# High-Input Green Water On-Farm Trials in Northeast Thailand

*Eighth Work Plan, Thailand Research 4 (TR4)*
*Final Report*

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## Abstract

This report presents the results of high-input on-farm trials with farmers in Northeast Thailand. Based on AIT on-station trial results, technical recommendations for high-input green water culture were extended to 12 farmers through the Aquaculture Outreach Program (AOP). Pond size varied greatly among the project farmers, averaging 658 $m^2$. Measurements of water color indicated turbid water existed in most project farmers' ponds, which were poor in natural feed and unfavorable for fish growth. All the project farmers, upon receiving seed, started nursing fry in hapas in their ponds. The size of hapas varied greatly among farmers, averaging 5 $m^3$. The average number of fry released into a hapa for nursing was estimated to be 2,333, ranging from 800 to 4,000. The duration of nursing fry in hapas ranged from 30 to 57 days with an average of 41 days. Pig concentrate and rice bran (2:1) were recommended as supplementary feed for fry throughout nursing. On average, farmers fed 130 g of pig feed concentrate and 76 g of fine rice bran per day per 1000 fry. Density of fry during nursing, which was largely affected by the size of hapas, ranged between 93 and 556 $m^{-3}$ with an average of 242 $m^{-3}$. The survival rate of the fry at the end of nursing in most of the farms was estimated to be 75%, with a range of 44 to 80%). Farmers were advised to stock 2 to 3 fish $m^{-2}$ in ponds; actual stocking density was 3.1 fish $m^{-2}$. The culture period, recommended at six months, varied from four months for two farmers whose pond water level dropped rapidly after the cessation of the rainy season, to eight to eleven months for most farmers. Farmers were advised to apply fertilizers (urea and TSP) at weekly intervals at the rate of 4 kg N and 1 kg P $ha^{-1}$ $d^{-1}$, respectively. Only two farmers reported that they applied urea at the recommended rate. Most farmers applied P at a higher rate than recommended. Despite AOP recommendations and support for the monoculture of sex-reversed tilapia for the on-farm trial, a number of farmers mixed other fish species in their pond. Total fish production was found to vary from one pond to another. Extrapolated yield (averaging 944 kg $rai^{-1}$, with a range of 292 to 1322 kg $rai^{-1}$) was higher than that expected on the basis of on-station trials (600 kg $rai^{-1}$). Virtually all project farmers experienced a substantial increase in fish yield, which was associated with a change in water color from turbid to green or dark green after application of urea and TSP. At the end of the trial, virtually all the participant farmers were very satisfied with the significant increase in fish production from their ponds. Average yields were nearly three times higher from high-input green water practices compared to previous years' yield without such practice. The average estimated gross margin (Baht 17,000 $rai^{-1}$ in 7.5-mo culture period) in this trial was also higher than expected.

## Introduction

The Asian Institute of Technology (AIT) Aquaculture Outreach Program (AOP), through its project based in Udorn Thani province in Thailand, has been working directly with farmers and local institutions in developing and disseminating appropriate aquaculture techniques, which aim at bringing about sustainable increases in fish production on small-scale farms in Northeast Thailand. Between 1989 and 1993, a large number of farmers in the region became aware of the AOP recommendations for fry nursing and pond fertilization. These recommendations, the application of ruminant manures and modest inputs of urea, allow for a substantial increase in fish production with only a small investment.

By 1993, however, in the context of Thailand's rapidly growing economy, these technical recommendations, aimed at increasing production for food self-sufficiency, were insufficient to fulfill the growing aspirations of farmers to produce a surplus for the buoyant local market. In recent years, fish consumption has greatly exceeded local supply in Northeast Thailand. Consequently, disadvantaged consumers were paying a relatively high price for their fish products because the shortfalls were made up by imports from the central region. Although fertilization of ponds with ruminant manure and other on-farm wastes—previous AOP recommendations—could produce fish at minimal costs, fish yields were correspondingly low (on average < 500 kg $ha^{-1}$ $yr^{-1}$). Moreover, introduction/improvement of aquaculture in small-scale agriculture systems was constrained by the limited scope of on-farm resources to be integrated into fish culture. Therefore, intensification through fertilization of fish ponds with low-cost, off-farm inputs was considered a viable option to increase the fish yields of small-scale agriculture systems.

One relatively low-cost technology to increase fish yield on small-scale farms is the fertilization of ponds with chemical fertilizers. Pond fertilization has been an on-station research area of the Pond Dynamics/Aquaculture CRSP project at AIT for a number of years (Lin et al., 1997). Study results demonstrated that fish yields of appropriately fertilized ponds could exceed 4,000 kg $ha^{-1}$ $yr^{-1}$, a nearly 10-fold increase over that in traditional farms of Northeast Thailand. Similarly, in other on-station experiments conducted in Northeast Thailand that applied urea and triple superphosphate (TSP), an extrapolated yield of sex-reversed tilapia was 5,049 ± 231 kg $ha^{-1}$ $yr^{-1}$ (808 kg $rai^{-1}$ $yr^{-1}$) (AOP, 1992). Given the farmers' demand for new technology and AITs on-station experiment results, the AOP developed a further round of recommendations emphasizing use of low-cost, off-farm inputs, namely urea and TSP, for fertilizing fish ponds. Liming ponds with low alkalinity was also recommended. Hence, fertilization of the pond with inorganic fertilizers to produce a surplus of fish over the amount required for household consumption was introduced as a potential source of income.

In Thailand, tilapia fills an important niche in providing low-cost animal protein to poorer urban and rural people and ranks as the most important cultured freshwater fish. However, one of the major setbacks in tilapia culture is the species' prolific fecundity, which leads to overpopulation of the ponds, subsequent high competition, and hence the production of tiny fish with low value (Ufodike and Madhu, 1986; Szyper et al., 1995). An effective solution to the problem of uncontrolled reproduction is the culture of monosex male progenies, which combine the benefits of population control with the faster growth of male stock. In a number of earlier AOP trials, all-male culture of tilapia produced larger, more uniformly sized fish. To address the problems of uncontrolled breeding and recruitment of tilapia, culture of hormonally sex-reversed tilapia was recommended for this on-farm trial.

In 1994, the first year of high-input green water on-farm trials, three farmers in Udorn Thani, who had previously taken part in project trials, volunteered to follow the recommendations. Outreach staff from the Udorn Thani office visited all three farmers fortnightly in order to keep detailed records. Significant increases in fish yield resulting from the first-year on-farm trial encouraged the expansion of the recommendations throughout the region (AOP, 1995). Later, in 1995/96, AOP, in collaboration with the Department of Fisheries (DOF), carried out high-input on-farm trials with a total in 12 farmers of Udorn Thani, Nakorn Phanom, and Sakorn Nakorn provinces of Northeast Thailand. This report presents the results of these high-input on-farm trials.

## METHODS AND MATERIALS

The high-input on-farm trial was jointly carried out by the AOP and the DOF. Provincial Fisheries Officers selected and recruited the trial farmers, who volunteered to take part in the on-farm trials (Table 1). AOP and DOF staff jointly visited all farms, estimated pond size, and assessed water quality by testing alkalinity and water color prior to stocking. Stocking density and lime and fertilizer requirements for each pond were also estimated on the basis of the AOP (Table 2).

The AOP has not commonly supported trials with inputs or credit, but the "culture" of the DOF in conducting on-farm

Table 1. Distribution of the participant farmers by location, high-input on-farm trial, Thailand.

| Location | Number | Farmer's Name |
|---|---|---|
| UDORN THANI | | |
| | 1 | Mr. Tongsoon |
| NAKORN PHANOM | | |
| | 2 | Mr. Phai |
| | 3 | Mr. Chairat |
| | 4 | Mr. Sopar |
| | 5 | Mr. Boonsong |
| | 6 | Mr. Kampong |
| | 7 | Mr. Sunan |
| SAKORN NAKORN | | |
| | 8 | Mr. Prasobchai |
| | 9 | Mr. Wantamid |
| | 10 | Mr. Sagnuansak |
| | 11 | Mr. Surin |
| | 12 | Mr. Tawatchai |

Table 2. Technical recommendations for high-input, green-water on-farm trials. On the basis of on-station and on-farm trials, total fish yield at the end of 6-mo grow-out period is expected to be 600 kg $rai^{-1}$.

Pond Inputs:

| Input | Input Rate ($rai^{-1}$) | Considerations |
|---|---|---|
| Lime | 200 kg only once in the beginning | apply when alkalinity ($CaCO_3$) is < 50 mg $l^{-1}$ |
| Urea 46:0:0 | 9.8 kg $wk^{-1}$ (6.1 g $m^{-2}$ $wk^{-1}$) | apply after dissolving in water |
| TSP 0:46:0 | 5.6 kg $wk^{-1}$ (3.5 g $m^{-2}$ $wk^{-1}$) | soak overnight in water and mix thoroughly before applying to pond |
| Chicken Manure | depends on availability | amount of urea and TSP should be adjusted with the amount of manure applied (N: 4 kg $ha^{-1}$ $d^{-1}$ and P :1 kg $ha^{-1}$ $d^{-1}$) |

Stocking Recommendation:

| Stocking Density | Species | Stocking Period | Considerations |
|---|---|---|---|
| 2-3 fingerlings $m^{-2}$ (3,200-4,800 fingerlings $rai^{-1}$) | Sex-reversed tilapia | 6 mo | nursing fry in hapa prior to stocking [Recommended size to stock: 5 g (6-8 cm)] |

demonstrations has been to offer input support. The DOF officers were not confident that they could recruit farmers in the absence of such inputs and agreed to help the project farmers with some amount of lime, urea, and TSP free of charge. Considering the scarcity of sex-reversed tilapia in the region, AOP staff supplied seed free of charge to all project farmers.

District Fisheries Extension Officers visited project farmers regularly. In order to record the activities carried out by the farmers, the AOP staff and the DOF Fisheries Officers visited farms fortnightly. The AOP conducted a short questionnaire survey after the complete harvest of fish from all project farmers' ponds.

### Technical Recommendations

Introduction and promotion of aquaculture into small-scale rice-based farms raises concerns about alternative use of resources. Fertilization of fish ponds with off-farm inputs (urea and TSP) is hoped to become a viable option, since it does not interfere with the existing resource allocation pattern of small-scale farming systems. Additionally, use of inorganic fertilizers does not put excessive economic burden (in comparison to intensive aquaculture) on the farmers since they are relatively inexpensive. In a number of on-station trials, daily supplements of inorganic fertilizers at the rate of 4 kg nitrogen (N) and 1 kg phosphorus (P) $ha^{-1}$ as urea and TSP, respectively, were found to produce optimum yields. Hence, based on AIT on-station trial results, a package of technical recommendations for high-input green water trials was developed (Table 2).

## RESULTS AND DISCUSSION

### Farming Systems of the Project Farmers

The farm holding size of project farmers ranged from 0 to 50 rai with an average of 21 rai (1 rai = 6.25 ha). The average farm holding size of the project farmers was found to be nearly 25% less than the average of the 1988 AOP baseline survey in the region (Table 3).

Almost all project farmers cultivated their own land. However, a couple of farmers rented-in or rented-out the land for cultivation. The area under cultivation in the project farms was smaller than the size of holdings and was estimated to range from 3 to 39 rai with an average of 16 rai (Table 3).

All the project farmers had nuclear families consisting of husband, wife, and one or more children. All of the farmers relied mainly on family labor for all agricultural activities. In most cases, the husband and wife comprised the labor force in the family. Average family size of the project farmers was five, with an average labor force of two to three. In contrast to these average figures, Mr. Sopar, a project farmer of Nakorn Phanom, reported that five of his six family members worked on his farm. Therefore, he was able to cultivate all 30 rai of his land. By contrast, despite his large farm holding (50 rai), Mr. Surin, whose labor force size was three, cultivated 35 rai, and Mr. Phai cultivated even less (21 rai), as his labor force was only two: himself and his wife.

Livestock rearing activities among the project farmers also varied greatly. Except for Mr. Sunan of Nakorn Phanom, all of the farmers owned livestock and/or poultry. Cattle was the most common species, raised by two-thirds of the project farmers, followed by pigs, raised by one-third. Poultry farming was not popular; only three farmers—Mr. Phai, Mr. Sopar, and Mr. Surin—were involved in rearing chickens. Mr. Tongsoon, the only farmer to own buffalo, possessed the most large animals (nine cattle and three buffaloes) among the project farmers. Ownership of livestock and poultry by the project farmers is presented in Table 4.

### Aquaculture Subsystem of the Project Farmers

Fish culture was found to be a relatively new activity (average 4.6 yr) for most of the farmers. For five farmers, it was a newly introduced subsystem in their farm, as they had been raising fish for only one year. By contrast, Mr. Phai, a farmer of Nakorn Phanom, had been culturing fish for 30 years (Table 5). Virtually all the project farmers reported that they supplied negligible amount of supplementary feed and animal manure to the pond and that they had experienced very slow growth and low fish yields from their ponds.

### Pond Characteristics

Pond size varied greatly among the project farmers. The average pond size was estimated to be 658 $m^2$. Mr. Tongsoon

Table 3. Size of holding, area under cultivation, household size, and household labor force of the project farmers.

| Farmer's Name | Size of Farm Holding (rai) | Cultivated Land (rai) | Family Size (number) | Family Labor Force (number) |
|---|---|---|---|---|
| Mr. Tongsoon | 16 | 39 | 4 | 2 |
| Mr. Phai | 50 | 21 | 4 | 2 |
| Mr. Chairat | 15 | 8 | 5 | 3 |
| Mr. Sopar | 30 | 30 | 6 | 5 |
| Mr. Boonsong | 14 | 14 | 7 | 2 |
| Mr. Kampong | 7 | 5 | 4 | 2 |
| Mr. Sunan | 14 | 14 | 3 | 2 |
| Mr. Prasobchai | - | 3 | 5 | 2 |
| Mr. Wantamid | 11 | 9 | 4 | 2 |
| Mr. Sagnuansak | 8 | 8 | 5 | 2 |
| Mr. Surin | 50 | 35 | 3 | 3 |
| Mr. Tawatchai | 20 | 7 | 6 | 2 |
| Mean (SD) | 21.4 (15.4) | 16.0 (12.3) | 4.7 (1.2) | 2.4 (0.9) |

Table 4. Ownership of livestock and poultry by the project farmers.

| Farmer's Name | Cattle | Buffalo | Pigs | Chickens |
|---|---|---|---|---|
| Mr. Tongsoon | 9 | 3 | - | - |
| Mr. Phai | - | - | - | 100 |
| Mr. Chairat | 4 | - | 10 | - |
| Mr. Sopar | 3 | - | - | 320 |
| Mr. Boonsong | - | - | 7 | - |
| Mr. Kampong | - | - | 2 | - |
| Mr. Sunan | - | - | - | - |
| Mr. Prasobchai | 7 | - | - | - |
| Mr. Wantamid | 4 | - | - | - |
| Mr. Sagnuansak | 1 | - | 3 | - |
| Mr. Surin | 5 | - | - | - |
| Mr. Tawatchai | 4 | - | - | 72 |
| Mean | 5 | - | 6 | 164 |

Table 5. Pond size, water color, and farmers' involvement in fish culture.

| Farmer's Name | Pond Size ($m^2$) | Water Color at Start of Experiment [1] | Involvement in Fish Culture (yr) |
|---|---|---|---|
| Mr. Tongsoon | 1,440 | 2 | 1 |
| Mr. Phai | 800 | 5 | 30 |
| Mr. Chairat | 640 | 3 | 2 |
| Mr. Sopar | 1,300 | 1 | 1 |
| Mr. Boonsong | 400 | 2 | 3 |
| Mr. Kampong | 350 | 1 | 1 |
| Mr. Sunan | 345 | 2 | 1 |
| Mr. Prasobchai | 494 | 1 | 2 |
| Mr. Wantamid | 896 | 1 | 6 |
| Mr. Sagnuansak | 885 | 2 | 4 |
| Mr. Surin | 380 | 2 | 4 |
| Mr. Tawatchai | 300 | 2 | 0 |
| Mean (SD) | 686 (386) | 2.0 (1.3) | 4.6 (8.2) |

[1] Scaling for water color: 1 (clear), 2 (turbid), 3 (greenish and turbid), 4 (light green), 5 (green), and 6 (dark green).

and Mr. Sopar owned the largest ponds (1,440 and 1,300 $m^2$, respectively), whereas the pond of Mr. Tawatchai was the smallest (300 $m^2$). The pond size data are presented in Table 5.

Water quality was assessed in all project farmers' ponds prior to commencing the trial (Table 5). The overall average water color (2.0) presented in Table 5 indicated turbid water in most of the project farmers' ponds, indicating that the ponds were poor in natural feed and not favorable for fish growth. Most of the project farmers were not aware of the significance of fertile green water as fish culture is a relatively new activity for most of them. However, the water in Mr. Phai's pond was green (5.0). The color suggested that plenty of natural food was available in the pond and reflected his much greater experience.

## DOF and AOP Support

In line with the understanding reached at the start of the project, the AOP supplied sex-reversed tilapia fry to the project farmers. Additionally, the AOP supported farmers with some feed, particularly pig feed concentrate and fine rice bran, for raising fry in hapas. But other input support (urea, TSP, lime, and feed during nursing), which was to be supplied free of charge by the DOF, varied from district to district. Mr. Tongsoon of Udorn Thani did not receive any input support from Provincial Fisheries Officers because the area was under an ongoing Agricultural Extension Project and the farmers were supposed to seek support from the Bank of Agriculture and Agricultural Cooperatives (BAAC) if needed. The farmers of Sakorn Nakorn accepted the DOFs input support but wanted to buy fertilizer on their own. Therefore, only six farmers, all from Nakorn Phanom, were the beneficiaries of DOF input support for the entire six-month culture period (Table 6).

## Nursing Details

All the project farmers, upon receiving seed, started nursing fry in hapas in their ponds. Fry with an average size of 1 cm were distributed to 11 farmers the last week of February 1995. Mr. Tongsoon had to delay nursing since the water level in his pond was inadequate to start nursing in February. Therefore, upon his request, the AOP officials supplied fry to Mr. Tongsoon

Table 6. DOF and AOP input support to project farmers.

| Farmer's Name | Fry[1] (Number) | Feed[1] (kg) | | Fertilizers and Lime[2] (kg) | | | Total Support (Baht equivalent) |
|---|---|---|---|---|---|---|---|
| | | *Pig Feed Conc.* | *Rice Bran* | *Urea* | *TSP* | *Lime* | |
| Mr. Tongsoon | 4,000 | 4 | 2 | | | | 1,258.0 |
| Mr. Phai | 3,200 | 6 | - | 200 | 100 | 50 | 3,745.5 |
| Mr. Chairat | 1,600 | 4 | 2 | 100 | 50 | | 4,006.0 |
| Mr. Sopar | 3,200 | 2 | 1 | 250 | 100 | 60 | 4,148.0 |
| Mr. Boonsong | 800 | 2 | 1 | 47 | 27 | 5 | 929.0 |
| Mr. Kampong | 1,200 | 2 | 1 | 57 | 32 | 50 | 1,281.0 |
| Mr. Sunan | 1,200 | 2 | 1 | 73 | 20 | 60 | 1,316.9 |
| Mr. Prasobchai | 1,000 | 2 | 1 | | | | 329.0 |
| Mr. Wantamid | 4,000 | 2 | 1 | | | | 149.0 |
| Mr. Sagnuansak | 3,000 | 2 | 1 | | | | 929.0 |
| Mr. Surin | 3,000 | 2 | 1 | | | | 929.0 |
| Mr. Tawatchai | 2,000 | 2 | 1 | | | | 989.0 |
| Mean (SD) | 2,050 (1,179) | 2.7 (1.3) | 1.2 (0.4) | 121.2 | 54.8 | 45.0 | 1,667.5 (1,432.5) |

[1] AOP Support
[2] DOF Support

Table 7. Nursing details in high-input on-farm trial, Thailand.

| Farmer's Name | Hapa Size ($m^3$) | Size at Start of Nursing (cm) | Size at End of Nursing (cm) | Days Nursed | Fry at Start of Nursing | Density at Nursing (fry $m^{-3}$) | Survival at End of Nursing (%) |
|---|---|---|---|---|---|---|---|
| Mr. Tongsoon | 20.3 | 2 | 8 | 35 | 4,000 | 198 | 99.5 |
| Mr. Phai | 20.3 | 2 | 6 | 56 | 3,200 | 158 | 84.4 |
| Mr. Chairat | 4.9 | 1 | 7 | 40 | 1,600 | 329 | 44.1 |
| Mr. Sopar | 20.3 | 1 | 8 | 31 | 3,200 | 158 | 96.9 |
| Mr. Boonsong | 4.9 | 1 | 7 | 41 | 800 | 165 | 68.8 |
| Mr. Kampong | 4.9 | 1 | 7 | 57 | 1,000 | 206 | 77.5 |
| Mr. Sunan | 4.9 | 1 | 6 | 30 | 1,200 | 247 | 1.6 |
| Mr. Prasobchai | 5.4 | 1 | 6 | 35 | 1,000 | 185 | 95.5 |
| Mr. Wantamid | 20.3 | 1 | 7 | 43 | 4,000 | 198 | 75.0 |
| Mr. Sagnuansak | 5.4 | 1 | 7 | 30 | 3,000 | 556 | 96.7 |
| Mr. Surin | 32.4 | 1 | 7 | 43 | 3,000 | 93 | 100.0 |
| Mr. Tawatchai | 4.9 | 1 | 8 | 51 | 2,000 | 412 | 65.0 |
| Mean (SD) | 12.4 (9.7) | 1.2 (0.4) | 7.0 (0.7) | 41.0 (9.6) | 2,333 (1198) | 242 (130) | 75.4 (28.9) |

the third week of March. The details of nursing are presented in Table 7.

Hapa size varied greatly among the farmers. The hapas of two-thirds of the project farmers were approximately 5 $m^3$. By contrast, four farmers had hapas 20 $m^3$ or larger. The average size of nylon hapas used for nursing was estimated to be 12.4 $m^3$.

The average number of fry released into hapas for nursing was estimated to be 2,333. Numbers stocked ranged from 800 (Mr. Boonsong) to 4,000 (Mr. Tongsoon and Mr. Wantamid). In general, variation in the number of fry nursed by the project farmers was related to pond size, since the AOP staff had estimated the number of fry required to maintain the recommended density (2 to 3 fish $m^{-2}$) at the time of stocking.

The duration of nursing fry in hapas ranged from 30 to 57 days with an average of 41 days. Despite a wide range in nursing duration, the size of fingerlings at the end of nursing was estimated to lie in the narrow range of 6 to 8 cm. This was because stocking density and feeding management while nursing fry in nylon hapas varied greatly among the project farmers. Water quality also has an important role in the growth of fry during nursing. In general, the size of fingerlings at the end of nursing in all the farms was related to the duration of nursing and amount of supplementary feed supplied.

Pig concentrate and rice bran applied at a 2:1 ratio were recommended as supplementary feed for fry throughout nursing. On average, farmers fed 130 g of pig feed concentrate and 76 g of fine rice bran per day per 1000 fry. Thus, on average, farmers followed the ratio recommended by the AOP. Mr. Tongsoon, who nursed 2-cm fry for only 35 days and supplied 340 grams of feed per 1000 fry per day (the highest rate among all the project farmers), had 8-cm fingerlings at the end of nursing. By contrast, Mr. Wantamid, who nursed fry for 43 days but with the minimum quantity of supplementary feed, had 7-cm fingerlings at the end of nursing. In addition to pig feed concentrate and rice bran, a number of project farmers reported that they had supplied some other inputs during nursing. Morning glory, a common vegetable crop, was a popular supplementary feed.

Density of fry during nursing, which was largely affected by the size of hapas, ranged from 93 fry $m^{-3}$ (Mr. Surin) to 556 fry $m^{-3}$ (Mr. Sagnuansak), with an average of 242 fry $m^{-3}$. Despite the large variation in fry density, its effect on growth was not obvious. Density is expected to affect growth of fry if *in situ* production of natural feed (plankton) is occurring; however, as presented earlier (Table 5), water in most of the ponds was clear or turbid, suggesting a very low availability of natural feed (plankton) at the beginning of the trial. But feeding during nursing varied widely among the participant farmers. Hence, the wide variation in time required for fingerlings to reach lengths of 7 to 8 cm was due to the different amounts and types of feed supplied by the farmers during nursing.

The survival rate of fry at most of the farms was estimated to be 75% or more (up to 100%), except for three farmers— Mr. Tawatchai, Mr. Boonsong, and Mr. Chairat. The survival rate of their ponds fell between 44 and 70%. Mr. Sunan, who supplied pig fat as a supplementary feed during nursing, had < 2% fry survival. It appears that the supplement of pig fat killed virtually all the fry in his hapa. Later, the DOF Extension Officers resupplied Mr. Sunan with 1,000 fingerlings of tilapia, common carp, *Puntius*, and *Pangasius*.

## Stocking Density

As mentioned earlier (Table 2), farmers were advised to stock 2 to 3 fish $m^{-2}$. There is an inverse relationship between total number of fish stocked and the growth of an individual fish in a culture facility. Maintenance of proper stocking density aims to produce the maximum biomass of the optimum or desired size fish from a culture facility. While maintaining stocking density, attempts should be made to ensure a balance among total food demand for fish growth, *in situ* production of natural feed, and supplementary feed in the pond.

Prior to seed distribution, pond size was estimated on all farms. Based on pond size and the recommended stocking density, the total number of fry to stock was estimated and farmers were supplied with the sex-reversed tilapia fry accordingly. Therefore, average stocking density, 3.1 fish $m^{-2}$, remained quite close to or within the recommended range (2 to 3 fish $m^{-2}$) in all farmers' ponds, except in Mr. Surin's and Mr. Boonsong's. The former stocked 8 fish $m^{-2}$, the highest (and extreme) stocking density among the project farmers, and the latter stocked only 1 fish $m^{-2}$, the lowest (Figure 1).

## Culture Period

The culture period, recommended for six months, varied notably among the farmers. Two farmers, namely Mr. Phai and Mr. Wantamid, had to terminate the trial after four months as water level in their ponds dropped rapidly after the cessation of the rainy season. By contrast, a number of farmers whose ponds retained sufficient water extended the culture period, which, in general, ranged between 8 and 11 months. The farmers' preference for larger fish was the main reason for extending the culture period. A total of six farmers, though they cultured fish for the extended period, also followed a multiple harvesting strategy in order to fulfill household consumption as well as cash needs. By contrast, Mr. Sopar, who had another pond with enough fish for household consumption, continued fish culture for 11 months. Market price was another factor that led some farmers to extend the culture period. Mr. Sagnuansak and Mr. Sopar harvested most of their stock at the time of the visit of Princess Sirindhorn, a member of Thai Royal family, to the village school since the price of fish in the local market was high at that time.

## Pond Fertilization

Pond fertilization during the culture period varied greatly among the farmers. DOF support, scheduled for the specified experimental period, was discontinued after six months; however, a number of project farmers raised fish for more than six months. After free input support was discontinued, fertilization practice among the DOF-supported farmers started to vary to a greater extent than before. Details of the project farmers' pond fertilization practices are presented in Table 8.

All the project farmers, following the AOP recommendation, applied lime in their ponds prior to commencing the trial. The average amount of lime applied was estimated to be 1,160 kg $ha^{-1}$, but the amount applied varied widely. Mr. Surin applied lime at an extrapolated rate of nearly 4,000 kg $ha^{-1}$, the highest rate among all farmers. By contrast, Mr. Wantamid applied at the rate of 112 kg $ha^{-1}$, the lowest rate among participant farmers.

Farmers were advised to apply fertilizers (urea and TSP) at weekly intervals at the rate of 4 kg N and 1 kg P $ha^{-1}$ $d^{-1}$, respectively. In the beginning, based on the recommendation, AOP staff assisted the project farmers in estimating the weekly requirement of these fertilizers for their ponds.

Though all the participant farmers applied urea as a pond input, only two farmers, Mr. Tongsoon and Mr. Tawatchai, reported that they applied the recommended quantity. Others applied either less or more than the recommended rate. Mr. Phai applied the highest amount of urea, at an extrapolated rate of around 21 kg $ha^{-1}$ $d^{-1}$. He also applied organic manure in his pond. Therefore, total N supplied to Mr. Phai's pond was estimated to be excessively high (10.5 kg $ha^{-1}$ $d^{-1}$), more than twice the recommended rate. Two other farmers, Mr. Sunan and Mr. Sagnuansak, also applied an excessive amount of urea; both of them applied N at a rate 50% higher than recommended. The rest of the farmers applied 2 to 4 kg N $ha^{-1}$ $d^{-1}$, except Mr. Wantamid, who applied N at the lowest rate (only 5% of the recommended rate).

Most farmers applied P at a higher rate than recommended. The average rate of application of TSP was nearly two times the recommended rate (1.9 kg $ha^{-1}$ $d^{-1}$). Mr. Phai, who applied an excessively high rate of N, also applied the highest amount of TSP (5 kg P $ha^{-1}$ $d^{-1}$). By contrast, Mr. Surin and Mr. Wantamid did not apply TSP at all. Mr. Prasobchai was the only farmer who applied TSP at the recommended rate.

In addition to urea and TSP, all farmers reported that they applied animal and/or poultry manure to their ponds. Mr. Phai, who applied N and P at extremely high rates, also applied approximately 650 kg of chicken manure to his pond. Mr. Wantamid and Mr. Surin applied a considerable amount of buffalo and cattle manure to their ponds, which contributed to the P supply to some extent since neither of them applied TSP. Both inorganic and organic sources are considered when estimating the total N and P supply in the pond. Hence, the total N and P supplies presented in Figure 2 represent the sum of inorganic fertilizers and organic manure.

The application of animal manure was often based on its availability at the farm (Table 4). However, two farmers applied chicken manure as an off-farm input. Mr. Tongsoon and Mr. Sagnuansak applied chicken manure as a pond input, although they did not own any chickens. By contrast, Mr. Tawatchai, despite having chickens and cattle on his own farm, applied cattle manure but not chicken manure (Table 8).

## Species Stocked

Despite AOP recommendation of and support for the monoculture of sex-reversed tilapia for the on-farm trial, a

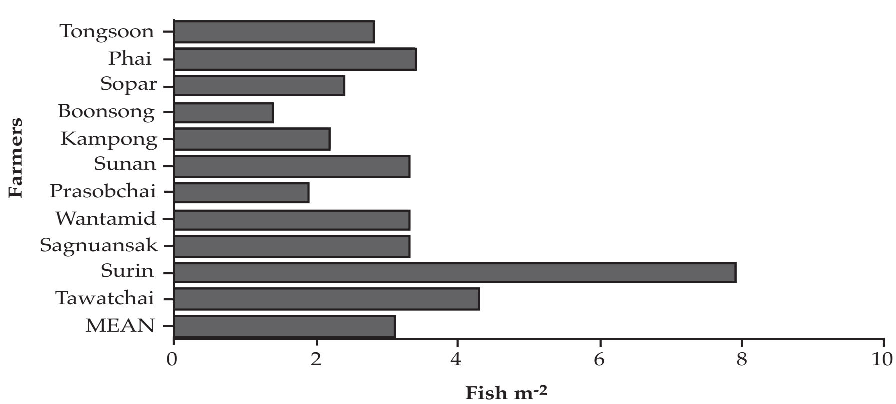


Figure 1. Estimated stocking density in farmers' ponds in high-input on-farm trial.

Table 8. Pond fertilization during culture period.

| Farmer's Name | Culture Period (d) | Lime Added before Culture Period (kg pond$^{-1}$) | Urea | | TSP | | Manure (kg pond$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | *kg pond$^{-1}$* | *N kg ha$^{-1}$ d$^{-1}$* | *kg pond$^{-1}$* | *P kg ha$^{-1}$ d$^{-1}$* | *Buffalo/ Cattle* | *Chicken* | *Pig* |
| Mr. Tongsoon | 150 | 40 | 150 | 3.47 | 150 | 3.3 | 1,000 | 360 | |
| Mr. Phai | 120 | 80 | 200 | 10.4 | 100 | 5.1 | | 650 | |
| Mr. Chairat | 330 | 25 | 150 | 3.3 | 50 | 1.1 | | | 96 |
| Mr. Sopar | 270 | 60 | 224 | 3.1 | 100 | 1.4 | | 448 | |
| Mr. Boonsong | 270 | 5 | 47 | 2.1 | 27 | 1.2 | | | 120 |
| Mr. Kampong | 270 | 50 | 57 | 2.9 | 32 | 1.6 | | | 180 |
| Mr. Sunan | 150 | | 73 | 6.5 | 20 | 1.8 | | 50 | |
| Mr. Prasobchai | 120 | 25 | 28 | 3.0 | 10 | 1.0 | | | 1,500 |
| Mr. Wantamid | 270 | 10 | 10 | 0.3 | | 0.0 | | | 420 |
| Mr. Sagnuansak | 270 | 200 | 30 | 5.9 | 200 | 3.9 | | 150 | 200 |
| Mr. Surin | 270 | 150 | 34 | 1.8 | | 0.1 | | 1,150 | |
| Mr. Tawatchai | 240 | 50 | 50 | 4.1 | 30 | 2.3 | | 2,760 | |
| Mean (SD) | 228 (72) | 63 (60.5) | 110 (93) | 3.6 (1.5) | 72 (64) | 1.8 (1.5) | | | |

number of farmers mixed other fish species in their ponds. These additional species did not appear to have a significant effect on stocking density or yield in most of the farmers' ponds. Mr. Sunan, a farmer of Nakorn Phanom, stocked a mix of different species since virtually all the sex-reversed tilapia fry supplied to him died at the time of nursing. Therefore, Mr. Sunan practiced polyculture for his on-farm trial.

## Harvesting and Yield

As mentioned earlier, the project farmers followed different strategies for stocking, feeding, and harvesting. Total fish production also varied from one pond to another. It is interesting that average extrapolated yield (944 kg rai$^{-1}$) was estimated to be higher than the expected yields based on on-station trials (600 kg rai$^{-1}$) (Table 9). Moreover, average yield recorded in these trials was higher than that recorded in a similar trial with three farmers—namely Mr. Sawat, Mr. Bang, and Mrs. Vichai—of Udorn Thani in 1995. Among other factors, the difference between the recommended (6-month) and practiced (average 7.5-month) culture periods contributed to higher average yield estimated from these on-farm trial results. Data analysis revealed a positive correlation (correlation coefficient = 0.56) between total yield and culture period. Similarly, a positive relation was established between total yield and stocking density (correlation coefficient = 0.51).

Extrapolated yields ranged from 292 to 1,322 kg rai$^{-1}$. Mr. Tawatchai produced 244 kg of fish from his pond, which was equal to an extrapolated yield of nearly 1,300 kg rai$^{-1}$. The higher yield recorded in Mr. Tawatchai's pond was associated with the optimum stocking density (Figure 1), extended culture period (nine months), and adequate fertilization (Figure 2). Mr. Sunan's harvest had the highest extrapolated yield, slightly higher than that recorded in Tawatchai's pond, and was probably associated with polyculture of larger fingerlings. The yield presented in Table 9 is total fish harvested from the pond. For a number of cases, the yield presented is the cumulative yield of multiple harvests. For others, it represents a single harvest at the end. The varying harvest strategies (single vs. multiple) and culture periods selected by the farmers might also have affected the total yield, causing differences in yield per unit area.

## Significance of the Trial

The significance of this high-input on-farm trial is discussed in terms of change in water color, farmers' perceptions of the trial, and three interrelated aspects of aquaculture—production, socioeconomic, and environmental concerns.

Water Color

At the beginning of the on-farm trial, when water quality was assessed, Mr. Phai was the only farmer with green water in his pond. Mr. Phai, who had been raising fish for 30 years, was aware of the significance of water color for fish growth. In the other farms, pond water was either clear or turbid prior to commencement of the trial. However, when water quality was assessed at the end of the trial, most of the ponds had become green or dark green (Figure 3). The observed change in water color was due to the growth of plankton as a result of fertilization. Virtually all project farmers experienced a substantial increase in fish yield, which was associated with the change in water color from turbid to green or dark green (rich in plankton) after application of urea and TSP. As indicated by the change in water color, *in situ* production of an ample amount of natural feed was accomplished by applying low cost off-farm inputs, thus achieving the main objective of this on-farm trial.

Farmers' Perceptions

At the end of the trial, virtually all the participant farmers were very satisfied with the significant increase in fish production from their ponds. Ten out of twelve farmers expressed that they had decided to continue this practice in the coming years. Two farmers, namely Mr. Chairat and Mr. Kampong, though satisfied with the production, expressed difficulties in purchasing fertilizers (due to either unavailability or expense), particularly TSP, in the local market. When asked about difficulties in following the recommendations, all the participant farmers reported that the recommendations were very easy to follow and they were confident that they could continue the practice without technical assistance in the years to come. Moreover, farmer-to-farmer dissemination of the high-input fertilization technology was evident. Virtually all the project farmers reported that they had relayed the recommendations to their relatives and/or neighbors.

In general, most of the farmers were satisfied with the size of fish obtained at the end of the trial. However, three farmers, namely

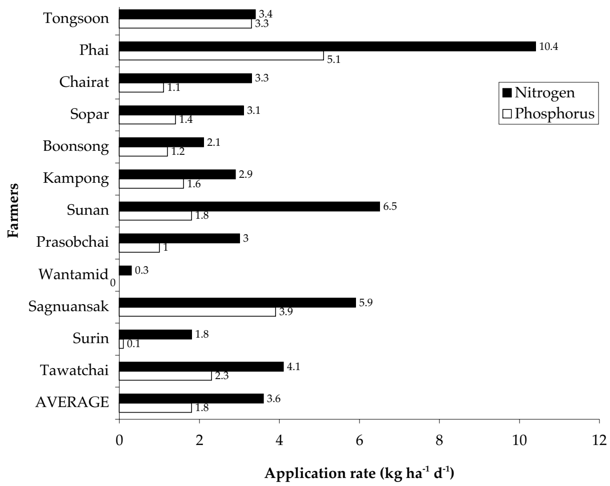


Figure 2. Average N and P (kg ha$^{-1}$ d$^{-1}$) applied during culture period.

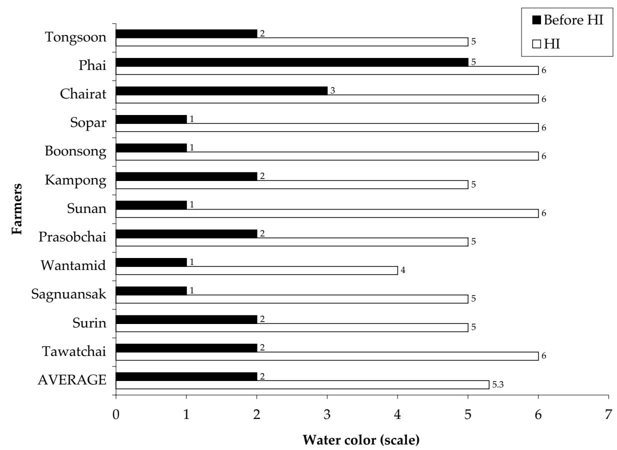


Figure 3. Water color of the participant farmers' ponds before and after high-input fertilization (HI). Scaling for water color: 1 (clear), 2 (turbid), 3 (greenish + turbid), 4 (light green), 5 (green), and 6 (dark green).

Mr. Sunan, Mr. Wantamid, and Mr. Tawatchai desired larger fish (2 to 3 fish kg$^{-1}$) than they had obtained (4 to 5 fish kg$^{-1}$). Mr. Surin, who had stocked at an excessively high density (8 fish m$^{-2}$), was the only farmer to express dissatisfaction about the size of individual fish obtained at the end of the trial. Since the individual fish remained quite small, Mr. Surin desired a minimum size of 6 fish kg$^{-1}$. Overall, farmers' perceptions regarding high-input green water technology were highly satisfactory.

Production

Though the trial was carried out with a limited number of participant farmers, the recommendation was found to be one of the viable alternatives to increase fish production under low-input farm conditions. Despite limited control over the trial, the average yield recorded (944 kg rai$^{-1}$) was higher than the expected yield (600 kg rai$^{-1}$) based on on-station results. Moreover, all project farmers, except Mr. Prasobchai, reported a significant increase in fish yield in 1995/96 over the previous year. Average yields were nearly three times higher using high-input green water practices than previous years' yields without using these practices (Figure 4).

The average extrapolated fish yield recorded in a similar on-farm trial carried with three Udorn farmers in 1995 was 460 kg rai$^{-1}$ (AOP, 1995). Interestingly, in this study average production was estimated to be 944 kg rai$^{-1}$ (> 50% higher than the expected yield [600 kg rai$^{-1}$] on the basis of on-station trial results). However, on-station trial results were based on a six-month culture period. By contrast, the average culture period in this study was 7.5 months (range: 4 to 11 months). The average extrapolated yield of the four farmers—Mr. Tongsoon, Mr. Phai, Mr. Prasobchai, and Mr. Wantamid—who raised fish for six months or less was still estimated to be higher (668 kg rai$^{-1}$) than the expected yield. Four other farmers—Mr. Kampong, Mr. Sunan, Mr. Surin, and Mr. Tawatchai—who cultured fish for nine months harvested an extrapolated yield of nearly 1,200 kg rai$^{-1}$ or greater. Mr. Prasobchai was the only farmer whose production remained below the on-station trial yield (Figure 4). Hence, fertilization of pond water by using low-cost off-farm inputs (urea and TSP) has proved to be a promising

Table 9. Culture period and fish yield in the high-input on-farm trial.

| **Farmer's Name** | **Culture Period (m)** | **Fish Yield** | | |
|---|---|---|---|---|
| | | *kg pond$^{-1}$* | *kg ha$^{-1}$* | *kg rai$^{-1}$* |
| Mr. Tongsoon | 5 | 743 | 5,159.7 | 825.6 |
| Mr. Phai | 4 | 358 | 4,475.0 | 716.0 |
| Mr. Chairat[1] | | | | |
| Mr. Sopar | 11 | 780 | 6,000.0 | 960.0 |
| Mr. Boonsong | 9 | 180 | 4,500.0 | 720.0 |
| Mr. Kampong | 9 | 260 | 7,428.6 | 1,188.6 |
| Mr. Sunan | 9 | 285 | 8,260.9 | 1,321.7 |
| Mr. Prasobchai | 5 | 90 | 1,821.9 | 291.5 |
| Mr. Wantamid | 4 | 510 | 5,692.0 | 910.7 |
| Mr. Sagnuansak | 9 | 490 | 5,536.0 | 885.9 |
| Mr. Surin | 9 | 300 | 7,894.7 | 1,263.2 |
| Mr. Tawatchai | 9 | 244 | 8,116.7 | 1,298.7 |
| Mean (SD) | 7.5 (2.5) | 385 (222) | 5,899 (1953) | 943.8 (312.5) |

[1] Final harvest data of Mr. Chairat are not presented since he had migrated by the time fish were harvested.

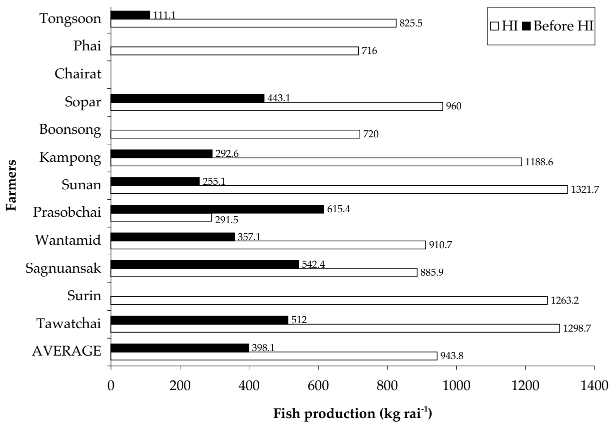


Figure 4. Fish production (per rai) before and after high-input (HI) pond fertilization. A number of farmers started this trial in a new pond. Therefore, fish yield before the high-input on-farm trial was no available in those cases.

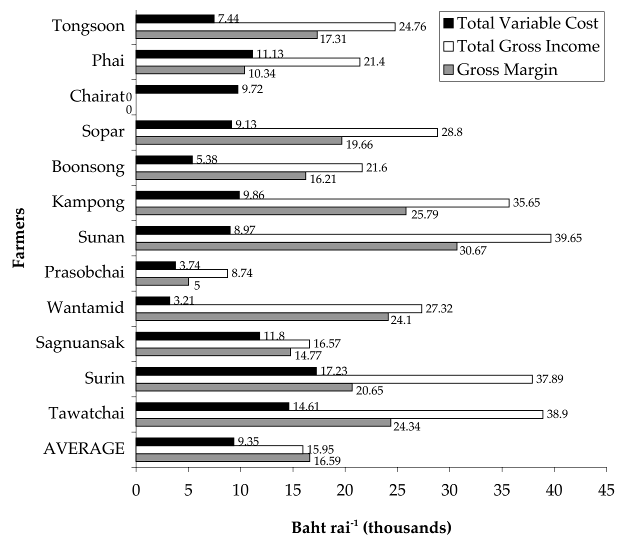


Figure 5. Gross margin analysis of high-input on-farm trial (HI).

recommendation due to its tremendous potential to increase fish production under small-scale farm conditions.

Socioeconomic Aspects

Application of inorganic fertilizers (urea and TSP) as opposed to pig manure and night soil for greening pond water is a widely acceptable option for many societies. Therefore, farmers are not hesitant to use this technology in order to fulfill their household needs for fish. Additionally, surplus fish production over household consumption can be sold in the market to a wide range of consumers.

Prior to commencing the trial and based on the on-station results, expected total variable cost (per rai) for fertilization of

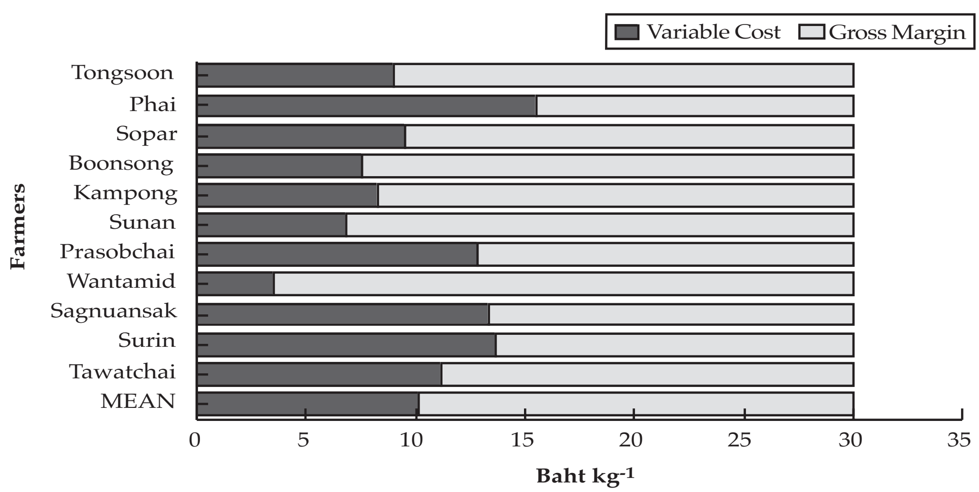


Figure 6. Total variable costs and gross margin of fish production (per kg) in high-input on-farm trial. Market price of fish at the time of survey in Northeast Thailand local markets was around 30 Baht $kg^{-1}$.

Table 10. Estimated costs of high-input trials based on the recommendation for a one-rai pond.

| Input | Price per Unit (Baht) | Amount per Week | Total Amount | Total Cost (Baht) |
|---|---|---|---|---|
| Sex-Reversed Tilapia Fry Fingerlings | 0.5 | - | 3,000 | 1,500.0 |
| Urea (kg) | 5.0 | 9.8 | 251 | 1,255.0 |
| TSP (kg) | 8.0 | 5.6 | 140 | 1,120.0 |
| Lime (kg) | 1.0 | - | 200 | 2,00.0 |
| Overall | | | | 4,075.0 |

Table 11. Economics of high-input green water experiment.

| **Farmer's Name** | **Cost** (Baht) | | | | | | | **Fish Yield** (kg) | **Gross Return** (Baht) | **Gross Margin** (Baht) |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Feed Cost (During Nursing)* | *Pond Maintenance* | *Fry Cost*[1] | *Feed Cost (Supple-mentary)* | *Fertilizers and Manure* | *Marketing Costs* | *Total Variable Costs* | | | |
| Mr. Tongsoon | 361.0 | 64.0 | 1,200.0 | 1,184.0 | 3,844.0 | 50.0 | 6,704.0 | 743 | 22,290 | 15,586 |
| Mr. Phai | 635.0 | | 960.0 | | 3,970.0 | | 5,566.0 | 358 | 10,740 | 5,174 |
| Mr. Chairat | 156.0 | 30.0 | 480.0 | 1,440.0 | 1,785.0 | | 3,891.0 | | | -3,891 |
| Mr. Sopar | 220.0 | 180.0 | 960.0 | 3,240.0 | 2,792.0 | 30.0 | 7,422.0 | 780 | 23,400 | 15,978 |
| Mr. Boonsong | 92.0 | 90.0 | 240.0 | 270.0 | 654.0 | | 1,346.0 | 180 | 5,400 | 4,054 |
| Mr. Kampong[2] | 91.5 | 150.0 | 700.0 | 360.0 | 856.0 | | 2,157.5 | 260 | 7,800 | 5,642.5 |
| Mr. Sunan[3] | 92.5 | 140.0 | 560.0 | 360.0 | 784.0 | | 1,936.0 | 285 | 8,550 | 6,614 |
| Mr. Prasobchai | 96.0 | 43.0 | 300.0 | 381.0 | 336.0 | | 1,156.0 | 90 | 2,700 | 1,544 |
| Mr. Wantamid | 159.0 | 100.0 | 1,200.0 | 226.5 | 1,16.0 | | 1,801.5 | 510 | 15,300 | 13,498.5 |
| Mr. Sagnuansak | 187.5 | 600.0 | 900.0 | 2.4 | 4,840.0 | | 6,530.0 | 490 | 14,700 | 8,170 |
| Mr. Surin | 367.0 | 236.0 | 900.0 | 1,354.0 | 1,237.0 | | 4,094.0 | 300 | 9,000 | 4,906 |
| Mr. Tawatchai | 239.0 | | 900.0 | 995.0 | 907.0 | | 2,741.0 | 244 | 7,320 | 4,579 |
| Mean | 224.7 | 163.3 | 775 | 892 | 1,843.4 | 40 | 3,778.7 | 385.4 | 11,563.64 | 6,821.25 |
| (SD) | (161.6) | (166) | (320) | (925.8) | (1,607.4) | (14) | (2,266.6) | (222) | (6,663.42) | (5,801.04) |

[1] Fry cost includes sex-reversed tilapia as well as other fish (if any).
[2] In addition to sex-reversed tilapia, Mr. Kampong added other fish fry at the time of stocking.
[3] Mr. Sunan had to buy all new seed at the time of stocking because all fry in his hapa died from pig fat fed during nursing.

pond water was estimated to be Baht 4,075 (Table 10). Given an expected fish production of 600 kg rai$^{-1}$ in a six-month culture period and a market price of Baht 30 kg$^{-1}$, the extrapolated gross return was expected to be Baht 18,000. Therefore, a gross margin of nearly Baht 14,000 was expected from a one-rai pond.

The gross margin analysis on the basis of this on-farm trial is presented in Figure 5. The average estimated gross margin (Baht 17,000 rai$^{-1}$ for a 7.5-month culture period) in this trial was higher than expected. Gross margin per rai was estimated to be > Baht 20,000 in the case of four participant farmers, namely Sunan, Tawatchai, Wantamid, and Kampong. These four farmers all raised fish for nine months. Prasobchai had the lowest gross margin (Baht 5,000 rai$^{-1}$). For others, it ranged from Baht 10,000 to 20,000 rai$^{-1}$ (Figure 5).

Assessment of the labor used for different activities, particularly for the day-to-day activities (e.g., fertilizer application and feeding) was not practicable because these activities involved negligible time and farmers were not able to maintain a record of such activities. Therefore, labor cost has not been considered in cost benefit analyses of the high-input on-farm trial. Economic analysis (Table 11) is based on the input costs (fertilizers, feed, seed, and lime) and total output estimated on the basis of total harvest (cumulative or single) and fish price (Baht 30 kg$^{-1}$) in the local market.

The average cost of production was estimated to be Baht 10.1 kg$^{-1}$ of fish. In general, production cost was associated with the quantity of inputs, particularly urea and TSP, applied. Despite very high total yield, cost per kilogram of fish production was also quite high in the case of Mr. Phai. In his case, excessive application of urea and TSP substantially increased production costs, which were estimated to be Baht 15 kg$^{-1}$ of production. Four other farmers—Mr. Prasobchai, Mr. Sagnuansak, Mr. Surin, and Mr. Tawatchai—also had high production costs (> Baht 10 kg$^{-1}$ of fish). For the rest, the input cost was estimated at < Baht 10 kg$^{-1}$ of fish production. Mr. Wantamid had the lowest production costs. Though production cost in his farm was approximately Baht 4 kg$^{-1}$ of fish, total production in his pond was also low due to an inadequate input supply. Mr. Kampong and Mr. Sunan obtained higher yields with relatively low investments. The extrapolated yields from both of their farms was higher than the average, i.e., 1,200 and 1,300 kg rai$^{-1}$, respectively. Meanwhile, their cost per kilogram of fish production (approximately Baht 8 and 7, respectively) was significantly less than the average cost of production (Figure 6).

A comparison between the recommended fertilizer rate and farmer practice reveals additional methods to minimize production cost for some farmers. For example, had Mr. Phai applied fertilizers at the recommended rate, assuming the production was unchanged by additional inputs, the production cost would have been lower since he applied urea and TSP at rates higher than recommended (Table 8). The economic analysis revealed that virtually all the project farmers were successful in producing adequate yields with relatively low production costs. Moreover, it also indicates a way to maintain high production by further minimizing production costs, i.e. by the application of fertilizers within the range of recommended rates.

Nonetheless, before introducing high-input green water technology to a wide range of farm families, a detailed assessment is necessary. Since high-input green water technology involves cash expenses to buy inorganic fertilizers, recommendations need to be tailored to the socioeconomic situations of the farmers. A couple of farmers in this trial, despite their satisfaction with the production technology, reported that application of urea and TSP as pond inputs caused them an additional financial burden. Inorganic fertilizers are relatively inexpensive external inputs for fertilizing a fish pond. Therefore, it is expected that a substantial increase in fish production with a small investment would allow small-scale farmers to sell fish and earn cash income. Most of the project farmers in this on-farm trial were successful in selling fish in the local market, which in general was surplus over household consumption.

Environmental Concerns

A pond is used not only for fish culture in most of the small-scale farms of Northeast Thailand. Pond water is widely used for irrigating fruits and vegetables. Additionally, ponds are a source of water for farm animals for many households. Sometimes ponds are the only source of water for household purposes (e.g. cleaning and cooking) as well. Thus, a farmer with a single pond in a relatively dry area always makes multiple uses of pond water. An environmental impact assessment of high-input green water technology on-farm was beyond the scope of this trial. Therefore, despite its tremendous potential to increase fish production, the impact of the high-input inorganic fertilization system must be assessed in order to understand whether it has negative effects on other sub-systems within the farm. The use of fertilized pond water for different purposes (e.g., household and agricultural) needs to be assessed. In general, most of the ponds are closed and there is little chance to pollute the surrounding environment unless pond water is pumped and drained.

## ANTICIPATED BENEFITS

Culturists throughout southeast Asia and other tropical countries who are remote from CRSP research sites and to whom the CRSP experiments have not been extended. Also, CRSP participants will benefit by receiving more directly the critical needs of fish farmers throughout the region. Finally, regional biologists will benefit from the training and experimental work designed and overseen by CRSP researchers.

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