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Optimum resource allocation on single crop paddy farms in Southern Taiwan

Ching Yuan Chao
Iowa State University

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OPTIMUM RESOURCE ALLOCATION ON SINGLE CROP PADDY FARMS IN SOUTHERN TAIWAN

by

Ching-Yuan Chao

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of

MASTER OF SCIENCE

Major Subject: Agricultural Economics

Signatures have been redacted for privacy

Iowa State University
Of Science and Technology
Ames, Iowa

1961
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I. INTRODUCTION

Taiwan, situated about 100 miles off the southeast coast of the Chinese mainland, is an island. It has a total area of 35,961 square kilometers (about 13,884.53 square miles), of which about 25% (8,333,500 hectares) is under cultivation. Taiwan today has a total population close to 10 million, about 50% of which consists of farm population. There are around 770,000 farm families averaging six-seven persons per family. Average farm size is only 3.00 acres.

Taiwan lies in the sub-tropical region with high temperatures, strong sunlight and abundant rainfall and is suitable for the production of rice, sweet potatoes, sugar-cane and other crops. Crops can be grown on the farms throughout the year due to the favorable natural conditions. In accordance with the data\(^1\) of 1958, rice is the most important crop, followed by sweet potatoes, sugar-cane, peanuts, tobacco, soybeans, tea, and bananas. The value of rice production is approximately 41.43% of the total value of agricultural products with 9.13%, 7.90% and 3.30% for sweet potatoes, sugar-cane and peanuts, respectively.

Since the land resources are limited in Taiwan, keen competition among crops has existed in the use of land. For

---

instance, spring planted crops such as "hu-tze" sweet potatoes, spring sweet potatoes, spring peanuts, 1st upland rice, jute, sesame and small pea, can be grown on the same field at the same time. Since the farm size is very small, usually only one crop is produced. Hence these crops compete directly for use of the land.

Most farmers in Taiwan do not allocate their resources properly, so that they can not maximize their profits. This study attempts to specify the optimum farm plans on single crop paddy farms in Southern Taiwan. It also is designed to provide information to help farmers to allocate their resources properly in order to maximize their farm income. The analysis was made by using the linear programming methods.

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1"Hu-tze" is an interplanting method to plant a crop in the field a few weeks before the harvest of the previous crop. For instance, spring planted "hu-tze" sweet potatoes are planted in late October before the harvest of the 2nd rice crop.
II. OBJECTIVES OF STUDY

The central objective of this study is to determine farm plans which maximize profits for particular farm situations on single crop paddy farms in Southern Taiwan. The more specific objectives are to determine optimum farm plans from the standpoint of resource allocation and crop enterprise combination under the following situations: (1) resources and prices fixed; (2) one resource variable; (3) two resources variable; (4) one price variable; (5) two prices variable.

Linear programming is a recent empirical tool made available to agricultural economists. It has been widely applied to farm management and agricultural production research in the United States. The main purpose of this study is to apply the technique in solving optimum resource allocation problems and to demonstrate how linear programming methods can be used in the study of farm management problems in Taiwan. Also, the results are expected to provide information and guidance in farm organization to farmers in Southern Taiwan for their profit-maximizing farm plans.
III. METHODS OF ANALYSIS

The analysis was carried out by using the linear programming techniques. The mathematical technique permits simultaneous consideration of many possible plans. It allows specification of the most profitable plan, considering capital, land, labor and other restrictions on the farm.

Linear programming has been used as a research tool to specify the optimum allocation of resources and combination of enterprises on farms. The term "linear" refers to "straight line" relationships in production. For this study, it refers to constant resource requirements per hectare or constant yields for each additional hectare, month of labor, or dollar of resources used for different crop.

In linear programming, the optimum plan for a given situation depends on the resources available, the input-output coefficients, and the prices employed in the programming. A change in any one of these three components will change the optimum plan.

When supplies of resources or prices are fixed, the conventional simplex method is quite adequate for the solution of maximum problems. This method was applied to this study. If supplies of resources or prices are variable, a modified simplex method may be used. This modified method is described
as variable resource or price programming.¹

Supplies of resources and prices of most farm products are variable in Southern Taiwan. Therefore this study also involves application of the techniques of variable resource and price programming to specify optimum plans for farms.

---

IV. SOURCE AND NATURE OF DATA

A. Field Survey

The survey was carried out in 11 townships in the county of Chiayi in 1956. Fifty-six single crop paddy farms were selected as samples. Those farms were well organized. The distribution of samples is shown in Table 1.

Table 1. Distribution of samples in the townships

<table>
<thead>
<tr>
<th>Village</th>
<th>Mingsung</th>
<th>Chikow</th>
<th>Talin</th>
<th>Hainian</th>
<th>Shuishang</th>
<th>Chiayi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Suntsun</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56</td>
</tr>
</tbody>
</table>

B. Nature of Data

The following data were collected for each sample of the survey:

1. Farm resources such as acreage of operation, operator and family labor available, and capital.
2. Crop systems.
3. Yields per hectare.
4. Value of production and by-products per hectare.
6. Capital expenses per hectare such as seed and seedling, fertilizers, animal labor, materials, etc.

6. Requirement of labor days during growing-season months.
V. DESCRIPTION OF SAMPLE FARMS

A. Resources

Land, labor and capital expenses are considered as farm resources of the study. The averages of available resources is shown in Table 2.

Table 2. Average resources of sample farms

<table>
<thead>
<tr>
<th>No. of farms</th>
<th>Land (ha.)</th>
<th>No. of family laborers participating in farming</th>
<th>Capital expense (NT$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>56</td>
<td>1.97</td>
<td>2.23</td>
<td>2.03</td>
</tr>
</tbody>
</table>

a The rate of exchange is 1 United States dollar to 56 new Taiwan dollars.

For simplification, it is assumed that the resource supplies of sample farms are 2 hectares of land, NT$7,000 for capital expenses, and 65 working days of labor in May, August and November, respectively.

B. Crop Enterprises and Their Combination

1. Crop enterprises

There are the following four groups of crops according to their planting season in the region:

(1) Spring planted crops - "Hu-tze" sweet potatoes,
spring sweet potatoes, spring peanuts, 1st upland rice, jute, sesame, small pea and green pea.

(2) Fall planted crops - Fall sweet potatoes, 2nd rice and tomatoes.

(3) Year planted crops - ratoon sugar-cane.

(4) Over one year planted crops - Fall "hu-tze" sugar-cane and fall sugar-cane.

2. Enterprise combinations

As the average size of sample farm in the region is only 2 hectares, the only way for operators to increase their farm income is to make intensive use of their land. Hence, two or more crops are usually grown on the same field in a year. The main crop enterprise combinations or crop systems are "hu-tze" sweet potatoes-2nd rice, spring sweet potatoes-2nd rice, jute-2nd rice, 1st rice-2nd rice, ratoon sugar-cane, fall "hu-tze" sugar-cane and fall sugar cane. The growing period of fall "hu-tze" sugar-cane or fall sugar-cane is about 18 months. It is not included in this study.

---

1 There are a limited number of farms which have enough irrigation water to produce the 1st rice and 2nd rice crops.
VI. INPUT-OUTPUT COEFFICIENTS

Linear programming techniques require input-output coefficients and prices for each crop produced on the farm. Input-output coefficients can be defined as the quantity of resources required to produce one unit of a specified crop or to cultivate one hectare of land under a specified crop system. Input-output coefficients are required for each crop or crop system for the three resources – land, labor and capital expenses, and for the prices and yields.

A. Per Hectare Resource Requirements

As a step in establishing input-output coefficients it is necessary to establish labor and capital requirements, or inputs per hectare. In linear programming, these inputs are taken to be constants per hectare of land. The capital and labor requirements per hectare for the several crop systems are shown in Table 3.

B. Prices and Yields

The prices and yields of each crop used for establishment of input-output coefficients were the averages of sample farms in 1959. They are shown in Table 4.
Table 3. Per hectare capital and labor requirements for crop systems

<table>
<thead>
<tr>
<th>Crop System</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute-2nd rice</td>
<td>0.63</td>
<td>0</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>11.00</td>
</tr>
<tr>
<td>Sweet potato-2nd rice</td>
<td>0.63</td>
<td>0</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>11.00</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>0.63</td>
<td>0</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>11.00</td>
</tr>
<tr>
<td>Rice-2nd rice</td>
<td>0.63</td>
<td>0</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>11.00</td>
</tr>
<tr>
<td>Rice-2nd rice</td>
<td>0.63</td>
<td>0</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>11.00</td>
</tr>
</tbody>
</table>

Table 3. Per hectare capital and labor requirements for crop systems
Table 4. Average yield and price of product of sample farms in 1968

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield per hectare (kg.)</th>
<th>Price per kilogram (NT$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratoon sugar-cane</td>
<td>79,453.15</td>
<td>0.16</td>
</tr>
<tr>
<td>&quot;Hu-tze&quot; sweet potatoes</td>
<td>21,706.42</td>
<td>0.33</td>
</tr>
<tr>
<td>Spring sweet potatoes</td>
<td>17,400.01</td>
<td>0.37</td>
</tr>
<tr>
<td>Spring peanuts</td>
<td>1,750.00</td>
<td>4.80</td>
</tr>
<tr>
<td>Jute</td>
<td>2,040.78</td>
<td>4.61</td>
</tr>
<tr>
<td>1st rice</td>
<td>1,750.00</td>
<td>2.16</td>
</tr>
<tr>
<td>2nd rice</td>
<td>3,747.60</td>
<td>2.16</td>
</tr>
</tbody>
</table>

C. Input-Output Coefficients

Input-output coefficients were computed from the above Tables 3 and 4. For instance, it requires NT$3,339.42 of capital expense, 18.42 labor days in May, 19.85 labor days in August and 48.50 labor days in November to cultivate 1 hectare of "hu-tze" sweet potatoes and 2nd rice crop. From this survey we know that operator and family labor is limited in supply in May, August and November in the region, so we consider these three months' labor as a limited resource. Input-output coefficients of crop systems are shown in Table 5.
**Table 5. Input-output coefficients of crop systems**

<table>
<thead>
<tr>
<th>Crop system</th>
<th>Value of products and by-products per ha. (NT$)</th>
<th>Amount of resource required per ha. (Input coefficients)</th>
<th>Capital expense (NT$)</th>
<th>May labor (days)</th>
<th>Aug. labor (days)</th>
<th>Nov. labor (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratoon sugar-cane</td>
<td>12,406.87</td>
<td></td>
<td>3,446.14</td>
<td>7.83</td>
<td>4.15</td>
<td>7.94</td>
</tr>
<tr>
<td>&quot;Hu-tze&quot; sweet potatoes-2nd rice</td>
<td>16,490.82</td>
<td></td>
<td>3,339.42</td>
<td>18.42</td>
<td>19.83</td>
<td>48.50</td>
</tr>
<tr>
<td>Spring sweet potatoes-2nd rice</td>
<td>15,398.94</td>
<td></td>
<td>3,690.81</td>
<td>4.99</td>
<td>22.08</td>
<td>36.27</td>
</tr>
<tr>
<td>Jute-2nd rice</td>
<td>18,219.05</td>
<td></td>
<td>4,680.90</td>
<td>30.77</td>
<td>51.66</td>
<td>7.99</td>
</tr>
<tr>
<td>1st rice-2nd rice</td>
<td>17,714.27</td>
<td></td>
<td>3,480.58</td>
<td>14.02</td>
<td>15.11</td>
<td>26.67</td>
</tr>
</tbody>
</table>
VII. OPTIMUM RESOURCE ALLOCATION AND CROP ENTERPRISE COMBINATION

Optimum, or profit maximizing, plans are presented in this section. The data provided in Tables 2, 3, 4 and 5 of the previous sections and the quantities of resources specified, are sufficient to make a linear programming solution for maximum profit under fixed or variable resource and price situations. To illustrate the different technique when the analysis is carried out with all resources and prices fixed, and when one or two of them allowed to vary, the procedures and results will be presented in the following subsections.

A. Fixed Resource and Price Programming

It is assumed that farmer A has a choice among cropping systems which were indicated in Table 3. He has 2 hectares of land to use for these cropping systems, NT$8,000 in capital for cash expenses, and 65 working days in May, August and November, respectively. The input-output coefficients and prices are listed in Table 5. Now we want to know what is his optimum farm plan.

The simplex method was applied to determine the profit maximizing plan for the situation indicated above. For convenience, we identify ratoon sugar-cane by $P_1$, "hu-tze" sweet potatoes-2nd rice by $P_2$, spring sweet potatoes-2nd rice by $P_3$, 
jute-2nd rice by $P_4$, and 1st rice-2nd rice by $P_5$. The $P_0$ column indicates the number of output units from each real activity, and the amount of unused resources.

Since resources can be used for production or they can go unused, so we denote "non-use" of a resource as an enterprise (activity) and use the term "disposal enterprise" for non-use. The symbols used for disposal activities are: $P_6$ for land, $P_7$ for capital expense, $P_8$ for May labor, $P_9$ for August labor, and $P_{10}$ for November labor. We include "input coefficients" for these "disposal activities". For example "land non-use" requires 1 unit (hectare) of land for non-use of the land resource, and no capital or labor is required for it. Hence, all other input coefficients are zero under $P_6$ column. Input coefficients for the other disposal activities are treated similarly.

The $C_j$ row and $C_S$ column show the price per output unit of real activity. One requirement of linear programming is that a resource can not have a cost attached to it, if it is unused, hence the price denoted for the disposal activities are zero.

The $Z_j$ row is the opportunity cost. The figures indicate the amount of revenue which would have to be sacrificed from the present program to permit the inclusion of 1 unit (hectare) of the $j$th activity in the program. The $Z_j - C_j$ row is the marginal revenue (expressed as a negative quantity) of
one unit of the jth activity. It means the addition to total revenue resulting from the production of one additional unit of the particular cropping system. The total revenue appears in the $Z_j - C_j$ row in the $P_0$ column. It is the summation of the price per unit of activity multiplied by the number of units produced. The added column $R$, is for determining the most limiting resource for a particular cropping system.

The presentation of a linear programming solution for optimum resources allocation and enterprises combination by the simplex method is shown in Table 6.

1. **Finding the first most profitable cropping system**

Plan 1 of Table 6 contains the data on resource quantities, input-output coefficients and prices which were outlined previously. Since the resources remain unused in this plan, there is nothing to produce, hence the $Z_j$ row (opportunity cost) is zero. The $Z_j - C_j$ figures will be the same as the $C_j$, except with minus signs instead of plus signs.

We wish to bring in some of the real activities in the plan. Because only one of these plans can be introduced at a time, the problem of which one to choose arises. The usual rule is to select the real activity having the largest negative figure in the $Z_j - C_j$ row. If this rule was followed in Table 6, the first cropping system to introduce would be $P_4$.

Column $R$ indicates the quantity of $P_4$ which can be
<table>
<thead>
<tr>
<th>Week</th>
<th>Activity</th>
<th>Resource</th>
<th>Cost</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plan</td>
<td>100</td>
<td>$500</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Procurement</td>
<td>200</td>
<td>$1000</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>Simple method</td>
<td>500</td>
<td>$2000</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>The process of the simplex method</td>
<td>1000</td>
<td>$5000</td>
<td>1000</td>
</tr>
</tbody>
</table>

*Note: 'Resource' column represents the amount of resources required for each activity.*
produced by each particular resource, if other resources were not limiting. It is computed by dividing the resource supplies in the $P_0$ column by the input coefficients in the $P_4$ column as shown in $R$ column in plan 1. August labor is the most limiting factor. It allows only the production of 1.25 hectares of $P_4$, if the entire supply of August labor is used, hence $P_9$ is the outgoing row.

2. Finding the second most profitable cropping system

Plan 2 is computed from plan 1. The first step is to bring in $P_4$ instead of $P_9$. This is done by dividing each figure in the $P_9$ row of plan 1 by the figure appearing at the intersection cell of this row with the $P_4$ column. The figure in the intersection cell is 51.66. Hence, we divide 65 by 51.66 and get 1.25825. This is the hectares of $P_4$ cropping system, we can produce and which is entered on the $P_4$ line of the new section, under column $P_0$. Under $P_6$, we have $0 + 51.66 = 0$; under $P_7$, we have $0 + 51.66 = 0$, etc.

Completion of row $P_4$ in the new section allows completion of all other rows. Starting with the land row, all figures on this row are computed by the procedure as follows: Subtract, from the quantity in the same column on the land row of the previous section, the product formed by multiplying (a) the quantity in the same column in the $P_4$ row of the new plan and (b) the input-output coefficient of $P_4$ for land in
the previous section. Hence, the figures on the land row of plan 2 are:

\[
\begin{align*}
2 & - (1.25823)(1) = 0.7417 \quad \text{(Column } P_0) \\
1 & - (0)(1) = 1 \quad \text{" } P_6 \\
0 & - (0)(1) = 0 \quad \text{" } P_7 \\
0 & - (0)(1) = 0 \quad \text{" } P_8 \\
0 & - (0.01936)(1) = -0.01936 \quad \text{" } P_9 \\
0 & - (0)(1) = 0 \quad \text{" } P_{10} \\
1 & - (0.08033)(1) = 0.91967 \quad \text{" } P_1 \\
1 & - (0.38386)(1) = 0.61614 \quad \text{" } P_2 \\
1 & - (0.42741)(1) = 0.57259 \quad \text{" } P_3 \\
1 & - (1)(1) = 0 \quad \text{" } P_4 \\
1 & - (0.29249)(1) = 0.70751 \quad \text{" } P_5
\end{align*}
\]

The remaining \( P \) rows can be computed in the same way.

Now compute the \( Z \) row: Take each figure on the incoming product \((P_4)\), and multiply it by the price, then enter each of them under the respective columns on the \( Z \) line. The computation of the new \( Z_j - C_j \) row is done by subtraction of the price of each column from the figure on the \( Z_j \) row. For example, the \( Z_j - C_j \) for \( P_1 \) in plan 2 is \( 1,463.53629 - 12,406.87 = -10,943.33371 \).

Now we decide to introduce \( P_5 \) into the plan, the largest negative \( Z_j - C_j \) figure is the clue. Looking at \( R \) column in plan 2, capital is the most limiting factor, hence \( P_7 \) is the outgoing row.
3. **Finding the third most profitable cropping system**

The computational steps outlined for plan 2 are duplicated for plan 3. The largest negative figure of $Z_j - C_j$ row is $P_2$. $P_2$ should now enter the plan. The $R$ column indicates land to be the "most limiting resource", so $P_6$ is the outgoing row.

4. **Optimum program**

The fifth plan is computed in section five of Table 6. The $Z_j - C_j$ row is also used to determine whether the plan is optimum. All figures on the $Z - C$ row now in plan 5 are positive, and an optimum program has been determined. It indicates that a further increase in total revenue is impossible. An optimum plan is always denoted by a $Z - C$ row filled with non-negative figures, when the objective is profit maximization.

The figures in the $P_0$ column now provide details on the final plan. The $P_4$ figure is 0.86556; we will produce 0.86556 hectares of jute-2nd rice. The $P_5$ figure is 1.13444; we will produce 1.13444 hectares of 1st rice-2nd rice. The $P_8$ or May labor figure is 22.46192; we have 22 days of unused May labor. The $P_6$ or November labor figure is 27.82906; we have 28 days of unused November labor. The $P_9$ figure is 3.14337; we have 3 days of unused August labor. The $Z$ and $Z - C$ figures under $P_0$ column are 35,865.45738, indicating a gross profit of
NT$35,865. This is the maximum gross revenue which we can obtain for the "fixed" supply of resources and "fixed" prices.

Most farms, which have the same fixed resource and price situations as farm A in Southern Taiwan, usually produce 1 hectare of the 1st rice-2nd rice and 1 hectare of the jute-2nd rice on the one hand, or produce "hu-tze" sweet potatoes-2nd rice, 1st rice-2nd rice, and jute-2nd rice on the other hand as shown in plans 3 and 4. Neither of these are optimum plans for the farm. Hence, plan 5 will guide farm operators in using their scarce resources properly in order to maximize their profits.

B. Variable Resource Programming

We have applied the conventional simplex method to determine the optimum farm plan under a fixed resource and price situation in the preceding section. Since resource supplies vary among farms, we have to consider situations in which resources are variable. A series of solutions of these situations was worked out by Drs. Heady and Candler.¹ They developed the variable resource programming which is the modified simplex method. In this section we consider the case where first one and then two resource supplies are allowed to vary.

¹Heady and Candler, op. cit., pp. 233-263.
1. **One resource variable programming**

We suppose that farmer A was allowed to vary the supplies of capital with all other resources remaining constant. What are the optimum plans for the different capital levels of farmer A? Now we apply one resource variable programming to decide the optimum farm plan.

The procedure of one resource variable programming is very similar to the simplex method, but there are the following two exceptions as shown in Table 7.

1. Since the supply of capital is variable, the original supply of capital is recorded as zero. The supply of capital becomes successively more negative in succeeding sections. For instance, it is -5,961.00 in plan 2. It means that if the original supply of capital had been NT$5,961, then the plan 2 would just exactly exhaust the capital supply.

2. The capital row is never selected to be the outgoing row.

   (a) To each section is added a \(\bar{D}\) row. It indicates the marginal revenue per unit of capital for each activity. It is used to select the outgoing column. The \(\bar{D}\) row is obtained by dividing the individual negative coefficients in the \(Z - C\) row by the appropriate input-output coefficients for capital. The \(\bar{D}\) row is computed only for activities with negative figures in the \(Z - C\) row. For example, the coefficients of \(\bar{D}\) row are computed only for activities with negative figures in the \(Z - C\) row, such as the coefficients of \(\bar{D}\) row in the
<table>
<thead>
<tr>
<th>Date</th>
<th>Labor 1</th>
<th>Labor 2</th>
<th>Labor 3</th>
<th>Labor 4</th>
<th>Labor 5</th>
<th>Labor 6</th>
<th>Labor 7</th>
<th>Labor 8</th>
<th>Labor 9</th>
<th>Labor 10</th>
<th>Labor 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>1,612</td>
<td>1,606</td>
<td>1,524</td>
<td>1,432</td>
<td>1,398</td>
<td>1,383</td>
<td>1,370</td>
<td>1,358</td>
<td>1,342</td>
<td>1,336</td>
<td>1,330</td>
</tr>
<tr>
<td>June</td>
<td>1,606</td>
<td>1,599</td>
<td>1,522</td>
<td>1,434</td>
<td>1,399</td>
<td>1,384</td>
<td>1,371</td>
<td>1,359</td>
<td>1,343</td>
<td>1,337</td>
<td>1,331</td>
</tr>
<tr>
<td>July</td>
<td>1,599</td>
<td>1,592</td>
<td>1,516</td>
<td>1,428</td>
<td>1,393</td>
<td>1,378</td>
<td>1,365</td>
<td>1,353</td>
<td>1,337</td>
<td>1,331</td>
<td>1,325</td>
</tr>
<tr>
<td>August</td>
<td>1,592</td>
<td>1,585</td>
<td>1,508</td>
<td>1,420</td>
<td>1,385</td>
<td>1,370</td>
<td>1,357</td>
<td>1,345</td>
<td>1,329</td>
<td>1,323</td>
<td>1,317</td>
</tr>
<tr>
<td>September</td>
<td>1,585</td>
<td>1,579</td>
<td>1,501</td>
<td>1,413</td>
<td>1,378</td>
<td>1,363</td>
<td>1,350</td>
<td>1,338</td>
<td>1,322</td>
<td>1,316</td>
<td>1,310</td>
</tr>
</tbody>
</table>

Note: The table above shows the labor hours for each month from May to September. The data is presented in a tabular format with columns representing different months and rows representing labor hours. The data is rounded to the nearest whole number.
first section of Table 7 are:

\[
\frac{-18,406.87}{3,248.14} = -5.6204 \text{ in the } P_1 \text{ column}
\]

\[
\frac{-16,480.62}{3,339.42} = -4.93823 \text{ in the } P_2 \text{ column}
\]

\[
\frac{-15,398.54}{3,690.81} = -4.17213 \text{ in the } P_3 \text{ column}
\]

\[
\frac{-18,819.05}{4,680.90} = -3.94181 \text{ in the } P_4 \text{ column}
\]

\[
\frac{-17,714.27}{3,450.50} = -5.08958 \text{ in the } P_5 \text{ column}
\]

Thus, for \( P_5 \) the marginal productivity per dollar of capital is 5.09. It is also the highest marginal productivity of capital given by \( P_5 \) which is chosen as the outgoing column.

The optimum farm plans at the different supply of capital levels is summarized in Table 8. The data in Table 8 are presented graphically in Figure 1. The horizontal axis refers to amounts of capital between zero and NT$10,000, while

<table>
<thead>
<tr>
<th>Table 8. Summary of the optimum plans of capital variable programming for farm A in Chiayi, Taiwan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>
Figure 1. Graphic representation of the optimum plans of capital variable programming for farm A in Chiayi, Taiwan.
MARGINAL PRODUCTIVITY OF CAPITAL

TOTAL INCOME

P_5 (HECTARES) P_4 (HECTARES)

CAPITAL (NT$)
the vertical axis indicates the marginal productivity of capital, total income, and amounts of the real activity. The total income and quantities of real activity corresponding to NT$0, NT$6,961.00 and NT$8,105.10 of capital were entered in Figure 1. The lines AA' and BB' correspond to the appropriate plans for NT$6,961.00 and NT$8,105.10 of capital respectively. Take line AA' as an example. It can be seen to correspond to the production of 2 hectares of P5, a total income of NT$36,422.54, and the marginal productivity of capital is NT$8.09.

Since we are dealing with linear programming, we can draw straight lines between the points which are the capital levels NT$0, NT$6,961.00 and NT$8,105.10. These straight lines tell us the optimum plans for intermediate capital levels. Suppose we are interested in the optimum plan for NT$2,000 of capital. We draw a line CC' which cuts the horizontal axis at NT$2,000.00. The CC' line cuts the P5 line at the 0.59 hectares level, the total income line at NT$10,097.13, and the marginal productivity of capital line at NT$5.09. This is the optimum plan for NT$2,000 of capital.

2. Two resource variable programming

The above analysis is the optimum plan for one resource variable. Now we want to expand to allow two resource variables. Suppose farm A was allowed to vary the supplies of
land and capital with all other resources remaining constant. What are the optimum plans for the different land and capital levels of farm A? The solution to it is to apply two resource variable programming.

The computations for two resource variable programming is only a small modification of the one resource variable programming method.

To illustrate two resource variable programming, we run two one resource variable plans; one for land, ignoring the capital restriction, and a second for capital, ignoring the land restriction. The first section of Table 9 is the same as the first section of Table 7 except that the initial supply of land is recorded as zero.

We deal with the supply of land variable, and form the coefficients of the row by dividing the negative row by their land coefficients. The highest marginal productivity of land is given by $P_4$ in section 1 of Table 9, hence $P_4$ is the outgoing column. To compute the column, both the land and the capital row are ignored. The most limiting resource is $P_9$ and it is the outgoing row.

The computation of plans 2, 3, 4, 5 and 6 is the same as plan 1. Up to plan 6, all figures on the row now are positive, and an optimum plan has been determined.

The figures in the column now provide details on the final plan. It needed 8.13649 hectares of land and
NT$26,630.23 of capital to produce 8.14712 hectares of ratoon sugar cane and 0.03937 hectares of jute-2nd rice. The $P_9$ or August labor figure is 29.16120; we have 29 days of unused August labor. The $Z - C$ figures are 101,797.54, indicating a gross profit of NT$101,797.54. This is the maximum gross revenue which we can obtain from the variable supplies of land and capital with other resources remaining constant.

The optimum farm plan at the different supplies of land and capital level is summarized in Table 10. Figure 2 is a graph of the data in Table 10. The horizontal axis refers to amounts of land between zero and 9 hectares, while the vertical axis indicates the amounts of capital and income. For example, when the supply of land is 5.56 hectares, it needs

Table 10. Summary of the optimum plans of two resource variable programming for farm A in Chisayi, Taiwan

<table>
<thead>
<tr>
<th>Section</th>
<th>Land needed (ha.)</th>
<th>Capital needed (NT$)</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>Income (NT$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.26</td>
<td>0</td>
<td>22,950.36</td>
</tr>
<tr>
<td>2</td>
<td>1.26</td>
<td>5,896.48</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.26</td>
<td>0</td>
<td>22,950.36</td>
</tr>
<tr>
<td>3</td>
<td>2.26</td>
<td>10,660.16</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.60</td>
<td>2.26</td>
<td>50,901.16</td>
</tr>
<tr>
<td>4</td>
<td>5.56</td>
<td>19,211.41</td>
<td>3.82</td>
<td>0</td>
<td>0</td>
<td>0.63</td>
<td>1.11</td>
<td>78,635.42</td>
</tr>
<tr>
<td>5</td>
<td>6.63</td>
<td>22,603.30</td>
<td>5.57</td>
<td>0</td>
<td>0.44</td>
<td>0.63</td>
<td>0</td>
<td>87,159.53</td>
</tr>
<tr>
<td>6</td>
<td>8.19</td>
<td>26,630.23</td>
<td>8.15</td>
<td>0</td>
<td>0</td>
<td>0.04</td>
<td>0</td>
<td>101,797.54</td>
</tr>
</tbody>
</table>
Figure 2. Graphic representation of the optimum plan of land and capital variable programming for farm A in Chieyi, Taiwan.
NT$19,211.41 of capital and the total income is NT$78,535.42.

C. Variable Price Programming

We dealt with one or two resource variable programming under fixed price situations in the previous sections. The price is very changeable in a realistic situation, so we want to know how optimum farm plans should change as prices vary. A series of solutions of these situations was worked out by Drs. Heady and Candler.¹ They developed the variable price programming which is the modified simplex method. In this section we consider the case where first one and then two prices are allowed to vary.

1. One price variable programming

It is assumed that farm A was allowed to vary the price of \( P_1 \) or \( P_5 \) with other prices fixed. What are the optimum plans for the one price variable of farm A? One price variable programming was applied to decide the optimum farm plans.

a. The modified simplex procedure for \( P_1 \) price-variable programming

The first step is to construct a simplex matrix with zero ratoon sugar cane price.

The second step is to compute the optimum plan with zero \( P_1 \) price and other prices fixed in the usual way. There is no

¹Heady and Candler, op. cit., pp. 265-306.
negative $Z_j - C_j$ coefficient in plan 1, thus section 5 represents the optimum plan when the price of $P_1$ is zero. The plan calls for 0.86559 hectares of $P_4$ and 1.13441 hectares of $P_5$. The gross profit of the plan is NT$35,865.47.

The third step is to introduce $P_1$ into the plan, raising its price by the value of its $Z_j - C_j$, i.e. NT$17,815.69151.

The fourth step is to calculate the $\Delta C_{P_1}$ ratio. We want to know how much the price of $P_1$ can be increased without one of the coefficients in the $Z - C$ row becoming negative. The answer to this question is provided by the ratio

$$C_{P_1} \geq \frac{Z_j - C_j}{r_{P_1j}},$$

$\Delta C_{P_1}$ represents a change in the price of rattoon sugar cane, $r_{P_1j}$ represents the input coefficient in the $P_1$ row and $j$th column, $Z_j - C_j$ is the $j$th activity's entry in the $Z - C$ row.

In the sixth section of Table 11 there is only disposal activity $P_7$ with negative coefficient. The change $P_1$ price for $P_7$ column is:

$$\Delta C_{P_1} = \frac{Z_j - C_j}{r_{P_1j}} = \frac{0.41632}{(-0.00069)} = 603.36.$$

The new $Z_j - C_j$ coefficients are recorded in the $Z - C'$ row of section six. The $Z - C$ row of sixth section of Table 11 was computed on the basis of $P_1$ price of NT$17,815.69, while the $Z - C'$ row was computed for the situation where $P_1$ price has raised to NT$18,219.05 per hectare. There are no
negative figures in the 2 - G row, hence plan 2 is still optimum at NT$18,219.05 for P1.

There are no negative entries in the P1 row of plan 3, so we already have maximum P1 output.

We found the optimum farm plans for P1 prices ranged from zero to an excess of NT$18,219.05 per hectare. These plans are summarized in Table 12.

b. The modified simplex procedure for P5 price-variable programming It is further assumed that farm A was allowed to vary the price of P5 with other prices fixed. The procedures for P5 price-variable programming is the same as P1 price-variable programming. It is shown in Table 13.

From Table 13 we know that plan 4 is the optimum plan where P5 price is NT$18,219.04 per hectare, the production of P5 is 2 hectares. There is no possibility of expanding its production. The unused resources are: NT$1,042.78 of capital, 36.64 days of May labor; 34.86 days of August labor; 11.69 days of November labor. The gross profit is NT$36,438.08.

The optimum farm plans for variable price of P5 are summarized in Table 14.

2. Two price variable programming

We found the optimum plans when one price changed in the last section. Now we want to expand to allow two price vari-
Table 12

Summary of the optimum plans of price $p_i$ respecting production for firm A in Chiang Rai.
Table 1. Summary of the optimum plans of price \( P \) and \( t \) for farm \( y \) in China. Taiwan.

| Income (in $) | \( P \) | \( t \) | \( P \) | \( t \) | \( P \) | \( t \) | \( P \) | \( t \) | \( P \) | \( t \) | \( P \) | \( t \) | \( P \) | \( t \) | \( P \) | \( t \) |
|--------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.75         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.85         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.95         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.05         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.15         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.25         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.35         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.45         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.55         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.65         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.75         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.85         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.95         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.05         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.15         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.25         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.35         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.45         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.55         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.65         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.75         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.85         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2.95         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.05         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.15         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.25         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.35         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3.45         | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
ables. Suppose farm A was allowed to vary the prices of $P_4$ and $P_5$ with all other prices fixed. What are the optimum plans when the prices of $P_4$ and $P_5$ are to be varied? The solution to it is to apply two price variable programming.

The computations for two price variable programming is only a small modification of the one price variable programming method.

Section 1 of Table 15 is the same as the first section of Table 13 except that the price of $P_4$ is zero and the $Z_j - C_j$ is zero instead of -18,219.05 under $P_4$ column.

The optimum plan was computed with zero $P_4$ and $P_5$ prices and other prices fixed in the usual way. There is no negative $Z_j - C_j$ coefficients in plan 1, hence it represents the optimum plan when the price of $P_4$ and $P_5$ is zero. The plan calls for 0.28616 hectares of $P_1$ and 1.73384 hectares of $P_3$. There are NT$736.72 of capital, 84.26 days of May labor and 25.61 days of August labor unused. The gross profit of plan 1 is NT$30,000.82.

First we deal with the price of $P_5$ variable, ignoring the $P_4$. The $P_5$ is not in plan 1. It will have a positive $Z_j - C_j$ unless the price per hectare increases to NT$14,384.78. When the price of $P_5$ rises to NT$14,384.78 per hectare, the $Z_j - C_j$ for $P_5$ becomes zero and $P_5$ can be introduced into plan 2 without loss of income.

Plan 2 of Table 15 is the optimum plan for zero $P_4$ price
and NT$14,384.7820 of \( P_5 \). There are no negative figures in the \( P_5 \) row, hence \( P_5 \) can be increased. The \( C_{P_5} \) ratios are computed. They are 1,013.76 of \( P_{10} \) and 156.34 of \( P_2 \), since we are interested in the minimum price rise necessary to make another optimum plan, hence the minimum price rise is NT$156.34, which will give a zero \( Z_j - C_j \) for \( P_5 \) in plan 3.

There are no negative entries in the \( P_5 \) row of plan 4. We have found the optimum plan for \( P_5 \) price of NT$16,490.81 per hectare and zero \( P_4 \) price.

We next examine the plans generated when the price of \( P_4 \) is increased while the price of \( P_5 \) fixes at NT$16,490.81 per hectare. In plan 4, \( P_4 \) is not in the plan, but it has a \( Z_j - C_j \) value of NT$16,490.81270. When the price of \( P_4 \) rises to NT$16,490.81 per hectare, the \( Z_j - C_j \) for \( P_4 \) becomes zero and \( P_4 \) can be introduced into plan 5 without loss of income.

Plan 8 of Table 13 is the optimum plan for a \( P_4 \) price of NT$31,533.23270 when the \( P_5 \) price is fixed at NT$16,490.81270 because there are no minus figures in the \( P_4 \) row.

Now we fix \( P_4 \) price of NT$31,533.23270 and vary the \( P_4 \) price. The procedures for maximizing \( P_4 \) production are the same as for previous plans. When the price of \( P_5 \) rises to NT$33,829.01270 per hectare in plan 11, there are no minus figures in the \( P_5 \) row, hence plan 11 is the optimum plan for
The figures in the $P_0$ column provide details on plan 11. The $P_6$ figure is 1.94846; we produce 1.94846 hectares of the 1st rice-2nd rice crops. The $P_7$ figure is 1,030.23810; we have NT$1,030.24 of unused capital. The $P_8$ figure is 36.16407; we have 36.16 days of unused May labor. The $P_9$ figure is 34.02890; we have 34.03 days of unused August labor. The $z - c$ figures are 68,329.94009 indicating a gross profit of NT$68,329.94. This is the maximum gross revenue which we can obtain from the variable price of $P_4$ and $P_5$ with other prices fixed.

The optimum farm plans of farm A for price $P_4$ and $P_5$ variable are summarized in Table 16.

Figure 3 is a graph of the optimum plans of farm A for price $P_4$ and $P_5$ variable in Table 16. The horizontal axis refers to the price of $P_5$ per hectare, while the vertical axis indicates the price of $P_4$ per hectare. For example, plan 2 is the optimum plan for NT$14,384 of price $P_5$ at point A on the horizontal axis and NT$12,412 of price $P_4$ at point F on the vertical axis, hence FK and AK are the price borders for $P_5$ and $P_4$. The area OFKA is the optimum plan for NT$14,384 of price $P_5$ and NT$12,412 of price $P_4$. By the same principle, the area CJPD is the optimum plan for NT$23,448 of price $P_5$ and NT$31,533 of price $P_4$. 

$P_5$ price of NT$33,529.01270.
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Table 16. Summary of the optimum farm plans of price \( \eta \) and variable production for farm A in Chertan, Lebanon.
Figure 3. Graphic representation of the optimum plans of prices $P_4$ and $P_5$ variable programming for farm A in Chisyi, Taiwan
VIII. INTERPRETATION AND RECOMMENDATIONS

The foregoing sections have presented the results obtained in the analysis. This section will interpret the findings and make recommendations which consist of limitations of the study and suggestions for future research.

A. Interpretation of Findings

Profit-maximizing farm plans have been worked out by the application of linear programming methods in the previous sections. Now we want to interpret the real meaning of their results to farmers and farming in Taiwan.

1. Fixed resource and price

The optimum farm plan for the fixed resource and price programming was given in Table 6. It is to use 1.13444 ha. of land to produce the first rice crop in the spring and to produce the second rice crop in the fall, the remaining 0.86556 ha. of land is utilized to produce jute in the spring and the second rice crop in the fall. In such a way, the farmer is making optimum utilization of his land resource. Since production is limited by the scarce resources of land and capital, there are 22.46 days of May labor, 3.14 days of August labor and 27.83 days of November labor that are not used. The maximum gross profit of the plan is NT $35,865.46.

Now the problem is whether the optimum plan provides
guidance in farm organization to farmers in Southern Taiwan. It can be used as a farm organization model for farmers in the region, if their method of production, soil, climate, topography, economic conditions and the amount of resources and price are similar to sample farms. It is especially helpful to young or beginning farmers. Since livestock systems, amounts of home consumption products, members of family, pieces and shape of land are still different from farm to farm, farmers may necessarily make some modifications of the optimum farm plan in order to meet their own farm situations.

We know that labor is the surplus resource from the optimum farm plan. The real farm problem is how to utilize labor in Taiwan. There are two ways to solve it: (1) to shift farm labor to non-farm employment; and (2) to increase the supply of the land resource.

There are only 883,466 hectares of cultivated land in Taiwan, 535,674 ha. of which are paddy fields and 349,792 ha. upland farms. The number of farm families in Taiwan is recorded as 769,925. This gives an agricultural population of 4,880,901 which make up 48.62 per cent of the total population of Taiwan. Under such a farm land and population ratio, it is very difficult for farmers to increase the supply of the land resource. Hence, to shift farm labor to non-farm use is the only way to solve the surplus labor problem.
2. Variable resource

a. Capital variable Although farm capital is a scarce resource in Taiwan, its supply varies among farms. In addition, there are some agricultural financing agencies such as the Taiwan Land Bank and the Cooperative Bank, which lend money to farmers in order to increase their production. Hence, some efficient farmers do not find it difficult to get a loan from the bank. Most farmers want to know what the optimum plans are for the different capital levels with all other resources and prices remaining constant.

Farmers can find their answers in Table 7. For instance, with a capital level of NT$6,961.00, 2 ha. of land was entirely used to produce 1st rice and 2nd rice crops. The maximum gross profit of the plan is NT$35,428.54; with a capital level of NT$8,186.10, it includes 1.0469 ha. of the 1st rice - 2nd rice and 0.9531 ha. of the jute - 2nd rice crop systems. The maximum gross profit of the plan is NT$35,909.65.

The results of the analysis is the real picture of farm plans in Southern Taiwan. Farmers with limited capital usually specialize in the production of rice for the following reasons: 1) The 1st rice - 2nd rice crop system requires less capital than the jute - 2nd rice system. 2) Rice is the main source of food for home consumption. 3) Rice is a kind of stable crop. On the other hand, rich farmers usually diversify
their farming and produce jute which is a cash crop and requires more capital and labor than other crops in order to maximize their profit.

b. Land and capital variable In general, land and capital supplies vary among farms. Most farms of Taiwan do not allocate their resources properly when two resources are allowed to be variable. Optimum plans for different land and capital levels which will help show farmers how to maximize their profit are given in Table 9.

The optimum plans for the different land and capital levels with the labor resource and prices remaining constant are shown in Table 9. It can be seen that farm A produced more rice with a lower level of land and capital, and produced more sugar-cane with a higher level of land and capital. For instance, with a level of land at 2.86 ha. and capital of NT$10,660.16, it included 0.60 ha. of the jute - 2nd rice, and 2.26 ha. of the 1st rice - 2nd rice crop systems; with a level of land at 6.63 ha. and capital of NT$22,603.30, it included 5.57 ha. of ratoon sugar-cane, 0.44 ha. of spring sweet potatoes - 2nd rice and 0.63 ha. of jute - 2nd rice in the cropping systems.

There is a tendency for the larger farms to produce more sugar-cane in southern Taiwan. It is due to the fact that sugar-cane is a relatively extensive crop and requires less capital and labor than other crops. In general, the larger
farms are short of labor during rush seasons, hence farmers prefer to produce sugar-cane in order to have their family supply the labor.

The results of land and capital variable programming is not only practical, but also provides information to help farmers allocate their resources properly in order to maximize their profits.

3. Variable price

a. One price variable Since the land resources are limited in Taiwan, keen competition among crops or crop systems has existed in the use of land. Sugar-cane and rice are two main competitive crops in Taiwan, both of them playing an important role in the island economy. The former is for export and the latter is for food. The price which is the most important factor in determining the farmer's choice of crops or crop systems, is indicated in Tables 11 and 13.

There is one monopoly company called "The Taiwan Sugar Corporation" in Taiwan, which is owned by the government to produce sugar for export and domestic consumption. The Corporation draws its raw material - sugar-cane from its own farms and private farms. Approximately 80% of the raw material is drawn from the latter. The sugar-cane growing period is generally 12 to 18 months, while rice is about 3 1/3 months, hence most farmers, from the standpoint of risk and uncertainty, are not interested in growing sugar-cane. Thus,
the acreage of sugar-cane has decreased, resulting in the Corporation being unable to obtain enough cane. Thus, since 1955, the Corporation announces a guarantee price of sugar before the sugar-cane planting season in order to assure farmers that they will make a reasonable profit from sugar-cane production, and at the same time, to assure a stable supply of raw material to the Corporation. When a farmer decides to plant sugar-cane on his farm, he can make a contract with the Corporation. The farmer is required to send his harvested sugar-cane to the Corporation’s mill, and receive in return refined sugar on the basis of 50-50 division. The farmer can sell his share of sugar to the Corporation at guarantee price.

The guarantee price is calculated from the following formula:

\[
\text{Guarantee price of sugar} = \frac{\text{Total production cost of 1 ha. of sugar-cane and its inter-crops} - \text{1 ha. of competitive crops in the growing period}}{\text{Quantity of sugar returned to the farmer of 1 ha.}}
\]

Hence the guarantee price assures the sugar-cane growers that their net income from sugar-cane will not be less than its competitive crops.

The cost and net income data are collected from a survey of 2,000 sample farms every year.
The results of one price variable programming are not only to guide farmers on how to maximize their profits, but also to provide information to the government on how to set prices to adjust production. For instance, the Corporation may apply the one price variable programming technique to set the sugar-cane price to control its production. From plan 2 of Table 11, farm A will produce 0.94907 ha. of the ratoon sugar-cane and 1.05093 ha. of the jute – 2nd rice crops, if the sugar-cane price is NT$17,615.69. Furthermore, it is assumed that when the sugar-cane price is increased to NT$18,219.05 which is as high as the highest price of the competitive crop system P4, then farm A will produce sugar-cane on the whole farm.

b. Two price variable Two price variable programming allows the prices of product A and product B to vary with other prices fixed. The optimum plans for prices of P4 and P5 variable were shown in Table 16. They provide the following information to farmers and government in Taiwan:

1) How optimum farm plans should change as prices vary.
2) How price changes might affect the structure and operation of the farm.
3) How prices can best be adjusted to achieve administration objectives.

For instance, changes of price change optimum plans and affect the structure of the farm as follows:
1) When the price of P₅ was increased to NT$14,384.78 while the price of P₄ was zero, it produced 1.21454 ha. of P₃ and 0.78546 ha. of P₅. The maximum gross profit of the plan was NT$30,000.82.

2) When the price of P₄ was increased to NT$26,105.25 while the price of P₅ was fixed at NT$16,490.81, it produced 0.96774 ha. of P₄ and 0.99694 ha. of P₅. The maximum gross profit of the plan was NT$41,703.45.

3) When the price of P₅ was increased to NT$33,529.01 while the price of P₄ was fixed at NT$31,533.23, it produced 1.94846 ha. of P₅. The maximum gross profit of the plan was NT$65,329.94.

Two price variable programming may be impracticable to farmers in Taiwan, because it is too complicated for farmers to adjust their production when two prices vary.

B. Recommendations

1. Limitation of the study

   a. Linearity in programming. One of the basic assumptions of conventional linear programming is that input factors combine in fixed proportions at all levels of output. Also, output will vary in fixed proportions with any given input, and thus, we have neither economies nor diseconomies of scale in the use of a given process. In other words, it is assumed that the input-output curve or production function is linear
and the constant returns exist. In the "real world" this is not always the case, because of the existence of increasing or decreasing returns to scale.

If the relationship is one of decreasing returns to the inputs, the problem can be solved with a series of linear segments. Each linear segment becomes a separate process. The basic principle is that for any change in the proportions in which resources are used or products produced, a new process must be defined.

Increasing returns to the inputs present greater complications. Each successive segment of the function \( y' = f(x) \) has a greater slope than the one preceding. This relationship is not consistent with the maximizing procedure of linear programming; hence, the function \( y' = f(x) \) cannot be readily incorporated into the usual simplex model.

b. Homogeneity of resources It is assumed that each category of resource is homogeneous in the linear programming approach. Under an actual farm situation, resources such as land and labor may not be homogeneous, neither among farms nor within farms. Within a given farm, the lack of homogeneity of the resources presents a complication. The definition of more homogeneous limitational factors, such as a restraint for each soil type, will help solve this problem, but the price of this refinement is an added computational burden.

c. Computational burden The application of linear
programming requires a great deal of computational work. This problem is solved by high-speed electronic computers. Some computations would require several years for a person to calculate with a calculating machine, but computers can calculate them in a few hours. Computational work for this study was done by a calculating machine, so it includes only limited resource restrictions and activities in order to minimize the computational burden.

2. Suggestions for future study

Profit-maximizing farm plans of this study have been worked out by applications of fixed resource and price programming, variable resource programming and variable price programming. The results of the study can be applied to the farms under the following situations: 1) fixed resource and price; 2) one resource variable; 3) two resources variable; 4) one price variable; 5) two prices variable. In such a way linear programming techniques will be more applicable to solve the optimum problem under the situations indicated above.

For the purpose of solution of non-linear and dynamic problems, the following linear programming approaches are suggested for future research.

a. Non-linear programming

Since conventional linear programming is based on a simple linear input-output relationship, it may not be "real world" farm production as mentioned
in the previous sections. It seems to me that application of non-linear programming is necessary for future research. The non-linear programming approaches have been developed by Drs. E. O. Heady\textsuperscript{1} and R. Dorfman.\textsuperscript{2}

b. **Dynamic linear programming** Most farms in Southern Taiwan have a 3-year crop rotation program. Farm operators want to maximize their profits for a 3-year period. Since the optimum plan resulting from conventional linear programming is only for a 1-year period, it does not meet the need of farm operators. The application of dynamic linear programming technique\textsuperscript{3} to obtain optimum 3-year plans for the farms may solve the optimizing over time problems.

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\textsuperscript{1} Heady and Candler, \textit{op. cit.}, pp. 564-587.


IX. SUMMARY

The purposes of this study were to 1) determine optimum farm plans from the standpoint of resource allocation and crop enterprise combination for single crop paddy farms in Southern Taiwan, and 2) demonstrate how linear programming techniques can be applied to study farm management problems in Taiwan.

This study covered 56 single crop paddy farms in 11 townships in the county of Chiayi in Taiwan. Those farms were well organized. The average of available resources of sample farms are 2 hectares of land, 2 males and 2 females of family laborers participating in farming and NT$7,200 of capital for cash expenses. Two or more crops are usually grown on the same field in a year. The main crop systems are ratoon sugar-cane, "hu-tze" sweet potatoes - 2nd rice, spring sweet potatoes - 2nd rice, jute - 2nd rice, 1st rice - 2nd rice and ratoon sugar-cane.

A. Optimum Farm Plans

Profit-maximizing farm plans have been worked out by the application of linear programming methods under the following situations.

1. Fixed resource and price

The optimum farm plan for fixed resource and price programming was shown in Table 6. It was to produce 1.13444 ha.
of the 1st rice - 2nd rice crops and 0.86556 ha. of the jute - 2nd rice crops. There were 22.46 days of May labor, 3.14 days of August labor and 27.83 days of November labor that are not used. The maximum gross profit of the plan is NT$35,865.46.

2. Variable resource

a. Capital variable The optimum farm plans for the different capital levels were given in Table 7 as follows:

a) With a capital level of 0, there was nothing to produce, the income was also zero.

b) With a capital level of NT$6,961.00, 2 ha. of land were entirely used to produce the 1st rice and 2nd rice crops. There were 36.60 days of May labor, 34.76 days of August labor and 11.66 days of November labor that were not used. The maximum gross profit of the plan is NT$35,428.54.

c) With a capital level of NT$8,105.10, it includes 1.0469 ha. of the 1st rice - 2nd rice and 0.9531 ha. of the jute - 2nd rice crop systems; 20.80 days of labor in May and 29.46 days of labor in November were not used. The gross profit of the plan is NT$35,909.65. Since land and August labor were limiting resources, an increase in the supply of capital would not increase production, hence NT$8,105.10 is the optimum supply of capital. This amount of capital was close to the capital supply of sample farms in Southern Taiwan.
b. Land and capital variable

The optimum plans for the different land and capital levels with labor resource and prices remaining constant are shown in Table 9 as follows:

a) With a level of land 0 ha. and capital 0, there was nothing to produce. The income was also zero.

b) With a level of land 1.26 ha. and capital NT$5,896.48, it produced 1.26 ha. of the jute and 2nd rice crops; 26.24 days of May labor were not used. The maximum gross profit of the plan was NT$22,950.36.

c) With a level of land 2.86 ha. and capital NT$10,660.16, it included 0.60 ha. of the jute and 2nd rice, and 2.26 ha. of the 1st rice and 2nd rice crop systems; 14.62 days of May labor were unused. The maximum gross profit of the plan was NT$50,901.16.

d) With a level of land 5.56 ha. and capital NT$19,211.41, it included 3.82 ha. of the ratoon sugar-cane, 0.63 ha. of the jute - 2nd rice and 1.11 ha. of the 1st rice - 2nd rice crop systems. All labor days were used for production. The maximum gross profit of the plan was NT$78,635.45.

e) With a level of land 6.63 ha. and capital NT$22,603.30, it included 5.57 ha. of the ratoon sugar-cane, 0.44 ha. of spring sweet potatoes - 2nd rice and 0.63 ha. of jute - 2nd rice in the cropping systems.
2. **Variable price**

   a. **One price variable**  
   
   The prices of most farm products are variable in Taiwan. They change from year to year, from month to month, even from day to day. The optimum plans for price $P_1$ or $P_5$ variable with other prices fixed were shown in Tables 11 and 13, as follows:

   A) The optimum plans for price of $P_1$ variable
   
   a) With a price level of 0, there was no production of $P_1$ and the income of the plan is NT$35,865.47.
   
   b) With a price level of NT$17,616.69, it produced 0.94907 ha. of the rattoon sugar-cane and 1.05093 ha. of the jute - 2nd rice crops. There were 25.23 days of labor in May, 6.83 days of labor in August and 49.7 days of labor in November not used. The maximum gross profit of the plan is NT$35,865.47.

   c) With the price level of NT$18,219, 2 ha. of land were entirely used to produce the rattoon sugar-cane. The unused resources were: NT$1,523 of capital, 49.24 days of labor in May, 56.41 days of labor in August and 49.42 days of labor in November. The maximum gross profit of the plan is NT$35,438.10. Since land is the limiting resource, a rise in price will not increase production.

   B) The optimum plans for price of $P_5$ variable
   
   a) With a price level of 0, there was no production of $P_5$ and the income of the plan is NT$34,361.74.
b) With a price level of NT$16,236.30, it produced 0.36487 ha. of the "hu-tze" sweet potatoes - 2nd rice crops, 0.90723 ha. of the jute - 2nd rice crops and 0.73790 ha. of 1st rice - 2nd rice crops. There were 20.07 days of labor in May and 20.86 days of labor in November not used. The maximum gross profit of the plan is NT$34,361.73.

c) With a price level of NT$16,672.61, 1.13449 ha. of the 1st rice - 2nd rice and 0.86551 ha. of jute - 2nd rice crops were produced. The unused labor days were: 22.26 days of labor in May, 3.20 days of labor in August and 27.83 days of labor in November. The maximum gross profit of the plan is NT$34,683.68.

d) With a price level of NT$18,219.04, 2 ha. of land was entirely used to produce the 1st rice - 2nd rice crops. The unused resources were: NT$1,042.78 of capital, 36.65 days of labor in May, 34.86 days of labor in August and 11.70 days of labor in November. The maximum gross profit from the plan is NT$36,438.09. Since land is the limiting resource, a rise in the price will not increase production.

b. Two price variable
Most farmers wish to know how optimum farm plans will be changed as two prices are variable. The optimum plans for prices of \( P_4 \) and \( P_5 \) variable were shown in Table 15 as follows:

a) When the price of \( P_4 \) and \( P_5 \) were zero per ha., it produced 0.26616 ha. of \( P_1 \) and 1.73384 ha. of \( P_3 \). There were
of capital, 54.26 days of May labor, and 25.61 days of August labor not used. The maximum gross profit of the plan was NT$30,000.82.

b) When the price of $P_5$ was increased to NT$14,384.78 while the price of $P_4$ was zero, it produced 1.21454 ha. of $P_3$ and 0.78546 ha. of $P_5$. NT$783.56 of capital, 47.79 days of May labor, and 26.31 days of August labor were not used. The maximum gross profit of the plan was NT$30,000.82.

c) When the price of $P_5$ was increased to NT$14,341.12 while the price of $P_4$ was zero, it produced 0.53412 ha. of $P_2$ and 1.46588 ha. of $P_5$. There were NT$1,114.36 of capital, 34.35 days of May labor and 32.26 days of August labor not used. The maximum gross profit of the plan was NT$30,123.62.

d) When the price of $P_5$ was increased to NT$16,490.81 while the price of $P_4$ was zero, it produced 2 ha. of $P_5$. There were NT$1,038.90 of capital, 36.60 days of May labor, 34.78 days of August labor and 11.66 days of November labor not used. The maximum gross profit of the plan was NT$32,981.63.

e) When the price of $P_4$ was increased to NT$16,490.81 while the price of $P_5$ was fixed at NT$16,490.81, it produced 0.86537 ha. of $P_4$ and 1.13463 ha. of $P_5$. There were 22.26 days of May labor, 3.20 days of August labor and 27.82 days of November labor not used. The maximum gross profit of the plan was NT$32,981.63.
f) When the price of $P_4$ was increased to NT$26,105.25 while the price of $P_5$ was fixed at NT$16,490.81, it produced 0.96774 ha. of $P_4$ and 0.99894 ha. of $P_5$. There were 0.03531 ha. of land, 21.06 days of May labor and 30.67 days of November labor not used. The maximum gross profit of the plan was NT$41,703.45.

g) When the price of $P_4$ was increased to NT$31,533.13 while the price of $P_5$ was fixed at NT$16,490.81, it produced 0.73293 ha. of $P_4$ and 1.20073 ha. of $P_5$. There were 0.06535 ha. of land, 22.31 days of May labor and 49.58 days of November labor not used. The maximum gross profit of the plan was NT$46,996.27.

h) When the price of $P_5$ was increased to NT$23,448.16 while the price of $P_4$ was fixed at NT$31,533.23, it produced 0.86540 ha. of $P_4$ and 1.13457 ha. of $P_5$. There were 22.26 days of May labor, 3.20 days of August labor and 27.83 days of November labor not used. The maximum gross profit of the plan was NT$53,892.44.

i) When the price of $P_5$ was increased to NT$33,529.01 while the price of $P_4$ was fixed at NT$31,533.23, it produced 1.94846 ha. of $P_5$. There were NT$1,030.24 of capital, 36.16 days of May labor, 34.03 days of August labor and 10.98 days of November labor not used. The maximum gross profit of the plan was NT$65,329.94.
B. Suggestions for Future Research

Non-linear and dynamic linear programming approaches are suggested for future research for the purpose of the solution of non-linear and dynamic problems.
X. REFERENCES


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