENEFITS

The economic impact of new technologies will depend upon farm-level benefits of the new technologies. Yet the resource requirements of new technologies, farm availability of resources, farm economic structure, and other considerations may prevent adoption of new technologies. The principal benefit of this project was to shed light on the economic incentives and trade-offs among the traditional aquaculture production systems, CRSP-developed technologies, and a very intensive aquaculture pond enterprise. This will provide guidance for the direction of CRSP research in terms of the types of inputs and management systems that are likely to have the highest rates of adoption among farmers.

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Cite as: [Author(s), 2002. Title.] In: K. McElwee, K. Lewis, M. Nidiffer, and P. Buitrago (Editors), Nineteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]