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RESOURCE ALLOCATION FOR SMALL SCALE FARMERS OF THE STAR GRASS LINE IN I穆U DISTRICT, KENYA: A LINEAR PROGRAMMING APPROACH

By

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PROBLEM SETTING

Like in other parts of the country, increasing population growth is becoming a major problem in the farming sector of Embu district. This problem is aggravated particularly in the star grass zone (or coffee zone) as consequence of immigration of investors from the high potential areas around Mount Kenya who find that land is not available for purchase in sufficient quantity due to the already existing land size shrinkage in their own area. The star grass zone is the most important agricultural area of the district. This zone supports the livelihood of the majority of the population in the district. However, this zone is characterized by low yield regardless of its good potential for agricultural development. There is therefore need to investigate if more efficient ways of using the scarce resources can be found thus resulting in increased income of the small-holder farmers.

OBJECTIVES OF THE STUDY

The overall objectives of this study are to identify the factors which most constrain agricultural production in the star grass zone of Embu district and investigate different enterprise combinations on small scale farms to show how farmers' income can be increased by a reallocation of resources.

Specifically, the study addresses the following questions:

(a) To what extent are the farmers in the star grass zone maximising expected incomes in giving more attention to the production of coffee? Under what conditions does coffee compete for the available scarce resources on farms with the production of milk from dairy cow and cereals?

(b) What is the effect on the income of farmers if the available land area for cultivation was to be increased?

(c) How should family labour be deployed in the different enterprises and what use can be made of hired casual labour in the farming sector of the star grass zone? How does increasing the available family labour change optimal enterprise combinations on farms and the magnitude of farmers' income?
What is the effect of the supply of working capital on the optimal enterprise combinations?

To address these questions the present organization, and operational systems of the farms were examined. After gaining an understanding into the existing farm organizational systems of the area, farm plans were developed to investigate various combinations of the resources available for agricultural production.

HYPOTHESES

The study attempts to test the following hypotheses:

i) Within the existing farm organization in the star grass zone farming income is seriously limited by the physical constraints of land, labour and working capital. There are opportunities for farmers of the star grass zone to increase the income from farming operations by using a different enterprise mix.

ii) Coffee production is more profitable to farmers of the star grass zone of Embu district than milk production or food crop production in a situation where there is adequate labour availability.

iii) Milk production from dairy cows is more profitable than the other enterprises produced in the star grass zone where there is sufficient land available and labour is in short supply.

METHODOLOGY

Sampling Design

Geturi location was selected as the representative of the star grass zone in Embu district. The decision was taken to concentrate the survey in this one location which reflects the characteristics of the zone in mind. This approach is supported by Upton (3)*. He states:

Although it is probably true to say that every farm is unique in certain respects, there are many similarities between large numbers of farms over quite large areas. In any one such "type of farming area" or "land-use zone", the same basic foods and often the same cash crops are grown by particularly all the farmers, methods of production are broadly similar and so are attitudes, customs and social institutions. Thus, although there may be variations in farm sizes, and in some of the minor crops grown and livestock kept, the same basic system of farming is found over the whole area.

* Figures in brackets denote references cited at the end of the paper.
Information on farm size and farm type in the star grass zone in Gatung'or location was obtained from land registrar office of Embu district. Using this information the following procedure was followed to select sample farms. Farms were stratified based on farm sizes. In the process of stratification three farm classes were selected. These were (a) small farms of less than 3 hectares, (b) medium sized farms ranging from 3 to 6 hectares, and (c) large farms of more than 6 hectares.

A random sample of farms were selected from each of these strata with size proportional to the fraction of number of farms in the whole population. In the sample of 40 farms 24 farms were from small farm class and 12 and 4 farms were from the medium and large farms respectively.

Data

Structured questionnaires were used to collect data from the farmers in the sample. The data collection were made between the end of October 1979 and the beginning of January, 1980.

The major data collected included the size of holdings, capital assets and use of credit, type of crop grown in both the short rain periods, type and quantity of inputs used on the crops grown, crop yields in kilograms, amount and timing of labour used by the major field operations, family size and supply of family labour and the use of casual labour, market access and transportation costs, and the use and productivity of livestock.

The data collected had some limitations. Firstly, of all the farmers selected only 10 farmers kept any records and much of the data collected depended upon the recollections of farmers. Determination of plot sizes and the levels of inputs and outputs posed problems.

The other limitation of the data was that the survey took place in less than three months, and the data collected were from one short survey. As the result of this, data collected on labour were bound to be unreliable.

More difficulty was encountered in estimating the area of crops when they were mixed. To avoid this complication each crop mixture was treated as a single enterprise.
The major part of the data used in this study pertaining to livestock production, especially dairy husbandry, were acquired from farmers who kept records.

**PLANNING TECHNIQUES**

The mathematical structure of the linear programming model that was used in this study to explore the possibilities of optimizing farm return is as follows:

i) Maximize

$$Z = C_1X_1 + C_2X_2 + \ldots + C_nX_n$$

Subject to:

$$a_{11}X_1 + a_{12}X_2 + \ldots + a_{1n}X_n \leq b_1$$

$$a_{m1}X_1 + a_{m2}X_2 + \ldots + a_{mn}X_n \leq b_m$$

Where:

- $Z$ = Total objective function to be optimized
- $C_n$ = Net return per hectare of $n^{th}$ activity
- $X_n$ = Hectarage under $n^{th}$ crop or livestock
- $b_n$ = Availability requirement of $a^{th}$ resource of $n^{th}$ activity

ii) $X_n \geq 0$ for all values of $n$

iii) $\sum_{f=1}^{e} ef X_f \geq H$

This is the minimum requirement condition of the four specified food crops per household ($H$) that must be fulfilled before the maximization of the objective function.

Where:

- $ef$ = the number of units of food requirement $e$ that are contributed by activity $f$.

The final optimum plans were given by the solution of the linear programming problem through simplex method.
Parametric programming was used to perform sensitivity analysis to investigate the effect on the optimal solution if the parameters take on other values. In particular, the labour and land resources for each model farm were varied parametrically as these two types of resources were expected to be important determinants of the farm plan.

**NET RETURNS**

The objective function was to maximize net returns on the farm in annual cycle. The net returns were measured by deducting variable expenses from the gross income. In order to maintain uniformity, the output prices were taken as the prices prevailing at the local market in Gaturi location during the study period and the input prices as the actual market prices at the time of application of inputs. The costs of various inputs are based on one hectare in the case of crops and one head of cattle in the case of livestock enterprises. The various items of variable cost for crops were casual hired labour, fertilizers, seeds, herbicides, and pesticides. Those for livestock included concentrate, minerals, health control and casual labour. In the case of perennial crops like coffee and bananas, cash flow calculation was done in order to calculate the establishing costs. Then, the establishing cost is distributed over the life of a respective crop.

**INPUT-OUTPUT COEFFICIENTS**

The input coefficients refer to the requirements of a crop or livestock activity in respect of the inputs of different resources measured in terms of per hectare or livestock unit. The input coefficients for all the crop or livestock activities are the mean value of each characteristic based on the 40 sample farms.

**RESOURCE CONSTRAINTS OR RESOURCE SUPPLIES**

The resources on a farm consist of land, labour and working capital required to buy such inputs as seeds, fertilizers, concentrates, hired labour, pesticides and herbicides, etc. The availability of these resources act as constraints within which the feasible planning needs to be optimized. Whereas some of these resources can be supplemented through borrowing/hiring, others cannot. These constraints were land, labour, working capital and household subsistence requirement.
LAND

The mean available arable land was calculated to determine the levels at which land is to be constrained in each model. The values were calculated after allowing for all the waste land and the area under the homestead. Since crops are grown in two seasons in the area of study the available land is classified as long rain and short rain land.

LABOUR

The monthly supply of family labour was estimated as was the labour required each month by each enterprise. This was done on a per hectare basis for crops to be grown and a per head basis for livestock.

To make different comparisons between different types of labour it is necessary to express days and hours in terms of common denominator (i.e. man-days and man-hours respectively). In the models built for this study man-days are used in the quantification of labour. Following Norman's (2) assumption that physical labour productivity shows initially a positive correlation and then a negative correlation with increase in age, variation was made by age group in the standardization of labour. There was no differentiation made on basis of sex.

In the analysis of the available labour on farms, the first consideration was the number of days per week that farm work is done. In Geturi location farm work is done six days a week and six and a half hours in a day. Therefore, every month consists of about 24 working days. Farmers hire labour only when the available family labour is fully utilized. In study area labour is typically hired only during the peak period of the long and short rains farming activities although the amount required on a farm is, of course, a function of the enterprise mix.

WORKING CAPITAL

Farm operating cash or credit is considered to be a constraint to farm production. The operating capital of the farmer's own funds is separated from the borrowed money. In this way credit can then be treated as a variable cost. In the formulation, the farmer is assumed to use his own funds until they are exhausted, and then borrows up to some limit. An upper limit on the amount of funds the farmer borrows was set based on the results of the survey data.
HOUSEHOLD SUBSISTENCE REQUIREMENTS

Farm families have a subsistence requirement which must be included as a constraint in the models. This is essential as in small-holding agriculture, the subsistence requirements for food have to be met before they market produce. The basic per capita food consumption was introduced as a constraint in each of the models.

Information provided by sample respondents was used to identify the type of basic staple food in the area of study. These were maize, beans, bananas and Irish potatoes. The calorific values of these crops were computed, and for each model, the household subsistence requirement was calculated to be met by the four types of crops. The figure used in this study for the average calorific requirement by an adult is 2328 calories per day (1). The basic food crops were specified in kilograms to be introduced in the matrices as constraints.

THE MODEL FARMS

A model farm was built for each size group of farms and the aggregate holdings of all the sample farms. In total, four model farms were developed. These are:

i) Model I for farms less than 3.0 hectares (small farm model)

ii) Model II farm portraying farm group ranging in size from 3.0 hectares to 6.0 hectares (medium farm model)

iii) Model III farm presenting farm group which are over 6.0 hectares (large farm model)

iv) Model IV (aggregate holding model) was built for all the holdings in the 40 samples studied.

ANALYSIS

The first part of this section analyses the maximum levels of net returns (gross margin) obtainable and the optimum level of enterprise combinations if family labour alone was to be used on model farms. The second and third parts show the changes that occur in the plans prepared as the result of hiring casual labour to support the family labour and borrowing working capital respectively. Then, comparison of the existing and optimal plans are made for each model farm. Finally, the results of price sensitivity analysis are presented.
Family Labour Use:

When family labour alone is used on various model farms the optimal enterprise combination is as presented in Table 1. On the small farms the most profitable enterprises are the production of food crops. The main cash earning crops are maize, beans, Irish potatoes and onion. The maximum net return attainable from the sale of these crops amounted to Kshs. 1,124.0 per farm.

On the medium farms, the most profitable enterprises are the production of food crops and milk from cross-bred dairy cows. The cash earning enterprises are sales of milk, Irish potatoes and maize. The maximum net return generated amounts to Kshs. 7,550.

Food crops and milk production turn out also to be the most profitable enterprises on large farms. The net return realised by farmers accounts to Kshs. 7,641.0. It is also indicated that even on aggregate holdings when labour is not hired food crops and milk production are still the most profitable enterprises. The maximum net return realised is Kshs. 6,576.

Table II indicates Marginal Value Products (MVPs) of various limiting resources on the four model farms. The MVP is the extra revenue which results from increasing the quantity of a limiting input by one unit, all other input quantities remaining constant.

The limiting resources on the small farms are land, family labour (in months of March, September and November) and operating capital. The most limiting labour periods are during land preparation, planting, weeding and harvesting. Production of coffee on the small farms is limited by shortage of September and November family labour, which are coffee picking months. Milk production is constrained due to shortage of land.

The most limiting factor of production on medium farms is family labour during land preparation and weeding. If February, March, September and November family labour supply is increased by one man-day each the objective function in the optimal plan would increase by Kshs. 24.77, Kshs. 132.1, Kshs. 809.1 and Kshs. 28 respectively. These values indicate that it would be profitable to hire casual labour during the peak months on the medium farms. In Gaturi the cost of hiring one man equivalent casual labour per day is Kshs. 10.0. The daily wage of casual labour
<table>
<thead>
<tr>
<th>ENTERPRISE</th>
<th>SMALL FARMS</th>
<th>MEDIUM FARMS</th>
<th>LARGE FARMS</th>
<th>AGGREGATE HOLDINGS</th>
</tr>
</thead>
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<tr>
<td></td>
<td>LONG RAIN</td>
<td>SHORT RAIN</td>
<td>LONG RAIN</td>
<td>SHORT RAIN</td>
</tr>
<tr>
<td></td>
<td>LAND (ha.)</td>
<td>LAND (ha.)</td>
<td>LAND (ha.)</td>
<td>LAND (ha.)</td>
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<tr>
<td>Maize</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Beans (2)</td>
<td>-</td>
<td>0.10</td>
<td>-</td>
<td>0.11</td>
</tr>
<tr>
<td>Irish Potatoes (1)</td>
<td>0.16</td>
<td>0.13</td>
<td>0.25</td>
<td>0.13</td>
</tr>
<tr>
<td>Onion</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maize and beans (1) (interplanted)</td>
<td>0.61</td>
<td>0.50</td>
<td>0.43</td>
<td>0.51</td>
</tr>
<tr>
<td>Maize and beans (2) (interplanted)</td>
<td>0.43</td>
<td>0.50</td>
<td>0.43</td>
<td>0.46</td>
</tr>
<tr>
<td>Bananas</td>
<td>0.13</td>
<td>0.13</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Banana and maize (interplanted)</td>
<td>0.28</td>
<td>0.28</td>
<td>0.33</td>
<td>0.33</td>
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<tr>
<td>Crossbred cow (milk production)</td>
<td>-</td>
<td>-</td>
<td>1.49</td>
<td>1.49</td>
</tr>
<tr>
<td>Coffee</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Unused land</td>
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<td>0.30</td>
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<tr>
<td>Total</td>
<td>1.64</td>
<td>1.64</td>
<td>3.25</td>
<td>3.85</td>
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</table>
TABLE II: MARGINAL VALUE PRODUCT (MVP) OF LIMITING RESOURCES IN THE OPTIMAL PLAN OF MODEL FARMS WHEN FAMILY LABOUR ALONE IS USED

<table>
<thead>
<tr>
<th>RESOURCE</th>
<th>UNIT</th>
<th>SMALL FARMS MVP (KShs.)</th>
<th>MEDIUM FARMS MVP (Kshs.)</th>
<th>LARGE FARMS MVP (Kshs.)</th>
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<tr>
<td>Land</td>
<td>Hectare</td>
<td>1495</td>
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<td>-</td>
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<tr>
<td>February Family Labour</td>
<td>Man-day</td>
<td>-</td>
<td>24.77</td>
<td>-</td>
</tr>
<tr>
<td>March &quot; &quot;</td>
<td></td>
<td>27</td>
<td>132.1</td>
<td>150.6</td>
</tr>
<tr>
<td>September &quot; &quot;</td>
<td></td>
<td>58</td>
<td>809.1</td>
<td>790.2</td>
</tr>
<tr>
<td>November &quot; &quot;</td>
<td></td>
<td>-</td>
<td>28.0</td>
<td>27.0</td>
</tr>
<tr>
<td>Operating Capital</td>
<td>K. Shs.</td>
<td>1.96</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

labour is much less than the MVP of labour. On the large farms family labour is limiting in the months of March, September and November, while on aggregate holdings labour is limiting in the months of February, March, July, September and November.

Effect of Hired Casual Labour

It was observed in Table II that family labour was limiting production. When we allow for hiring of casual labour in the four model farms, all their net returns increase substantially as coffee enterprise is brought into optimal plans. The net returns increased from Ksh. 1,124 to Kshs. 1,433 (27%) in small farms, from Kshs. 7,550 to Kshs. 17,891 (137%) in medium farms, from Kshs. 7,641 to Kshs. 32,766 (329%) in large farms and from Kshs. 6,576 to Kshs. 14,392 (219%) in aggregate holdings. The big differences in net returns are due to different amount of land under coffee entering in the optimal plans.

The limiting resources in the new optimal plans are operating capital and land in small farms, operating capital in medium farms, January, September and November labour in large farms and operating capital in aggregate holdings.

2. Figures in brackets indicate increase in percentage.
Effect of borrowed capital

By allowing borrowing of capital in the four model farms the capital constraint was realized in small, medium farms and aggregate holdings. This resulted in increased net returns in these farms above the increase that was due to hired labour. The increase was from Kshs. 1,433 to Kshs. 3,138.56 (119%) in small farms, from Kshs. 17,891 to Kshs. 22,325 (25%) in medium farms and from Kshs. 14,392 to Kshs. 17,771 (23%) in aggregate holdings. There was no change in net returns in large farms because capital was not a constraint. The large farms have high income and enough cash in hand for their farming operation in the existing farm organization. The labour is a constraint here just because it is difficult to obtain adequate hired casual labour during the months of peak labour demand in Gaturi.

Comparison of Optimal and Existing Farm Plans

Table III shows the comparison of the optimal and existing farm plans in Gaturi of the three strata of farm sizes.

The farm returns generated by the optimal plan for the small farms is Kshs. 3,159 compared to Kshs. 2,649 of the existing plan. The optimal plan showed an increase of about 19% compared to the existing plan. This is an indication that a better reorganization of farm resources among the most profitable enterprises will increase farm gross margin substantially.

The maximum gross margin that can be obtained in the optimal plan for the medium farms amount to Kshs. 22,536 compared to Kshs. 17,250 for the existing farm plan. Thus optimal plan showed that farmers can increase their farm income by about 31% if resources are efficiently used among the most profitable enterprises.

Likewise, on the large farms if resources are to be used efficiently the gross margin can reach Kshs. 32,766 compared to the existing farm plan, which brought a gross margin of Kshs. 25,885. The optimal plan showed an increase of about 27 per cent.

As shown in the optimal plans for the three strata of farm sizes there are opportunities for farmers in Gaturi location to increase their farm income by more efficient reallocation of their resource endowments.
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**NOTES:**
- The table represents data for various categories and time periods.
- The table does not have a clear title or description at the top.
- The units are not specified in the table.
- The table includes a column for "Total," which sums up the values in the respective rows.
- The table contains a column with the heading "Hectare" and another with "Tropic Ranges," indicating a focus on geographic data.
- The data appears to be formatted in a way that requires interpretation for full understanding.
Results of Parametric Programming

The most limiting factor of production in each farm plan was varied parametrically to determine its importance in the farm plan at different levels of supply. This would assist to determine how farmers should alleviate their resources if these altered parameters were realised.

Land is the most limiting factor of production on the small farms with 1.64 ha. available for cultivation. This land supply was varied to determine if the optimal enterprise combination is affected by marginal changes in the supply of this resource. This was examined using the small farm model with access to hired labour and outside working capital. The land input was increased successively by 0.5 ha. with constant labour supply until further increase in land has no effect in the gross margin obtainable. Thus the land was increased from 1.64 ha. to 4.14 ha. and gross margin increased from Kshs. 3,169 to Kshs. 10,874. This is a very substantial increase. The optimal plan now indicates that it would be most profitable to keep more cross-bred cows for milk production, and grow less coffee trees. This is because labour is now a constraint and coffee is a labour intensive crop.

The most limiting factor of production on the medium farms was labour shortage. When the family labour is increased by four man-days successively the gross margin that can be achieved rose to Kshs. 22,470, Kshs. 22,615, Kshs. 22,969 and Kshs. 22,776 respectively. As labour increased further production is constrained by land shortage. When labour supply is increased production of coffee becomes the most profitable enterprise. Similar results were found in large farms where labour was also the constraining resource. Thus more coffee trees are grown at the expense of milk production. It was also found that although farmers are sensitive to changes in coffee prices and they would want to bring more land under coffee as coffee prices increase; picking labour is a major constraint and farmers were growing less than 2 ha. of coffee.

3. It was found that increase labour with less than four non-days does not have any impact on the optimal plan.
CONCLUSIONS AND POLICY IMPLICATIONS

The study has indicated that there are opportunities for farmers in Gaturi to increase their income substantially by reallocation of their resource endowments (i.e. land, labour and capital) among enterprises.

On the small farms the most profitable enterprises to produce are food crops and few coffee trees. Milk production from dairy cows on the small farms is hampered by shortage of land because the food crops compete for the available land. If the available land area for cultivation was to increase there are high opportunities for the small farms to gain much more additional farm income.

On the medium farms the most constraining factors of production are labour and available working capital on farms. Labour shortage for coffee picking during January and November are the most critical. When the family labour is supplemented with hired casual labour and borrowed working capital the most cash earning enterprise is the production of coffee. If only family labour is available then the production of food crop and milk production from crossbred cows would be the most profitable.

Labour is the most limiting factor of production on large farms. The best plan for the large farms is when the family labour is supported with hired labour. The most profitable enterprises to produce are food crops, coffee and milk from crossbred cows.

The rationality of farmers in Gaturi to concentrate more on coffee production than milk or food crop production can only be justified when there is enough hired casual labour available.

This study has various policy implications. The absence of extraction or mechanization for land preparation has contributed to the acute labour bottleneck in Gaturi. Extension agents should put effort to advise and encourage farmers to use ox-ploughing or to introduce hand driven tractors. Herbicides should be promoted to help reduce the weeding labour bottleneck. This would in turn call for provision of working capital in form of agricultural credit especially to medium farms where it is a major bottleneck.

Farmers should be encouraged to concentrate more on milk production than coffee production on farms where there is extreme labour shortage and enough land within the existing farm organisation. Farmers should be made aware that coffee production is only profitable when there is enough labour available. One way of encouraging milk production in Gaturi is to improve
milk marketing system in the area especially by introducing a dairy cooperative which is non-existent. The small farms are faced with severe land shortage and appropriate technology should be introduced to increase land productivity.

REFERENCES

