FINANCIAL (AND ECONOMIC) PERFORMANCE OF SHRIMP FARMING CLASSIFIED BY WATER MANAGEMENT

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ABSTRACT

Due to currently shrimp farms are facing with water pollution and disease transfer problems, low water exchange systems have been developed. To understand about these system economics, 120 sampled farms were randomized from four important shrimp culture provinces in Thailand in 2002. Farms were classified by water management, i.e. open, semi-closed, closed and recycle systems. This present study found that high operating costs are a major constraint of semi-closed systems. A lack of water exchange and deteriorated water quality within the systems has been identified to be a problem of closed systems. Large investment cost, limited land availability for setting up water treatment systems and low productivity and net income per total water surface area compared with other systems are some of the drawbacks preventing development of recycle systems. The study also found that the profitable systems were semi-closed and closed systems for small (<1.6 ha) and medium scale (1.6 to <4.8 ha) farms, while recycle systems were suitable for large scale farms (>4.8 ha). Based on economic costs (capital + operating costs) and shrimp harvest size price, only semi-closed and closed systems could obtain profit.

INTRODUCTION

A fundamental analysis of economic production is needed to understand the significance of inputs used in the production process in relation to the expected output (OEPP, 1999). Primary definition may be made of capital and operating costs. Capital costs include costs of farm construction and equipment used (e.g. pumps, aerators and scientific equipment). Operating costs are the amount of money that must be expended on productive inputs to obtain specific production outputs and can be further categorised into fixed and variable costs. Fixed costs include land rental, pond depreciation of installations and equipment. Variable costs include feed, seed, chemicals, fuel, wages, pond repair and miscellaneous costs. In general, the success of any culture system is measured by its profitability.

A number of studies on financial/economic aspects of shrimp farming have been done, mostly concerning system management (i.e., extensive, semi-intensive and intensive systems) and farm sizes. The present study extends the analysis to focus on classification by water management (i.e., open, semi-closed, closed and closed recycle system) to find out the more profitable and sustainable forms of farming.

Definitions of each culture systems are:

1. Open systems: large volumes of daily water exchange are used to control pond water quality at an acceptable level for shrimp growth. Water exchange is generally done 1-3 times per week.

2. Semi-closed systems: there is no water exchange in the first two culture months. After this, water is exchanged, according to water quality in the ponds. These use less water exchange than the open systems.

3. Closed systems: the ponds are just filled once, on preparation before culture. During the culture period, farmers attempt not to change any water at all and merely add water if necessary to compensate for loss by seepage or evaporation. These systems use the least water compared with the other systems.

4. Recycle systems: these systems generally consist of culture, treatment and water storage ponds. Water is recirculated through production ponds and into treatment and storage reservoirs, allowing it to be reused instead of adding new water

The specific aims of this study were :

1. To find out the differences in financial performance between culture systems and also to determine the most effective and profitable farms in the sampled provinces.

2. To determine significant factors affecting profitability of shrimp farming systems.

3. To determine the implications for future shrimp culture development.

MATERIAL AND METHODS

In this study questionnaires were employed. It was pre-tested first and it was then improved in response to the pre-test feedback. The survey was carried out between November 1999 and February 2000 during the harvest season. A multi-stage sampling technique i.e. cluster sampling and stratified random sampling methods was used. Four sampled provinces were selected and based on important province in each shrimp culture area of Thailand. These were Chanthaburi, Chachoengsao, Trang and Nakhon Si Thammarat.

The sample size selected for the economic review was calculated using the formula cited by Wanichbuncha (1999) but the precision value chosen was +4% as reliable economics data are more difficult to obtain and it was preferable to reduce the sample size to allow time for good data to be obtained. A large sample size is not necessarily reliable. The sample must be random and contain a sufficient number of cases to obtain the desired degree of confidence (Shang, 1981).

The sample size for the economic review was therefore, $n = \{(1.96)^2 x\ 0.95x(1-0.95)\}/(0.04)^2 = 114$ farms. This was increased in the study to 120 farms to allow 30 farms to be surveyed in each province. The sampled farms were classified into four farming systems using the average percentage estimations of a panel of key informants, comprising two shrimp culture experts (Dr.Chalor Limsuwan and Dr.Pornlerd Chanratchakool), four Department of Fisheries officials, eight shrimp farmers, and eight fee salesmen in the sample provinces. The results are presented in Table 1.

Descriptive statistics used were frequency, percentage, mean and standard deviation. Multi linear regression was applied for the relationships between output and input variables.

Table 1 Number of farms by systems in each sampled province for economic review

Province	Open system	Semi-closed system	Closed system	Recycle system	Total
Chanthaburi	1(2%)	5(16%)	22(76%)	2(6%)	30(100%)
Chachoengsao	7(24%)	5(16%)	13(44%)	5(16%)	30(100%)
Trang	1(4%)	24(80%)	4(14%)	1(2%)	30(100%)
Nakhon Si Thammarat	4(14%)	17(58%)	7(24%)	2(4%)	30(100%)

RESULTS

Different farm performance among sampled provinces

Economic results in the sampled provinces were different because of management practice difference. Closed systems were mainly found in Chanthaburi (76%) and Chachoengsao (44%), while semi-closed systems were in Trang (80%) and Nakhon Si Thammarat (58%). Open and recycle systems were more common in Chachoengsao at 7% and 16% of total farms in the province, respectively.

Most shrimp farms in Chachoengsao had at least a reservoir in their farms at 24 farms (80% of total farms in the province, median 50% of culture area) followed by 16 farms (52.3%) in Nakhon Si Thammarat (median 50%), 13 farms (43.3%) in Chanthaburi (median 40%) and 9 farms (30%) in Trang (median 27.5%). The median size of reservoir in all sampled provinces was the same as 0.4 ha. The reason for the highest percentage of reservoir use in Chachoengsao farms was because they operated low water salinity systems (0 to 10 ppt) which needed a reservoir for stocking saline water.

Before purchasing larvae, almost half the farms in Chanthaburi and Nakhon Si Thammarat checked the larvae by PCR technique, while only 30% of farms in Chanchoengsao and 20% in Trang farms did.

Economics of shrimp farms as classified by system management

Capital cost classified by system management

Average capital costs of each type of culture system are presented in Table 2. Farm construction costs (i.e., building, ponds, roads, water gates, canals, etc) were common elements in all systems. Average total capital cost of closed recycle systems was highest at US$ 27,821 ha^{-1} (US$ 2.8 kg^{-1} annual capacity) followed by open, semi-closed and closed systems at US$ 20,904 ha^{-1} (US$ 2.2 kg^{-1} annual capacity), 15,431 ha^{-1} (US$ 1.6 kg^{-1} annual capacity) and 13,965 ha^{-1} (US$ 1.5 kg^{-1} annual capacity), respectively. Almost all capital items (i.e. farm construction, pump and scientific equipment) were more expensive in recycle systems than in others.

The recycle systems had to set up reservoirs, treatment ponds and water supply canals within the farms, for which the construction cost was relatively high. Open systems were generally located near the sea, which sometimes caused difficulties in pond construction because of high permeability sand, or acid sulphate soils. Closed systems had the lowest farm construction cost as in most cases their ponds did not have water gates related to low water exchange practices, a major farm construction cost.

Pumps and scientific equipment were also found mostly in recycle systems, associated with water recirculation and frequency of water quality analyses. Some open systems were able to reduce pump costs by using tidal fluctuation for water exchange. Closed systems had highest costs of aerators as high organic loading required highly efficient systems.

Capital cost of open and closed systems showed higher levels variation with S.D. at 84% and 80% of their means, respectively compared with 45% of semi-closed and 54% of recycle systems. In open systems, this was merely due to high variation of farm construction and generator costs, while in closed systems this was related with high aerator cost.

Table 2 Capital cost by system management

Item (US$ ha-1)	Open (13)		Semi-closed (51)		Closed (46)		Recycle (10)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Farm construction	15,270	14,900	8,457	4,598	5,943	4,424	20,475	16,920
Pump	983	640	1,214	1,138	1,740	1,221	2,128	1,994
Aerator	3,114	2,217	4,596	2,018	5,280	4,857	3,968	3,152
Generator	1,537	1,813	1,125	1,039	940	752	1,172	371
Scientific equipment	0	0	39	35	62	60	78	70
Total capital cost	20,904	17,510	15,431	6,939	13,965	11,233	27,821	14,931

The number in the bracket is the number of samples, S.D.=standard deviation

Operating cost classified by farming system

The estimated costs and returns per ha per crop and per kg for each farming system are shown in Table 3.

The average fixed costs of closed systems were highest at US$ 2,330 $ha^{-1}crop^{-1}$ (US$ 0.49 kg^{-1}) and those of open systems the lowest at US$ 1,743 ha-1crop^{-1} (US$ 0.36 kg^{-1}). This was primarily due to the depreciation cost of aerators (approximately 4 years useful life) being greater in closed systems at US$ 909 ha-1crop^{-1} of total costs (US$ 0.19 kg^{-1}), than in others which ranged from US$ 699 to 737 $ha^{-1}crop^{-1}$ (US$ 0.14 to 0.15 kg^{-1}). Closed system farms also had high interest and rental costs, as a high proportion of farmers operating these systems were found to rent the farms and were in debt. Another different cost item was equipment maintenance; closed recycle system operations had to use a range of equipment including pumps, aerators, and scientific equipment, resulting in higher costs at an average of US$ 615 $ha^{-1}crop^{-1}$ (US$ 0.12 kg^{-1}) compared with other systems ranging from US$ 317 to 347 $ha^{-1}crop^{-1}$ (US$ 0.06 to 0.07 kg^{-1}).

Of variable costs, feed, fry and energy were the major input costs in all farming systems. Average feed cost of open systems was lowest either as absolute terms and percent at US$ 4,258 ha-1crop^{-1} (US$ 0.88 kg^{-1}), probably because of good water quality and high water exchange carrying natural nutrients into the grow-out ponds, reducing costs of feed. Feed costs of the other systems ranged from US$ 5,233 to 5,408 $ha^{-1}crop^{-1}$ (US$ 1.10 to 1.12 kg^{-1}). Fry cost of closed systems was lowest at US$ 1,418 ha^{-1} $crop^{-1}$ (US$ 0.30 kg^{-1}) due to a low average stocking density of 53.5 PL m^{-2}, while that of other systems was 62.5 PL m^{-2} with costs ranging from US$ 1,512 to1,579 ha^{-1} $crop^{-1}$ (US$ 0.31 to 0.33 kg^{-1}). Energy cost (i.e., electricity and/or diesel costs) in open and semi-closed systems were higher at US$ 1,178 (US$ 0.24 kg^{-1}) and 1,366 ha^{-1} $crop^{-1}$ (US$ 0.28 kg^{-1}) respectively because of the greater frequency of pumping and aerating. Closed systems also had high energy costs at US$ 1,186 ha^{-1} $crop^{-1}$ (US$ 0.25 kg^{-1}), with less pumping due to limited water exchange, but high rates of aeration usage. Closed recycle systems had lower energy costs at US$ 1,005 ha^{-1} $crop^{-1}$ (US$ 0.20 kg^{-1}) owing to less external pumping and lower levels of aeration compared with closed systems.

Labour cost was also associated with system management and the use of external water, being higher in semi-closed and open systems at US$ 1,156 (US$ 0.24 kg^{-1}) and 999 ha^{-1} $crop^{-1}$ (US$ 0.21 kg^{-1}), respectively but lower in closed recycle and closed systems at US$ 588 (US$ 0.12 kg^{-1}) and 789 ha^{-1} crop-1 (US$ 0.17 kg^{-1}) respectively. The former systems needed more labour for water management in pumping and water exchange. However, this cost also depends upon types of worker and size of farm. For small farms managed by household labour, there is no labour cost, while for large farm managed by hired workers, labour cost increases.

Due to the limited water exchange strategy of semi-closed and closed systems, various chemicals (i.e., lime, BKC, chlorine, etc.) and/or antibiotics (i.e., oxytetracycline, oxolinic acid, etc.) were applied to maintain water quality in ponds and prevent or remedy diseases. This cost was greater in these two systems, at an average cost between US$ 532-652 ha^{-1} $crop^{-1}$ (US$ 0.11 to 0.13 kg^{-1}) while the closed recycle systems were lowest at US$ 419 ha^{-1} $crop^{-1}$ (US$ 0.08 kg^{-1}) as its reused water was less affected by external water. In conclusion, the average total variable cost of open systems were lowest at US$ 8,482 (range 3,527 to 14,570, median 7,329) or US$ 1.75 kg^{-1} followed by this of closed recycle, closed and semi-closed systems at 8,904 (range 2,165 to 28,906, median 8,244) or US$ 1.80 kg^{-1}, 9,275 (range 2,483 to 12,737, median 8,080) or US$ 1.95 kg^{-1} and 10,191 (range 2,547 to 22,269, median 9,242) $ha^{-1}crop^{-1}$ or US$ 2.10 kg^{-1}, respectively.

However, when fixed costs are taken into account, the average total cost of semi-closed system farming was highest at US$ 11,690 (range 3,910 to 24,020, median 10,997) $ha^{-1}crop^{-1}$ or US$ 2.41 kg^{-1} followed by closed, closed recycle, and open systems at US$ 11,003 (range 3,630 to 32,067, median 10,045) or US$ 2.27 kg^{-1}, 10,923 (range 4,608 to 15,839, median 9,704) or US$ 2.21 kg^{-1} and 9,759 (range 5,274 to 16,781, median 8,965) $ha^{-1}crop^{-1}$ or US$ 2.01 kg^{-1}, respectively.

Average total costs of production of open, semi-closed, closed and recycle systems were US$ 2.1 kg^{-1} (range 1 to 3, median 2.2), US$ 2.6 kg^{-1} (range 1 to 6.9, median 2.5), US$ 2.4 kg^{-1} (range 0.5 to 8.6, median 2.2), and US$ 2.3 kg^{-1} (range 0.9 to 3.2, median 2.3), respectively. When the capital costs are taken into account, the average total investment cost of recycle system was highest at US$ 7.9 kg^{-1} (range 1.2 to 19.8, median 6.1) followed by open, semi-closed and closed systems at US$ 6.4 (range 1.2 to 8.9, median 5.9), 5.7 (range 2.2 to 9.8, median 5.5) and 5.4 kg^{-1} (range 2.3 to 8.5, median 5.1), respectively.

It was found that total cost of some farms in each system category were lower than an average of variable costs. This was mainly due to reducing stocking densities to lower levels than its average, which resulted in decreasing costs of feed, chemicals, labour and energy.

Costs and returns classified by farming system

Average shrimp production in kg ha^{-1} for each system type was little different with open, semi-closed, closed and closed recycle at 4,845 (range 1,781 to 6,250, median 5,000), 4,841 (range 1,562 to 9,375, median 5,000), 4,756 (range 2,500 to 9,375, median 4,687) and 4,950 (range 3,125 to 6,875, median 4,969) kg ha^{-1}, respectively.

Average harvest size of closed systems was largest at 56 shrimp kg^{-1} (range 30 to 110, median 55) followed by semi-closed, open and recycle systems at 57 (range 30 to 225, median 50), 58 (range 48 to 70, median 60), and 66 (range 45 to 90, median 70) shrimp kg^{-1}, respectively. Generally, shrimp price depends on harvest size and average shrimp prices for closed, semi-closed, open and recycle systems were US$ 5.58 kg^{-1} (range 2.95 to 9.63, median 5.58), 5.43 kg^{-1} (range 4 to 8.75, median 5.25), 5.5 (range 4.75 to 6.85, median 5), and 4.99 kg^{1} (range 4.18 to 6.25, median 5), respectively.

Thus total revenues of open, semi-closed, closed and closed recycle systems were US$ 26,648 (range 12,202 to 31,250, median 27,148) or US$ 5.5 kg^{-1}, 26,141 (range 8,984 to 53,203, median 25,391) or US$ 5.4 kg^{-1}, 26,634 (range 9,375 to 51,319, median 26,367) or US$ 5.6 kg^{-1} and 24,750 (range 13,047 to 35,938, median 24,219) $ha^{-1}crop^{-1}$ or US$ 5.0 kg^{-1}, respectively. Average profitability did not differ significantly among farming system types, though open system recorded the highest net profit at US$ 16,889 (range 6,928 to 23,231, median 16,684) $ha^{-1}crop^{-1}$ or US$ 3.4 kg^{-1} followed by closed, semi-closed and recycle systems at US$ 15,631 (range 2,145 to 46,214, median 17,929) $ha^{-1}crop^{-1}$ or US$ 3.2 kg^{-1}, 14,451 (range 1,950 to 40,327, median 14,779) $ha^{-1}crop^{-1}$ or US$ 2.8 kg^{-1} and 13,827 (range 4,299 to 21,936, median 15,273) $ha^{-1}crop^{-1}$ or US$ 2.7 kg^{-1}, respectively (Fig 4.1). Though the average net profit levels of recycle systems were the lowest, their production appeared to be more predictable with lower S.D. (22% of mean) compared with open (28.6%), semi-closed (29.5%) and closed (33%) systems.

However, the result showed that 40 farms (33% of total farms) obtained net profits less than capital costs with 19, 11, 6 and 4 farms in Trang, Chachoengsao, Chanthaburi and Nakhon Si Thammarat, respectively. These were 3 open (23.1% of total farms in the system), 19 semi-closed (37.3%), 16 closed (34.8%) and 2 recycle (20%) farms. Thus if they failed in the first crop, they could not pay money back.

Table 3 Costs and returns by farming system

Items (US$ ha-1crop-1)	Open Mean	%	Semi-closed Mean	%	Closed Mean	%	Recycle Mean	%
Cost of land or rental	371	3.6	619	5.0	548	4.7	402	3.6
Depreciation cost	709	6.9	699	5.7	909	7.8	737	6.6
Equipment maintenance cost	317	3.1	347	2.8	324	2.8	615	5.5
Interest	346	3.4	495	4.0	549	4.7	532	4.8
Fixed cost	1,743	17.0	2,160	17.5	2,330	20.1	2,286	20.4
Feed cost	4,258	41.6	5,408	43.8	5,233	45.1	5,255	47.0
Fry cost	1,578	15.4	1,579	12.8	1,418	12.2	1,512	13.5
Energy cost	1,178	11.5	1,366	11.1	1,186	10.2	1,005	9.0
Labour cost	999	9.8	1,156	9.4	789	6.8	588	5.3
Chemicals and antibiotics cost	437	4.3	652	5.3	532	4.6	419	3.7
Saline water cost	23	0.2	9	0.1	83	0.7	78	0.7
Others cost	9	0.1	21	0.2	34	0.3	47	0.4
Variable cost	8,482	83.0	10,191	82.5	9,275	79.9	8,904	79.6
Total cost	10,225	100	12,351	100	11,605	100	11,190	100
Production	4,845		4,841		4,756		4,950	
Farm-gate price (US$ kg-1)	5.5		5.4		5.6		5	
Total revenue	26,648		26,141		26,634		24,750	
Net profit	16,423		13,790		15,029		13,560	
Total cost (US$ kg-1)	2.1		2.6		2.4		2.3	
Total revenue (US$ kg-1)	5.5		5.4		5.6		5.0	
Net profit (US$ kg-1)	3.4		2.8		3.2		2.7	
Total cost+ capital cost (US$ kg-1)	6.4		5.7		5.4		7.9	

Primary correlation of net profit

Net profit in shrimp culture will be related to production and major costs. It increases when production and farm gate price increase and decreases when production cost increase.

Based on standard coefficient values (ß), among farming systems, fry cost was the most significant factor for higher net profit of open (ß = 0.81) and closed (ß= 0.13) systems, energy cost for semi-closed (ß = 0.43) and recycle (ß = 0.74) systems. While chemical cost was the most significant factor for net profit reduction of open (ß = -0.67) and closed (ß = -0.35) systems, feed cost for semi-closed (ß = -0.1) and recycle (ß = -0.81) systems. Relationships between variable cost and net profit in each farming system were shown as equations below.

Open system

Net profit = 20020 + 11.7(Fry cost) + 0.52(Feed cost) - 27(Chemical cost) - 10.9(Labour cost) - 3.9(Energy cost) $R^2 = 0.95$

Semi-closed system

Net profit = 12504 - 0.58(Fry cost) - 0.22(Feed cost) + 0.26(Chemical cost) + 1.7(Labour cost) + 1.9(Energy cost) $R^2 = 0.22$

Closed system

Net profit = 19990 + 2.9(Fry cost) - 0.03(Feed cost) - 9.5(Chemical cost) - 0.45(Labour cost) -2.4(Energy cost) $R^2 = 0.20$

Recycle system

Net profit = 42956 -11.5(Fry cost) -1.7(Feed cost) - 23.9(Chemical cost) + 8.3(Labour cost) + 6.1(Energy cost) $R^2 = 0.91$

DISCUSSION

The significant elements of capital cost were farm construction, accounting for almost 50% followed by aerator (38%) and pumps (10%). Operating costs comprised of fixed (17%) and variable elements (83%). Depreciation of farm equipment (e.g. pumps, aerators) was the major fixed cost category and feed, fry and energy costs were the main variable costs.

Due to geographic conditions and shrimp farmers' backgrounds, management practices differed widely, and therefore cost profiles differed across the provinces surveyed.

Recycle systems had highest average capital costs, particularly in association with the construction of reservoir ponds, treatment ponds and water supply canals. Pump costs were also higher as it is necessary to circulate water for treatment. Average total operating costs of open systems were lowest, followed by recycle, closed and semi-closed systems. The advantage of an open system was primarily because if located in a good water quality area, feed cost, the highest cost of shrimp culture, could be reduced by getting natural food or nutrients from water exchange. However, if the feed cost advantages of open systems were excluded, other costs were the same as other systems. Moreover, these area conditions were not available now and farm construction costs of these systems were also high if the farms were constructed in mangrove and/or permeable soil areas.

Although open systems showed the highest average net returns followed by closed, semi-closed and closed recycle systems, there was no significant difference ($P>0.05$) between net return and farming systems. They generally had net returns at around US$ 14,000 to16,000 $ha^{-1}crop^{-1}$ or US$ 2.7 to 3.4 $kg^{-1}crop^{-1}$. A constraint of open system farming is the risk if located near a source of water pollution or disease. According to Huguenin and Colt (1992), if sufficient qualities of good water are readily available, the decision will usually be towards open systems due to their greater simplicity, reliability and lower costs. However, if sufficient water is not available, or of poor quality, there will be a trend towards using closed or water reuse systems. For closed systems however, there is a risk of crop failures because of lack of water exchange and deteriorated water quality within the rearing ponds. A constraint of semi-closed systems is their rather high operating costs, while major obstacles of recycle systems development are large capital cost, limited land availability for setting up water treatment systems and lower productivity and net profit per total farm area at 1,719 kg ha^{-1} and US$ 4,801 ha^{-1}, respectively compared with open (3,785 kg ha^{-1} and US$ 13,195 ha^{-1}), semi-closed (3,782 kg ha^{-1} and US$ 11,289 ha^{-1}) and closed (2,973 kg ha^{-1} and US$ 9,769 ha^{-1}).

Recycle systems also require proper treatment pond management, whose cost averaged approximately US$ 4,150 $ha^{-1}year^{-1}$ (US$ 0.39 kg^{-1} $year^{-1}$), including costs of land, pond cleaning and repairing, pond and equipment depreciation, chemicals and opportunity costs, which was calculated from investment at an interest rate of 8% a year (OEPP, 1999). The method used was aerating for enhancing waste oxidation and decomposition and applying some chemicals such as limes and zeolite for waste settlement. This calculation was based on the Department of Fisheries recommendation that farm area should be 50% for culturing ponds, 15% for reservoir ponds, 20% for treatment ponds, 5% for sludge ponds and 10% for others (i.e. buildings, levees and roads).

To maintain the profit of the business, several major means are used including increasing yield, reducing costs, and increasing market price. To increase yield, farmers should pay more attention to management techniques such as pond preparation, larval quality, larval stocking density, feed quality, feed regime, aeration application, water and soil quality monitoring, etc.

To reduce the operating costs, farmers should attempt to reduce the costs of feed, fry and energy since these are the main input costs in all farming systems and sizes. Those of feeding trays, low stocking density, and more efficient aerators could facilitate this.

Results of analyses showed that the most relationships between inputs and profitability (output) among systems were not strong. These could be explained by many factors of which survival rates and disease problems were the most important factors affecting productivity and harvest sized which related to profitability. Increasing energy cost of semi-closed and recycle systems, and increasing of number of fry of closed systems were associated with an increase of profitability. While increasing feed cost of semi-closed and recycle systems, and chemical cost of closed systems had the most negative impact on net profit. Thus particularly in recycle systems, farmers should reduce feed cost and increase aeration application to obtain maximize profit.

Focusing on feed cost, it was the highest component (50% to 80%) of variable costs in all farming systems and sizes. If feed price increased, recycle system farms were found to be affected first followed by closed, semi-closed and open system farms since feed cost was the greatest input component (59%) of variable costs for recycle systems followed by 56%, 53%, and 50% for closed, semi-closed and open systems, respectively.

Based on the results earlier, to reduce other important production costs of farming systems, in open, semi-closed and closed systems, costs of pumping and aerating could be reduced by using high equipment. High chemicals and/or antibiotics application in semi-closed and closed systems could be reduced by stocking healthy larvae at an optimal density. High capital cost of recycle systems could be reduced by appropriate farm design.

Shrimp price generally depends on their harvest size. Thus the culture aim for all system or farm size management should be to produce large harvest sizes in order to obtain higher prices. The production of larger shrimp however is more costly since it requires more feed and other inputs. The farmer also has higher risks to consider as market prices might decrease. Thus the farmer has to balance the opportunity for increased profits in the future and the risks of continuing growing against the known value of the crop in the present period (Clay, 1996).

With a high and growing demand of shrimp in the world market, price has been increasing, with frozen shrimp prices of all sizes increasing 6%-10% over 1999 prices by the end of 2000 (Foodmarketexchange, 2002). The average shrimp harvest size in the study was 60.15 shrimp kg^{-1} (range 27 to 225, median 55). The price for size 51-60 in the US market was approximately US$ 8.4 kg^{-1}, while on February 22, 2002, in internal markets i.e. Mahachai auction and Nakhon Si Thammarat (Sapan Pla) there averaged US$ 5.8 kg^{-1} (Foodmarketexchange, 2002). At this price, all farming systems could operate successfully as their total costs per kg were still lower. However, if capital cost was taken into account for total production cost, only semi-closed and closed systems would obtain profit, as the production costs were US$ 5.7 and 5.4 kg^{-1}, respectively, lower than shrimp harvest price.

If market prices fell, open and recycle farming systems were affected before semi-closed and closed systems due to greater total cost (capital + operating costs). Small farms were also found more vulnerable to price fluctuations because of high total cost compared to large farms.

This study also found that management practice was related to economic characteristics. It is likely that poorer managed farms have to improve management practices, otherwise they will go out of business because of low profit relating to low production levels and/or small harvest sizes.

The successful farming systems in sampled provinces were as below:

* Chanthaburi - thirteen farms were identified, in which semi-closed and closed systems were operated at all farm sizes. Of these seven farms (53.8% of total) were small-scale (<1.6 ha) closed systems.

* Chachengsao - eight farms were noted, of which there were one each of all systems at small scale (<1.6 ha), one open and two closed systems at medium scale (1.6 to <4.8 ha), and one recycle farm at large-scale (>4.8 ha).

* Trang- four small - scale farms (<1.6 ha) could be found, in which there were one each of open and closed systems, and two semi-closed systems.

* Nakhon Si Thammarat - five farms were found. There were four small-scale (<1.6 ha) with one each of semi-closed and recycle systems, and two closed systems. The other farm was medium-scale (1.6 to <4.8 ha) closed system.

Thus semi-closed and closed systems were the profitable systems for small and medium scale farms in all sampled provinces, while recycle systems seemed to be suitable for the large-scale farm example in Chachoengsao. Though an open system farm was found profitable in each of Chachoengsao and Trang, these systems can not be developed further because of concerns about environmental degradation. Thus environmentally friendly systems i.e. low water exchange systems have to be developed, and will have to reach profitability targets expected for other systems.

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