A Linear Programming Analysis of Integrated Agriculture-Aquaculture Mixed Farming

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ABSTRACT
Aquaculture has the potential for contributing significantly towards enhancing farm income and hence towards solving the poverty problem among farm smallholders. This study attempts to evaluate the economics of mixed farming among sampled farmers in Central Perak and to assess the contribution of aquaculture to the overall farm income. Income from aquaculture was found to be substantial and has the potential for further increase if farm resources are allocated optimally or integrated agriculture with freshwater fish polyculture and broiler meat production can be implemented.

INTRODUCTION
In Malaysia, small-scale polyculture of freshwater fish is commonly practised by rubber smallholders as mixed farming together with livestock rearing, paddy cultivation and fruit farming. In certain parts of the country such as Central Perak, freshwater aquaculture provides significant additional income to these smallholders as well as providing an additional source of animal protein for local consumption. Aquaculture's potential for enhancing farm income has long been accepted by the government but its practical success has yet to be fully realized.

An option that has been tried by enterprising farmers throughout the country is Integrated Aquacultural Farming (IAF). This has been proved to be successful in countries like China and Israel, and to a lesser extent in Thailand, Indonesia and the Philippines (Cruz and Shehedah 1978; Delmondo 1979; Manik and Tiensonggrusmee 1979; Nasaruddin and Mohd. Sheffie 1979; Roestami et al. 1979; Wai 1979; Wetchagarun 1979). IAF is the integration of traditional farming with animal husbandry and fish polyculture. IAF is a system where practically nothing is wasted. In integrated fowl-fish-crop farming, the chicken manure serves as fertilizer for the fish pond as well for the agricultural crops. After the pond water absorbs the water soluble NPK (nitrogen, phosphorus, potassium) components from the chicken manure...
for a phyto-planktonic bloom, the manure wastes are then removed from the pond and further used as fertilizer for the agricultural crops. This removal of the manure from the aquatic medium is vital in preventing pond water oxygen starvation and its acidification from the effects of biodegradation of the animal manure. An ecological balance is thus maintained while a sufficient variety of farm produce is obtained to meet the family food needs as well as cash income (Alsagoff 1985).

This study analyses the economics of mixed farming with freshwater aquaculture as one of the farm enterprises as practised by smallholder farmers in Central Perak. It also attempts to demonstrate through linear programming that farm income can be optimised by upgrading present farms to an IAF system.

SOURCE OF DATA

Both primary and secondary data were used in the study. Primary data were obtained from the farmers in the study area of Bota district in Central Perak. In the state of Perak there were 1,946 fish culturists operating freshwater ponds in 1988 (Dept. of Fisheries Statistics 1989). Research budget constraints and the need to collect detailed information on farming activities and resource use over a period of one and a half years to reflect the farming seasons required the sample size to be limited to 10 case study farms. The ten respondents were initially visited and interviewed for general socioeconomic data, covering aspects such as household composition, age, educational level, land and freshwater pond sizes, and types of land use. Detailed information relating to the daily activities of the farm households, in particular with respect to their allocation of farm labour and the use of farm inputs, was collected for a period of one and a half years from January 1988 to July 1989. These data were used as inputs for technical coefficients and resource constraints in the programming model.

Secondary data on fish stocking and survival rates, and chicken stocking and survival rates were obtained from previous studies (Alsagoff 1985; Alsagoff et al. 1989). These data were used for the technical coefficients for fish stocking and poultry housing capacity constraints.

METHODS AND ANALYSIS OF DATA

The LP (linear programming) technique was used to build a farm model. The LP model requires the following specifications (Hazell and Norton 1986):

1) the alternative farm activities; their unit of measurement, their resource requirements, and any specific constraints on their production.

2) the fixed resource constraints of the farm.

3) the forecast activity returns net of variable costs, often referred to as gross margins.

The mathematical formulation of the LP problem is as follows:

\[
\text{Max } Z = \sum_{j=1}^{n} c_j X_j
\]

such that \[\sum_{j=1}^{n} a_{ij} X_j \leq b_i, \text{ all } i = 1 \text{ to } m\]

and \(X_j \geq 0\), all \(j = 1 \text{ to } n\)

where \(X_j\) = the level of the \(j\)th farm activity, such as the acreage of paddy grown. Let \(n\) denote the number of possible activities; then \(j = 1 \text{ to } n\).

\(c_j\) = the forecasted gross margin of a unit of the \(j\)th activity (e.g. dollars per hectare).

\(a_{ij}\) = the quantity of the \(i\)th resource (e.g. hectares of land or man-hours of labour) required to produce one unit of the \(j\)th activity. Let \(m\) denote the number of resources; then \(i = 1 \text{ to } m\).

\(b_i\) = the amount of the \(i\)th resource available (e.g. hectares of land or man-days of labour).

\(Z\) = the total gross margin from all the farm activities.

The LP programming model provides a natural framework for organizing quantitative information about the supply side of agriculture. It also enables different kinds of sensitivity analysis. The model is useful in calculating the implications of different resource endowments, different market conditions, and improved technologies such as integrated agriculture-aquaculture mixed farming. This kind of information is generated by the
model via variations in parameter values, with a new solution obtained for each set of parameter values.

The LP technique was used, first, to analyse the data collected from the sampled farm households, so as to determine the optimal mix of farm activities as currently practised by farmers in the area. It was then applied to an "ideal farm" where the proposed farming improvement with broiler meat production (in chicken houses built over the fish ponds) was incorporated into the present farm plan, instead of the existing, typical free-ranging chicken activity. Broiler meat production was suggested for the extra value of chicken manure as a source of NPK components to stimulate phyto-planktonic growth (for fish food) in the existing fish pond.

The data collected from the 10 farmers, who all have fish ponds with aquacultural activities, show that six of them also have rubber plots, ranging from 0.81ha to 1.62ha. Six of them also have banana plots of 0.4ha to 1.62ha. Four of the ten also own durian trees, ranging from an equivalent of 0.4ha to 1.62ha. Two of them have paddy fields (0.4 and 1.21ha) while two others have coconut holdings (0.32 and 0.81ha). The average monthly farm income ranges from $34 to $603 depending on the season. The group’s average monthly farm income of $311 was, however, below the poverty income level. The average annual income for the various farm enterprises was $479/ha for coconuts, $1,199/ha for rubber, $1,250/ha for bananas, $1,110/ha for paddy, $2,358/ha for durians (see Table 1).

The "ideal farm" used in the LP model was the average of the ten sampled case study farms. Thus the model farm was of a 2.5ha size, with 0.8ha under rubber (at 500 trees/ha density), 0.4ha bananas (at 1,060 trees/ha density), 0.4ha paddy, 0.5ha durian trees (at 90 trees/ha density) and 0.5ha coconut (at 130 trees/ha). The size of the fish pond was 0.10ha in which grass carp were stocked at the rate of 250/ha with a survival rate of 70%. Also stocked in polyculture were bighead carp, at 400/ha with 70% survival rate. It was also proposed that red Nile tilapia planktonic feeders be added in polyculture at 20,000/ha with 90% survival rate. The suggested broiler production was to be raised in 4 sheds (each 5 m x 3 m) built over the fish pond. One-week-old chicks bought and stocked at a maximum rate of 100/shed and with 5% mortality, led to 380 broilers sold every 2 months (Alsagoff et al. 1990; Jabatan Pertanian 1987: Kementerian Pertanian 1989; Taufik 1986).

**LP Model from the Proposed IAF Plan**

The LP matrix developed from the 10 farms had 9 crops and livestock activities subjected to 11 constraints. Variables in the model are as follows:

- \(X_1 = \text{rubber}\)
- \(X_2 = \text{banana}\)
- \(X_3 = \text{paddy}\)
- \(X_4 = \text{durian}\)
- \(X_5 = \text{coconut}\)

### TABLE 1

<table>
<thead>
<tr>
<th>Farm No.</th>
<th>Area (ha)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Average Return $/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber X1</td>
<td>0.45</td>
<td>927</td>
<td>596</td>
<td>3302</td>
<td>1064</td>
<td>743</td>
<td>1115</td>
<td>1199</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banana X2</td>
<td>0.40</td>
<td>1783</td>
<td>61</td>
<td>95</td>
<td>2669</td>
<td>684</td>
<td>1250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paddy X3</td>
<td>0.40</td>
<td>288</td>
<td>1500</td>
<td>1110</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durian X4</td>
<td>0.56</td>
<td>1656</td>
<td>3455</td>
<td>2432</td>
<td>1986</td>
<td>2358</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coconut X5</td>
<td>0.40</td>
<td>419</td>
<td>123</td>
<td>479</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish X6 and X7</td>
<td>0.19</td>
<td>225</td>
<td>402</td>
<td>198</td>
<td>482</td>
<td>1026</td>
<td>1452</td>
<td>2806</td>
<td>1291</td>
<td>3296</td>
<td>1885</td>
<td></td>
</tr>
<tr>
<td>Total Income $</td>
<td>5010</td>
<td>402</td>
<td>1148</td>
<td>7239</td>
<td>1026</td>
<td>1547</td>
<td>5802</td>
<td>4826</td>
<td>3920</td>
<td>6486</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Monthly Income $</td>
<td>418</td>
<td>34</td>
<td>95</td>
<td>603</td>
<td>86</td>
<td>129</td>
<td>484</td>
<td>402</td>
<td>327</td>
<td>541</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The objective function for the LP equation was to maximise annual farm income $Z where,

$$Z = 357X_1 + 112X_2 + 163X_3 + 436X_4 + 56X_5 + 7X_6 + 7X_7 + 3X_8 + 20X_9.$$ 

The net income for each of the activities is as shown in Table 2.

The net income per year is obtained after accounting for the initial stocking costs, mortality and other relevant operating costs. The objective function is subject to the following constraints:

1. Annual Labour Needed
The annual labour required for the nine enterprise activities is as shown in Table 3. The labour constraint is therefore:

$$122X_1 + 183X_2 + 365X_3 + 9X_4 + 56X_5 + 0.18X_6 + 0.18X_7 + 0.18X_8 + 17X_9 \leq 2,555 \text{ man-hours/yr}$$

The coefficients for the various enterprise activities are defined as follows:

For X1: 122 man-hrs/ha from 4 hrs/day work for 1.2ha

For X2: 183 man-hrs/ha from 2 hrs/day work for 0.4ha

For X3: 365 man-hrs/ha from 2 hrs/day work for 0.4ha

For X4: 9 man-hours/ha from 1.5 hrs/day work for only 30 days/yr/0.5ha

For X5: 56 man-hours/ha from 2 hrs/day work for 7 days each month/0.3ha

For X6, X7, X8: 0.18 man-hours/fish from 1hr/day work for 365 days/yr for a total of 2,065 fish stocked/0.1ha pond

For X9: 17 man-hours/6 broiler cycles from 3 hrs work each day caring for a maximum of 400 broilers for 6 production cycles of two months duration each with 5% mortality.

The total labour constraint of 2,555 man-hours is based on a 7 hour workday for 365 days.

2. Initial Capital and Annual Operating Costs
The total capital and annual operating cost constraint is $14,482 and is the value of maximum savings required at the beginning of the farm plan. The capital and annual operating costs constraint is therefore:

$$4.43X_1 + 79.38X_2 + 61.75X_3 + 0.75X_6 + 0.75X_7 + 0.05X_8 + 27.48X_9 \leq 14,482$$

<table>
<thead>
<tr>
<th>Activity</th>
<th>Net Income Per Year $</th>
<th>Details of Net Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber (X1)</td>
<td>357</td>
<td>Net income from 0.1 ha plot of rubber</td>
</tr>
<tr>
<td>Banana (X2)</td>
<td>112</td>
<td>Net income from 0.1 ha plot of bananas</td>
</tr>
<tr>
<td>Paddy (X3)</td>
<td>163</td>
<td>Net income from 0.1 ha plot of paddy</td>
</tr>
<tr>
<td>Durian (X4)</td>
<td>436</td>
<td>Net income from 0.1 ha plot of durians</td>
</tr>
<tr>
<td>Coconut (X5)</td>
<td>56</td>
<td>Net income from 0.1 ha plot of coconuts</td>
</tr>
<tr>
<td>Grass Carp (X6)</td>
<td>7</td>
<td>Net income from each 3.0 kg grass carp sold at $2.70/kg.</td>
</tr>
<tr>
<td>Bighead Carp (X7)</td>
<td>7</td>
<td>Net income from each 2.4 kg bighead carp sold at $3.30/kg.</td>
</tr>
<tr>
<td>Red Nile Tilapia (X8)</td>
<td>3</td>
<td>Net income from each 330 gm red tilapia sold at $10/kg.</td>
</tr>
<tr>
<td>Broiler (X9)</td>
<td>20</td>
<td>Net income per year from six two-month production cycle per year where each broiler is 1.8 kg and sold at $4.40/kg.</td>
</tr>
</tbody>
</table>
The coefficients for the various enterprise activities are shown in Table 3.

3. Maximum Fish Stocking Densities in the 0.1ha Pond

The size of pond, the feeding requirements and feeding habits of the fish stocked together with the water condition in the pond determine the maximum fish-stockig densities. The grass carp, which is herbivorous, is an upper strata foodniche fish. The bighead carp is a phyto-planktonic bottom strata foodniche fish. The tilapia is a planktonic middle strata foodniche fish. The recommended stocking rates are as follows:

i) 40 \times 6 \leq 1,000 \text{ sq metres herbivore upper strata foodniche for grass carp}

ii) 25 \times 7 \leq 1,000 \text{ sq metres phyto-planktonic bottom strata foodniche for bighead carp}

iii) 0.5 \times 8 \leq 1,000 \text{ sq metres planktonic middle strata foodniche for tilapia}

iv) 10 \times 7 + 0.5 \times 8 \leq 1,000 \text{ sq metres shared planktonic foodniche for bighead carp and tilapia}

4. Poultry Housing Capacity

The maximum number of broilers that can be produced given four sheds is 400. The broiler constraint is therefore:

\[ X_9 \leq 400 \text{ broilers for 4 sheds} \]

5. Land

The maximum land available for all the activities is 2.5 ha. The land constraint for each of the activities is as follows:

i) \( X_1 \leq 8 \text{ plots of 0.1ha rubber trees} \)

ii) \( X_2 \leq 4 \text{ plots of 0.1ha banana trees} \)

iii) \( X_3 \leq 4 \text{ plots of 0.1ha wet paddy cultivation} \)

iv) \( X_4 \leq 5 \text{ plots of 0.1ha durian trees} \)

v) \( X_5 \leq 3 \text{ plots of 0.1ha coconut trees} \)

**RESULTS AND DISCUSSION**

Results of the LP analyses reveal that there is an optimum solution to maximize annual farm income that is feasible in the proposed IAF model (see Table 4). The optimum annual farm income achieved is $12,474.25 ($1,039.50/month). This is 3.9 times the present monthly average of $311.67 (see Table 1). The feasible solution consists of the following crops and livestock enterprises:
i) 8X1 i.e. tap all 0.8 ha rubber at latex price of $1.13 - $1.59 per kilo

ii) 4X5 i.e. collect all 0.5 ha durians at $4/kg for grade B and $1/kg for grade C,

iii) 25X6 i.e. stock all grass carp for sale after 1 yr (3 kg at $2.70/kg with 30% mortality)

iv) 2,000X8 i.e. stock all tilapia for sale after 1 yr (330gm at $10/kg with 10% mortality)

v) 68X9 i.e. stock 68 chicks for 6 two-month production cycles for a total of 408 broilers for sale when 1.8 kg (at $4.40/kg with 5% mortality).

Introducing the IAF concept by adding another freshwater fish i.e. the red Nile tilapia to the existing set-up of grass and bighead carp, and poultry broiler production for the added value of free NPK production, not only tripled annual farm returns, but also changed the existing farming plan. Bananas, paddy and coconuts are not in the solution. For the freshwater polyculture activities, bighed carp loses out to tilapia which fetches a higher price, resulting in all the foodniches being utilized. However, grass carp which fetches about the same price as bighed carp, remains in the solution due to its speciality of feeding on macrophytes, grass and leaves and even tapioca shoots. In addition, relative to tilapia, the bighed carp is more costly to raise than grass carp.

Rubber tapping remains in the optimum solution. Poultry broiler enterprise enters the solution due to a short production cycle and good price.

Lastly, durian remains stable in the optimization runs, due to its high price and the fact that the initial planting costs were not accounted for in the model. It should be remembered that the durian tree takes up to 12 years before bearing fruit. The farmers all know this, which is why, during the fruiting season, their focus is on durian collection.

**Sensitivity Analysis**

Sensitivity or post-optimality analysis is the study of how the optimum solution and the values of the optimum combination of enterprises in the solution will change if the current values of the objective function, or the constraints that it was subjected to, change (Harold et al. 1986). By employing sensitivity analysis, we will be able to answer the following questions:

1) How changes in the coefficient of the objective function (Cj i.e. the prices of the different farm produce) will affect optimal solution.

2) How changes in the various constraints of the RHS (right-hand-side) values (Bi i.e. the area of land, labour hours, fish-stocking densities and working capital available) will affect the optimal solution.

**Range Allowable for Objective Function Coefficients (Cj):**

Table 5 shows the summary of the range when the Cjs are allowed to change without changing the optimal solution. It shows the range of validity for each farm enterprise (X1-X9) and the allowable limits of increase and decrease of each of the relevant coefficients. For rubber (X1) the annual net income can decrease from $356.83 to $141.11/0.10 ha/yr and still be in the optimal solution, so it is a very stable choice. For durian (X4) a decrease of $425.36/0.1 ha/yr to a price of $10.44/
0.1ha/yr is required before it will be out of the optimal solution. The net income can fall up to 21 cents for each 3kg of grass carp (X6) before it is driven out of the optimal solution. This large change required is because the grass carp is a macrophytic grass feeder. For tilapia (X8) the net income has to fall by 55 cents for each 330 gm fish before it is driven out of the solution. This is because the tilapia does not need any external feed as the phytoplankton produced from chicken manure is sufficient for its growth. The results suggest that the optimal plan is very stable.

TABLE 5
Sensitivity analysis: OBJ coefficient ranges

<table>
<thead>
<tr>
<th>Variable</th>
<th>Current Coefficient</th>
<th>Allowable Increase</th>
<th>Allowable Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>365.830000</td>
<td>Infinity</td>
<td>215.721600</td>
</tr>
<tr>
<td>X2</td>
<td>111.880000</td>
<td>99.769310</td>
<td>Infinity</td>
</tr>
<tr>
<td>X3</td>
<td>163.250000</td>
<td>260.048600</td>
<td>Infinity</td>
</tr>
<tr>
<td>X4</td>
<td>435.800000</td>
<td>Infinity</td>
<td>425.362500</td>
</tr>
<tr>
<td>X5</td>
<td>56.400000</td>
<td>8.544441</td>
<td>Infinity</td>
</tr>
<tr>
<td>X6</td>
<td>7.250000</td>
<td>7.041250</td>
<td>Infinity</td>
</tr>
<tr>
<td>X7</td>
<td>7.250000</td>
<td>47.783750</td>
<td>Infinity</td>
</tr>
<tr>
<td>X8</td>
<td>2.950000</td>
<td>4.000000</td>
<td>Infinity</td>
</tr>
<tr>
<td>X9</td>
<td>20.040000</td>
<td>30.638250</td>
<td>2.63570</td>
</tr>
</tbody>
</table>

Right-hand Side Range (Bi)

Table 6 summarises the allowable range for the quantity of available resources without changing the optimal solution. It shows that the available annual labour, fixed at 2,555 man-hours/yr (from a 7 hour 7 day work-week), can be reduced to 1,383 hours/yr which is 3.8 hours every day and still not change the optimum solution. This implies that the optimal plan still leaves ample time for the farmer to engage in other non-farm activities.

The working capital of $14,482 can be reduced by $12,264, i.e. be only $2,018 and the optimum mix of farm enterprises will not change. This is due to the strategic IAF system, where only 68 one-week-old chicks are bought for the initial 2-month growth cycle. The initial stocking costs for stocking 2,000 red tilapia at 5 cents each and 40 cents each for the 25 (4 inch) grass carp fingerlings totals a mere $110. After 2 months, when the broilers are sold, then that income can be channelled towards buying the second batch of one-week-old chicks and their starter and finisher ration with their accompanying Ranikhet F and Fowl Pox vaccines (Oh 1971). This result again provides support for the integrated farm plan as it reduces the need for a large capital outlay each year.

TABLE 6
Sensitivity analysis: righthand side ranges

<table>
<thead>
<tr>
<th>Row</th>
<th>Current RHS</th>
<th>Allowable Increase</th>
<th>Allowable Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2555.000000</td>
<td>5739.860000</td>
<td>1172.140000</td>
</tr>
<tr>
<td>3</td>
<td>14482.000000</td>
<td>Infinity</td>
<td>12463.780000</td>
</tr>
<tr>
<td>4</td>
<td>1000.000000</td>
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<td>5</td>
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<td>260475.500</td>
<td>1000.000000</td>
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<tr>
<td>13</td>
<td>400.000000</td>
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<td>332.167800</td>
</tr>
</tbody>
</table>

CONCLUSION

Based on the results presented above, it is evident that if resources can be allocated optimally, and agriculture integrated with aquaculture and livestock rearing, farmers can realize substantial increases in annual farm income. It is also evident that durian cultivation and fish rearing are the two most important sources of income for the farmers in the study area of Central Perak.

As a further step in the development of aquaculture among smallholders in the country, and as already indicated in the introduction of this paper, there is a real need to seriously look into the development of fully integrated agriculture-aquaculture farming systems or the IAF concept, so increase annual farm returns. This is further demonstrated by the recent MARDI-sponsored integrated fowl-rabbits-cum-catfish-cum-paddy complexes built in the Seberang Perai area (NST 1992). With multiple-crop production from the same unit farming area the farm returns should be easily increased to make farming a worthwhile option. Based on our experience from this study we are now setting up an experimental IAF in the Hulu Langat area of Selangor.

ACKNOWLEDGEMENT

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