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Economic and Social Returns to Technology and Investment in Thailand

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Progress Report

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Abstract

The first phase of this study was to conduct an analysis of the economic trade-offs associated with PD/A CRSP-developed technologies in Thailand using secondary data. This paper outlines conditions under which a small-scale tilapia producer in Thailand chooses among four PD/A CRSP–developed technologies: low-intensity inorganic fertilization (inorganic technology); organic fertilization with collected chicken manure (organic technology); organic fertilization in layer-fish integrated ponds (integrated technology); and high-input green water (HIGW) technology using intensive inorganic fertilization treatments. A mixed-integer programming (MIP) model of annual operations of a small-scale Thai tilapia farm was developed and used to attribute technologies to the production ponds based on maximization of net income. Eleven scenarios were developed that were based on the advantages of each of the four technologies. Results of this first-phase analysis will provide important insights into the key relationships to be explored in the survey data collection phase. The following progress report presents the results of the analysis conducted in Phase I and a draft of the survey instrument to be used in data collection in the second phase. (A draft of this survey may be obtained from the PD/A CRSP—Eds.)

Introduction

Factors Affecting the Choice of Production Technology in Small-Scale Tilapia Farms in Thailand

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) has been involved in fish production research in Thailand since 1983 (Engle and Skladany, 1992). Much of this effort has been focused on improving traditional tilapia culture technologies and developing new technologies that are accessible to Thai farmers. The goal of this paper is to identify conditions that influence a producer's choice of alternative tilapia technologies.

PD/A CRSP research on tilapia production in Thailand included topics such as

1) Relationships between primary production and yield of tilapia in ponds (Diana et al., 1988);
2) The role of chicken manure in the production of Nile tilapia (*Oreochromis niloticus*) (Knud-Hansen et al., 1993); and
3) The role of urea in pond fertilization (Knud-Hansen and Pautong, 1993).

As a result of these and other studies, several alternative tilapia culture technologies were developed. Examples of such technologies include low-intensity inorganic pond fertilization, organic pond fertilization with chicken manure, and high-input green water (HIGW) technology using relatively intensive applications of urea and triple superphosphate (TSP). Inorganic pond fertilization has the advantages of high nutrient content and low oxygen demand (Yamada, 1986). Organic pond fertilization with chicken manure requires more dissolved oxygen and has the advantage of producing significantly higher fish yields when compared to inorganic fertilization alone (Diana et al., 1990). The HIGW technology, using sex-reversed tilapia, has produced yields of over 5,000 kg ha^{-1} yr^{-1}, more than a tenfold increase over yields from traditional farms using ruminant manure and other organic farm refuse (Shrestha et al., 1997). In the face of such variety, producer choice of technology will depend on several factors that include fish yield, input prices, input availability, and financial considerations. Results of this paper will be useful in assisting Thai tilapia producers to choose the optimal technology under various production, market, and financial conditions.

Methods and Materials

Secondary data from four tilapia pond production technologies were available for this study:

1) Tilapia polyculture (TP) with mrigal (*Cirrhina mrigala*), puntius (*Puntius gonionotus*), silver carp (*Hypophthalmichthys molitrix*), and common carp (*Cyprinus carpio*) using low-intensity inorganic fertilization only;
2) TP using organic fertilization by applying collected (or purchased) chicken manure;
3) TP in layer-fish integrated ponds with chicken coops (with fresh manure and spilled feed dropping directly into ponds); and
4) Tilapia monoculture using HIGW technology and sex-reversed tilapia fingerlings.

The above production technologies are denoted hereafter as 1) inorganic, 2) organic, 3) integrated, and 4) HIGW, respectively.

Engle and Skladany's (1992) study of the economic benefits of using chicken manure in Thai tilapia polyculture provided annual production and price data for the inorganic, organic, and integrated technologies. Information about HIGW technology is available in Shrestha et al. (1997). Table 1 provides a summary of annual fish yield, inputs used, and cost associated with the four technologies. Prices are 1990 annual input and output prices in Thai Baht (1 Baht = US$0.04) from Engle and Skladany (1992). Table 1 shows that tilapia polyculture with the inorganic technology has the lowest yields, followed by tilapia monoculture with HIGW technology. However, the HIGW technology requires much lower fish stocking density when compared with the remaining technologies. Table 1 also shows that the integrated technology provides farmers with three sources of income: fish, eggs, and hens. The costs and benefits of having egg-laying hens in the integrated technology were calculated from Engle and Skladany's (1992) report.

The above data were used to develop a mixed-integer mathematical programming model (MIP) of annual operations of a Thai fish farm, assuming a producer has access to the above four technologies and also has the option of taking ponds out of production. The objective was to maximize net annual returns subject to the following constraints:

1) A pond balance constraint, which ensures that the total number of ponds stocked with fish (or out of production) is equal to the number of ponds in the farm;
2) Fingerling balance constraints, which account for the total number of fingerlings of each fish species stocked in all ponds;
3) Urea and TSP balance constraints, which account for the total use of inorganic fertilizers in all ponds; and
4) Financial constraints.

The financial constraints can be subdivided into loan balance constraints and a loan repayment constraint. The loan balance constraints evaluate the total amount of operating loans and investment loans that a producer must have in order to finance variable input purchases and new capital (e.g., chicken coops over ponds as are used in the integrated technology approach). The loan repayment constraint ensures that the total annual revenue is sufficient to pay back the operating loan (with interest), make annual payments on the investment loan, and cover the annual capital depreciation. We assume that net returns are calculated as returns above fixed costs, and the only capital payments included in the MIP model are associated with construction of chicken coops on ponds using the integrated technology.

Engle and Skladany's (1992) report indicated that a 1-ha pond using the integrated technology has approximately 1,100 hens housed in three bamboo coops (3 m × 18 m × 1.5 m) that cost 21,000 Baht (5-yr service life). Other capital expenditures associated with layer-fish integrated ponds are:

1) Coop roofs (3-yr service life), which require 4,500 Baht;
2) Plastic netting (1-yr service life), which requires 120 Baht; and
3) 45 feed trays (3-yr service life), 45 water trays (3-yr service life), 105 baskets (2-yr service life), and electric wiring and bulbs (10-yr service life), all of which require an additional 6,125 Baht investment.

The total capital investment in chicken coops accumulates to 31,745 Baht per 1-ha pond.

Table 1. Annual yield received and variable inputs applied in a 1-ha pond with respect to four alternative tilapia production technologies: ponds using low-intensity inorganic fertilizers (inorganic); ponds using collected (or purchased) chicken manure (organic); ponds integrated with layers (integrated); and high-input green water ponds (HIGW). All prices are in 1990 Thai Baht (1 Baht = US$0.04).

Output	Units	Inorganic		Organic		Integrated		HIGW	
		Quantity	*Price* (Baht unit^{-1})	*Quantity*	*Price* (Baht unit^{-1})	*Quantity*	*Price* (Baht unit^{-1})	*Quantity*	*Price* (Baht unit^{-1})
YIELD									
Total Fish Yield[a]	kg	4,646	12	6,034	12	6,034	12	5,049	12
Hens	head					1,100	40		
Eggs[a]	head					277,200	1.45		
VARIABLE INPUTS									
Fingerlings									
Tilapia	head	90,520	0.10	90,520	0.1	90,520	0.1	25,000	0.1
Mrigal	head	129,310	0.05	129,310	0.05	129,310	0.05		
Puntius	head	12,930	0.05	12,930	0.05	12,930	0.05		
Silver Carp	head	8,620	0.15	8,620	0.15	8,620	0.15		
Common Carp	head	17,241	0.15	17,241	0.15	17,241	0.15		
Lime	kg	43	6	43	6	43	6	1,250	6
Urea	kg	43	7					1,593	7
TSP	kg	143	12					910	12
Collected Manure	kg			9,600	0.25				
Chicken Feed	kg					Cost[b]: 213,175 Baht (1,100 hens)$^{-1}$			
Chicken Vaccines	vial					10	100		
Electricity for Chickens	months					12	100		
Diesel	l	43	12	43	12	43	12	43	12
Rent for Plastic Net	d	6	100	6	100	6	100	6	100

Source: Engle and Skladany (1992) and Shrestha et al. (1997).

[a] These are expected values.

[b] Chicken feed for the first year consisted of: 1) 1.09 kg chicken^{-1} of commercial feed I (7.16 Baht kg^{-1}) for the first six weeks; 2) 0.82 kg chicken^{-1} of commercial feed II (10.16 Baht kg^{-1}), 0.41 kg chicken^{-1} of corn grain (3.5 Baht kg^{-1}), and 1.36 kg chicken^{-1} of fine rice bran (4.3 Baht kg^{-1}) for the next six weeks; and 3) 7.64 kg chicken^{-1} of commercial feed III (10.16 Baht kg^{-1}), 15.27 kg chicken^{-1} of medium rice bran (2.4 Baht kg^{-1}), 5.09 kg chicken^{-1} of fine rice bran (4.3 Baht kg^{-1}), 8.91 kg chicken^{-1} of broken rice (3.5 Baht kg^{-1}), and 0.26 kg chicken^{-1} of minerals (12 Baht kg^{-1}) for the remaining 40 weeks.

The objective function is expressed as the difference of total annual payments (i.e., the sum of variable costs, annual interest payment on the operating loan, and the annual payment on the investment loan) from the total annual revenue. Variable inputs (outlined in Table 1) include fingerlings, chicken manure, urea, TSP, lime, diesel, electricity, chicken feed, and chicken vaccines. Annual revenue per pond is calculated for each technology by using the output quantity and price data contained in Table 1. Since ponds devoted to the integrated technology include hens that produce eggs for two years, a terminal condition is included in the objective function, which accounts for the current value of future returns over variable costs of selling eggs and hens during the following year.

The MIP model was developed for a farm with two 1-ha ponds. Such farm sizes are not atypical of small-scale Thai aquaculture; Shrestha et al. (1997) reported an average farm size of 3.4 ha among the farms participating in trials of the HIGW technology. Decision variables for the MIP model include the number of ponds (integer variables) that are devoted to one of the four possible technologies or are taken out of production. Other decision variables include the total quantity of fingerlings, urea, and TSP purchased during the year, and the amount of operating and investment loans taken by the producer. We also assumed a fixed annual interest rate of 12% (Engle and Skladany, 1992).

RESULTS

Annual operating costs (per 1-ha pond) under each technology are evaluated from Table 1 as follows (operating costs of ponds with no liming are included in parentheses): 1) 23,435 Baht (23,177 Baht) for inorganic technology; 2) 23,818 Baht (23,560 Baht) for organic technology; 3) 245,593 Baht (245,335 Baht) for integrated technology; and 4) 33,183 Baht (25,683 Baht) for HIGW technology. Clearly, integrated ponds are the most expensive to operate. Ponds using the inorganic technology are the least expensive to operate, followed by ponds using the organic technology. Gross income per pond from each technology can also be evaluated from Table 1 (in ascending order): 55,352 Baht (inorganic technology); 60,588 Baht (HIGW technology); 72,408 Baht (organic technology); and 474,348 Baht (integrated technology).

Table 2 reports the results of solving the MIP model for 11 different scenarios. Consistent with the goals of this paper, we designed the scenarios to determine input availability conditions, input price conditions, and financial conditions that would induce producers to select different technologies based on maximizing their expected net annual income.

In the first scenario all decision variables are unbounded, i.e., there is an infinite availability of fingerlings, chemicals, and loan funds. Results of the MIP model show that a producer should use layer-fish integration in both ponds for a net annual return of 673,583 Baht. Since Table 1 indicates that the integrated technology has the highest income potential, this result is not surprising. Scenarios 2, 3, and 4 impose upper bounds on the operating loan and investment loans. If the maximum operating loan is 246,000 Baht (scenario 2), given that the annual variable costs per pond with integrated technology is 245,593 Baht, then the optimal solution is to use layer-fish integration in one pond and leave the other pond empty. Although a 246,000 Baht operating loan is sufficient to put both ponds in production using the inorganic, organic, or HIGW technology, that loan amount is insufficient for having two production ponds if one pond uses the integrated technology. Hence, scenario 2 results are indicative of the income superiority of the integrated technology over the other three technologies. Scenarios 3 and 4 establish an upper bound for an investment loan (although an unlimited operating loan is available). In scenario 3, the investment loan is restricted between 63,490 Baht and 31,745 Baht. Since 63,490 Baht is required for capital investments in two ponds using the

Table 2. Annual net income, operating loan, and investment loan of a Thai tilapia farm with two 1-ha ponds.

	Scenario	Solution	Net Income (Baht)	Operating Loan (Baht)	Investment Loan (Baht)
1	No bound on any decision variable.	2 ponds: integrated	673,582	491,184	63,490
2	Operating loan bounded above by 246,000 Baht.	1 pond: integrated, 1 pond: empty	336,791	245,592	31,745
3	Investment loan restricted between 63,490 Baht and 31,745 Baht.	1 pond: integrated, 1 pond: organic	383,953	269,409	31,745
4	Investment loan restricted to be less than 31,745 Baht.	2 ponds: organic	94,923	47,634	0
5	Operating loan bounded above by 245,000 Baht.	2 ponds: organic	94,923	47,634	0
6	Operating loan bounded above by 245,000 Baht. Manure price increases to 1.39 Baht kg^{-1}.	2 ponds: HIGW	71,250	66,367	0
7	Operating loan bounded above by 245,000 Baht. All fingerling prices increased by 63%.	2 ponds: HIGW	67,911	69,517	0
8	Operating loan bounded above by 245,000 Baht. Upper bound on tilapia fingerling availability: between 181,040 and 115,520.	1 pond: organic, 1 pond: HIGW	82,787	57,001	0
9	Operating loan bounded above by 245,000 Baht. Upper bound on tilapia fingerling availability: between 90,520 and 115,520.	2 ponds: HIGW	71,250	66,367	0
10	Operating loan bounded above by 47,000 Baht.	2 ponds: inorganic	61,823	46,868	0
11	Operating loan bounded above by 47,000 Baht, no liming of ponds.	1 pond: inorganic, 1 pond: organic	78,620	46,735	0

integrated technology (a 31,745 Baht capital investment is required for one integrated pond), scenario 3 allows only one pond to be managed under the integrated technology. The second pond is managed using the organic technology. If the maximum investment loan falls below 31,745 Baht (scenario 4), insufficient funds are available to invest in chicken coops on either of the two ponds. Hence, in scenario 4 both ponds are managed under the organic technology.

Scenario 5 is related to scenario 2; the maximum available operating loan is restricted to 245,000 Baht, which is insufficient for a pond to be stocked using the integrated technology. The MIP model chooses both ponds to be managed under the organic technology. Hence, scenarios 4 and 5 indicate that if operating and investment loans are restricted such that insufficient funds are available for the integrated technology, *ceteris paribus*, a producer should manage both ponds using the organic technology, provided sufficient funds are available to implement the inorganic, organic, and HIGW technologies.

Scenarios 6 and 7 were designed to evaluate conditions additional to scenario 5, under which the producer should opt for the HIGW technology instead of the organic technology. Since chicken manure is purchased for ponds using organic technology, sufficiently high manure prices might make inorganic or HIGW technologies more profitable. In scenario 6, the results indicate that manure prices must increase from 0.25 Baht kg^{-1} (Engle and Skladany, 1992) to 1.39 Baht kg^{-1} in order for the HIGW technology to generate a greater expected profit than the organic technology. Similarly, scenario 7 was designed with the notion that since fingerling expenditure is lowest in HIGW technology, producers may select the HIGW over the organic technology if fingerling prices increase. Results of the MIP model indicate that for the organic to HIGW technological shift to occur, all fingerling prices must increase by at least 63%.

Scenarios 8 and 9 were intended to study the specific conditions associated with restricting the availability of fingerlings in order for producers to select the HIGW technology over the organic technology. Similar to scenario 7, these conditions were based on relatively low stocking requirements of the HIGW technology: 25,000 tilapia fingerlings ha^{-1} compared to 90,520 tilapia fingerlings ha^{-1} in the other three technologies. Scenario 8 is identical to scenzario 5, except an upper bound is imposed on the availability of tilapia fingerlings. The MIP model's solution is unchanged from scenario 5, provided sufficient tilapia fingerlings are available for stocking both ponds using the organic technology. If the tilapia fingerling availability drops between 181,040 and 115,520 fingerlings (scenario 8), one pond is managed using the organic technology and the other pond using the HIGW technology. In scenario 9, the tilapia fingerling availability is further reduced between 90,520 and 115,520 fingerlings. Under these conditions, there are insufficient fingerlings for stocking two ponds, such that at least one pond could be managed by the organic technology. Instead, the MIP model chooses both ponds to be managed using the HIGW technology. Similarly, if the availability of mrigal, puntius, silver carp and common carp fingerlings were sufficiently reduced, the results show that only the HIGW technology should be implemented.

The inorganic technology was not optimal in any of the above scenarios. As indicated above, the inorganic technology has the advantage of requiring the lowest annual operating investment of all four technologies; however, this technology suffers from producing the lowest expected annual revenue. Hence, whenever production and financial resources were sufficient, the MIP model rejected the inorganic technology in favor of the other three technologies. Scenarios 10 and 11 investigate conditions under which the inorganic technology might enter the solution. In scenario 10, the upper bound of the operating loan is reduced to 47,000 Baht, making it impossible for a farmer to keep both ponds in production unless one pond uses a non-inorganic technology. Only under such stringent conditions does the MIP model select the inorganic technology as an optimal solution. The low-income attribute of the inorganic technology is also highlighted in a 61,824 Baht net return in scenario 10, the lowest net return of all 11 scenarios. Scenario 11, an extension of scenario 10, requires no liming of ponds. Since liming is typically a function of soil characteristics, the liming regimen reported in Engle and Skladany (1992) and Shrestha et al. (1997) need not be representative of all fish farms in Thailand. If lime is not applied, *ceteris paribus*, the operating costs under organic and inorganic technologies decrease sufficiently for one pond to be managed using the organic technology and the other pond to be managed using the inorganic technology.

DISCUSSION AND CONCLUSIONS

This paper outlines conditions under which a small-scale tilapia producer in Thailand chooses among four PD/A CRSP–developed technologies: low-intensity inorganic fertilization (inorganic technology); organic fertilization with collected chicken manure (organic technology); organic fertilization in layer-fish integrated ponds (integrated technology); and high-input green water (HIGW) technology using intensive inorganic fertilization treatments. A mixed-integer programming (MIP) model of annual operations of a small-scale Thai tilapia farm was developed and used to attribute technologies to the production ponds based on maximization of net income. Eleven scenarios were developed that were based on the advantages of each of the four technologies. For example, the low-intensity inorganic fertilization technology has the advantage of having the lowest operating costs. The organic fertilization technology using collected chicken manure has the advantages of simultaneously having the second-lowest operating costs and the second-highest revenues. The HIGW technology has the advantage of requiring the lowest stocking density of all four technologies. The layer-fish integrated ponds technology has the advantage of generating the highest revenues of all four technologies.

Of these technologies, ponds with layer-fish integration provide the greatest net returns. However, implementing such technology necessitates relatively heavy operating and investment loans. When farmers are restricted by the amount that they can borrow, the results of the MIP model indicate organic fertilization with collected chicken manure to be their optimal choice.

Scenarios 6, 7, 8, and 9 in Table 2 outline conditions under which a farmer might shift from using the organic technology to HIGW technology. Scenarios 6 and 7 show that producers would be better off using the organic technology unless there is a relatively massive increase in chicken manure price or fingerling price. Scenarios 9 and 10 report that producers might opt for HIGW technology if there is an insufficient supply of fingerlings to implement the high stocking demands of the organic technology.

Scenarios 10 and 11 illustrate conditions under which the low-intensity inorganic fertilization technology might be chosen as optimal. Given that this technology has the lowest operating costs, the MIP model chooses this technology only when the maximum operating loan is insufficient to select another technology. Use of this technology always results in the lowest net returns.

Hence, the conclusions of this paper are that tilapia producers using PD/A CRSP–developed technologies would be better off by restricting their choice to organic fertilization of ponds using chicken manure. They should choose the high-input green water technology only when there are severe restrictions to the availability of fingerlings.

Anticipated Benefits

This study provides insights into the economic trade-offs associated with four pond production technologies developed by the PD/A CRSP in Thailand. These economic relationships will be further explored in the second phase of this project.

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