

The Use of Linear Programming in Land use Planning Strategies for Increased Food Crop Production

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Abstract – Land is the main asset in agricultural production and generally, limited availability of productive land is a major constraint to increased agricultural production and by extension food and nutritional security. The main feature of Kenya's agriculture is domination of small-scale farmers who account for over 75% of total agricultural production. Production is carried out on small land holdings averaging 2-3 hectares. Due to increasing population pressure on agricultural land, plantation forest under the plantation establishment and livelihoods support (PELIS) formerly *Shamba* System, has been an effective method of providing land to landless forest neighboring farmers. However there has been a concern that the system leads to destruction of forests through inadequate supervision by the Kenya Forest Service. This study therefore aimed at examining the benefits of this system of forest plantation establishment. Data on farming costs, revenue and socio-economic conditions were collected from the farmers. Net present value approach was used in investigating the financial benefit of the *Shamba* system to the forestland farmers. Linear programming crop-and-area allocation model was developed for examining ways of optimizing food production and income from the forest over a 30 - year period. Results show that *Shamba* system has a positive net financial return. The results suggest that the *Shamba* system is a viable activity and is of benefit to the forestland farmers.

Keywords – Linear Programming, Food Security, Forestland Farmer, *Shamba* System.

I. INTRODUCTION

Linear programming is an effective mathematical tool for solving the problem of enterprise combination under stated resource restriction Verinumbe et al. (1984). It has the advantage of giving the optimum solution which maximizes profit over the whole enterprise rather than on individual factor basis. It is also generally available on computer programmes, and several hypothetical variations in the problem set up can easily be tested by modification of values of restricted parameters as well as by changes in the technical input-output coefficients. Raintree and Turray (1980) have shown that the linear programming model can serve as a relatively inexpensive tool of economic evaluation where new technologies can be screened before the costly testing on farmer's field. The method is superior to simple cost/benefit analysis, where the resource base of farmers tends to be generally

neglected. The general linear programming problem with n decision variables and m constraints can be stated in the following form Sharma (1989):

$$\text{Optimise } \sum_{j=1}^n c_j x_j \quad (1)$$

Subject to the linear constraints

$$\sum a_{ij} x_j (\leq, =, \geq) b_i; \quad i = 1, 2, \dots, m \quad (2)$$

$$\text{and } x_j \geq 0; \quad j = 1, 2, \dots, n \quad (3)$$

II. FOREST PLANTATION ESTABLISHMENT AND FOREST FARMING

The history of plantation forestry in Kenya dates back to the beginning of the 20th century. One major contributory factor to the success of Kenya's industrial plantation has been the *shamba* system. This is a land use system where young plantation tree seedlings are raised alongside agricultural crops in forest reserve. It was introduced to the country in 1910 when forestland was rented out for cultivation and tree planting was done later. The *shamba* system also plays an important role in food production, household income and rural development. The importance of the system to the national food policy and welfare of the cultivators is unquestionable Cheboiwo (1997). It has been estimated that forestland produces about 7000 kg/ha of potatoes annually and about 1800 kg/ha of maize and beans Wanyeki, (1981). These crops provide both food and cash incomes to farmers. The system has had positive contribution in making land available to landless forest workers for food and cash crop production. Given the shortage of prime land for agricultural production country wide, especially of the quality of the forestland, the *shamba* system has the potential of making forest areas a center of significant agricultural activity Cheboiwo (1997).

III. DATA COLLECTION AND ANALYSIS

The study was conducted in Western Mau and Kinale Forests in Rift Valley and Central Provinces respectively. A structured questionnaire was used to collect data from forestland farmers. The questionnaire was first pre-tested on 20 randomly selected forestland farmers. After this the questionnaire was then revised and a final version developed which was used to collect data through



enumerators. A sample of 109 forestland farmers was interviewed, comprising of 69 and 40 farmers from Kinale and Western Mau respectively. The data collected included size of rented forestland, crops grown, area allocation to each crop, cost of inputs, crop production level and farm gate prices. From the Forest Department the following data was collected; total forest area, area under plantation, current area under the cultivation, age class distribution by area, cost of plantation establishment with and without the *shamba* system and the advantages and disadvantages associated with the *shamba* system.

Socio-economic contribution of the *shamba* system

A cost benefit analysis was done to determine the financial impact of the *shamba* system to the forest adjacent communities. Financial cost benefit approach was used. In this approach, the object of cost benefit analysis is the individual welfare that is the focus was on the financial contribution of the *shamba* system to the individual farmer. The costs were identified for labour, seeds, seedlings, fertilizers, land preparation, transport and other inputs such as pesticides. Farm production was quantified by crop per period. Market prices were used in computing the cost of inputs, while farm gate prices were used in determining the benefits of the crops to the farmers. Net present value (NPV) criteria and crop and area linear programming allocation models were used to determine possible optimal crop combination in order to maximize net financial benefits to the farmer.

Net Present Value (NPV)

NPV is the net present value of the farm returns. Financial costs and benefits were computed for each farm enterprise per farming period. From this net benefits were derived. These net benefits were then discounted to reflect the time value of money for the entire planning horizon of 30 years, which is the maturity period of cypress plantation. The figures arrived at formed the coefficients of the linear programming model which were used to investigate options of optimizing food production and the farmers income. The net benefits were subsequently maximized using the linear programming model. The Net Present Value (NPV) model used was as shown below:

$$NPV(\text{crops}) = \sum_{t=0}^T \frac{1}{(1+r)^t} (p_t - c_t) y_t \quad (4)$$

Where:

t= time horizon

r = interest rate

$1/(1+r)^t$ = discount factor

p_t and c_t = unit prices and costs in year t respectively

y_t = yield in year t

Modeling crop and area allocation

A linear programming model was used to find the optimal crop combinations that achieve the highest net returns subject to the prevailing constraints such as minimal domestic food production faced by the households. The programme developed was a forestland allocation and harvest schedule model. The objective was to maximize the discounted net financial returns from the *shamba* system over a 30-year time period (optimal maturity period of saw timber). The model used follows model II formulation of Johnson and Scheurman (1977).

The model formulation used was of the form shown below:

$$\text{Max} \sum_{i=1}^m NPV_{ij} \quad (5)$$

Subject to:

1. Area constraint

$$\sum_{i=1}^m a_{ij} = A_j \quad \forall_j \quad (6)$$

2. Minimum food production constraint

$$\sum_{i=1}^m Q_j = A_j \quad \forall_j \quad (7)$$

3. Area accounting constraint

$$\sum_{i=1}^m a_{ij} - A_j = 0 \quad \forall_j \quad (8)$$

4. Revenue accounting constraint

$$\sum_{i=1}^m r_{ij} - R_j = 0 \quad \forall_j \quad (9)$$

5. Crop production constraint

$$(a_{ij} * y_i) - q_{ij} = 0 \quad \forall_j \quad (10)$$

6. Revenue function

$$(q_{ij} * p_i) - r_{ij} \quad \forall_j \quad (11)$$

7. Discounting constraint

$$(Ry * d = NPV_j) \quad \forall_j \quad (12)$$

8. Area flow constraint

$$a_{ij} - \sum_{i=1}^n a_i = 0 \quad \forall_j \quad (13)$$

Where, n is the number of seasons it takes crop i to ripen.

Decision variables

NPV_{ij} = the discounted net financial benefits from the crops

a_{ij} = the area allocated to crop i in period j

A_j = the total area available in period j

Q_j = the total domestic quantity required in period j

q_{ij} = the quantity of crop i produced in period j

r_{ij} = the revenue earned from crop i in period j

R_j = the total revenue earned in period j

p_i = the farm gate price of crop i

d = the discount factor

y_i = the yield of crop i per hectare

Indices

$i = 1..m$: crop (variable) index

$j =$ period (planting) index

RESULTS AND DISCUSSION

Crops grown

Food crops were dominant in the two areas (Table 1). The main food crops grown in Kinale were potatoes, cabbage, kales, peas and spinach. These crops also served as cash crops in addition to pyrethrum. The main non-food cash crop grown in Western Mau was pyrethrum while maize beans and potatoes were the main food crops. Potatoes also served as an important cash crop in Western Mau. Horticultural crops were widely grown in Kinale. This may be due to its proximity to major market centers such as Nairobi and Nakuru and the availability of good



infrastructure. This makes Kinale farmers better off financially than their Western Mau counterparts. For example, according to GOK (2000) the average earnings per person per year in Kiambu district in 1999 was Ksh 17,500 while in Nakuru district in the same period, the average earnings was Ksh 10,241 per person per year. Maize crop was not very common in Kinale though it is a staple food. This may be because of unfavourable climate. Kinale is a high altitude area and so is unsuitable to maize farming. Another reason is financial in nature. Maize has the lowest per unit returns as compared to other crops grown in the area.

Table 1 Crops grown on rented forest land

Kinale	Western Mau
Carrots	Potatoes
Potatoes	Maize
Cabbage	Beans
Kales	Pyrethrum
Peas	-
Spinach	-
Onions	-

Source: Author's own work

Contribution of the shamba system to income and food security

Farm production in Kinale was generally higher than that of Western Mau. This was especially noticeable in potato production where in Western Mau production was less than a half of that of Kinale (Table 2) at 20 and 51.6 bags per acre respectively. The level of investment as exemplified by input costs could explain this difference. Investment level in Kinale is twice that of Western Mau. For example, in potato production farmers in Kinale spend an average of Ksh 2,952 of planting materials per acre while in Western Mau they spend only about Ksh 1,143 of planting materials for the same unit of land. Maize production figures for Kinale were based on GOK (1997) extracts. Table 3 presents the farm income of forestland farmers in Western Mau and Kinale. The per unit revenue contribution in Kinale is higher than that of Western Mau with the contribution of potato well pronounced. The presence of a ready market in Kinale environs may account for this. A ready market implies high demand and hence better prices. These data suggest there is a more efficient use of land for food and cash crop production in Kinale. The variation in maize and pyrethrum revenue contribution is not much different in the two areas.

Table 2: Crop output per acre 2005

Area	Crop								
	Maize (bags)	Potatoes (bags)	Pyrethrum (kgs)	Beans (bags)	Cabbage (bags)	Kales (bags)	Spinach (bags)	Peas (bags)	Onions (bags)
Kinale	-	51.6	620	-	52.7	209	63	20	20
Western Mau	10	20	600	3	-	-	-	-	-

Source: author's analysis

Table 3 Crop revenue in Ksh/ha 2005

Crop	Maize (bags)	Potatoes (bags)	Pyrethrum (kgs)	Beans (bags)	Cabbage (bags)	Kales (bags)	Spinach (bags)	Peas (bags)
	Average production per acre	10	20	600	3	-	-	-
Western Mau	Average price/unit	800	650	120	2400	-	-	-
	Revenue	8000	13000	72000	7200	-	-	-
Kinale	Average production per acre	-	51.6	620	-	52.7	209	63
	Average price/unit	-	730	120	-	990	440	525
	Revenue	-	37668	74400	-	52173	91960	33075
								35400

Source: author's own analysis

* Pyrethrum production is measured in Kg/acre and their farm gate prices are in Ksh/kg.

Optimizing land allocation under the shamba system

In coming up with the figures below (Table 4), it was assumed that the land holdings per household would be constant. Thus, if the total forestland available in a particular year increases or decreases the number of households will increase or decrease accordingly. The

annual food demand per person was taken to be an average of 125.6 kgs of maize, 26.4 kgs of potatoes and 20.4kgs of vegetables GOK (1994). Food production was estimated at 20 bags of maize and 60 bags of potatoes per acre respectively Oduol (1987), Wanyeki (1981) and GOK (1997). These factors were incorporated into the forestland



allocation and harvest schedule model to come up with the results below.

To meet the household food requirements and income generation the optimal plan will be to allocate 2691.55ha to maize production, 149.08ha to potatoes, 5231.05ha to cabbage and 61.11ha to carrot production in Kinale. Farm production at this level of allocation will be 53,831 bags of maize, 7752.2 bags of potatoes, 277,245.9 bags of cabbage and 3666.92 bags of carrots (Table 4). Some crops like kales and potatoes are harvested more than once in a year

and therefore the total hectareage of the forest under the crop may appear more than the total forest area. The optimal plan for Western Mau is to allocate 2948.5ha to potatoes production and 1693ha to maize-bean intercrops. This will yield 38939 bags of maize and beans and 176,910 bags of potatoes from the forestland for the entire planning horizon. In addition 2193.8ha will be devoted to pyrethrum production, which is a high-income cash crop in Western Mau.

Table 4: Potential food production on rented forest land 2005

Area		Crop				
		Maize	Potatoes	Cabbage	Carrots	Maize/bean intercrop
Kinale	Area in ha	-	149.08	5231.05	61.11	0
	Yld/ha(bags)	-	52	53	60	-
	Yield (bags)	-	7752.2	277245.9	3666.92	-
Western Mau	Area in ha	-	2948.5	-	-	1693
	Yld/ha(bags)	-	60	-	-	23
	Yield (bags)	-	176910	-	-	38939

Source: author's own work

Expected income generation

Net financial returns in Western Mau were higher than those of Kinale largely because of availability of more land in the former. However per unit financial returns were higher in Kinale than in Western Mau (Table 5). Over the 30-year planning horizon, net revenue for Western Mau will be Ksh 233.23m, 129.84m and 104.14m

while for Kinale it will be Ksh 95.25m, 48.45m and 38.87m at 10, 20 and 25% interest rates respectively (Table 5). These are the net financial returns for the entire forests over the planning horizon of 30 years. Since the net present value is positive at all the rates, the enterprise is worth undertaking.

Table 5 Financial returns from the *shamba* system (000' Ksh) 2005

	Interest	Potatoes	Pyrethrum	Maize/bean	Cabbage	Carrot	Total
	Rate (%)						
Western Mau	25	3050	99885	1206	-	-	104141
Mau	20	3870	124463	1508	-	-	129841
	10	6975	223418	2735	-	-	233229
Kinale	25	706	-	-	32406	12	38871
	20	785	-	-	40422	131	48496
	10	1690	-	-	79378	436	95255

Source: author's own analysis

Sensitivity analysis

In carrying out the sensitivity analysis, domestic food crop production constraint was omitted (Table 6). The assumption was that the forestland farmers would use the income they get from the cash crops to meet their food requirements. Under this scenario the following results were obtained.

In Kinale the expected income will be Ksh 209.08M, 107.59M and 85.51M at 10%, 20% and 25% rate of interest for the entire planning horizon. This is as a result of allocating 7958.09 ha to kale production and 184.7 ha to potato production. Kales give the highest net returns in

Kinale and thus without any constraint the linear programming model chooses this crop. Potato production is chosen in the last two years because it is no longer possible to grow kales because of their multi season nature. Kales require three years.

In Western Mau, the area allocation will be 4405 ha to pyrethrum production and 2430 ha to potato production. This will yield Ksh 369M, 205.23M and 164.54M at 10%, 20% and 25% interest rates respectively. Pyrethrum and potatoes are high yielding crops in Western Mau resulting in the two being chosen by the linear programming allocation model.

Table 6: Financial returns without domestic food production constraint (000' ksh) 2005

Forest area	Pyrethrum (ha)	Potatoes (ha)	Kales (ha)	Interest rate (%)	Net Returns (000' Ksh)
Western Mau	4405	2430	-	25	164.54
	4405	2430	-	20	205.23
	4405	2430	-	10	369
Kinale	-	184.7	7958	25	85.51
	-	184.7	7958	20	107.59
	-	184.7	7958	10	209.08

Source: author's own analysis

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Despite the fact that LP is a tool applicable in planning agroforestry strategies, it does not fully incorporate or capture risks and uncertainties in smallholder agroforestry decision making. As a result variations in crop yields due to variations in agro-ecological conditions or other factors could not be fully captured. Thus only average figures were used. Therefore, the results of this study can only be used as guides in determining the optimal enterprise mix in the agroforest.

Based on the analysis made and putting into the consideration the assumptions made, the following conclusions and recommendations were made:

The *shamba* system if well managed enhances food security for forestland farmers. It is an important source of income for forestland farmers. The system should be promoted and strengthened by improving on its weak areas since it is vital to the forestland farmers as a source of food and income. For instance at the operational level farmers should be co-opted in management of the forest plots. This can be done by appointing farmers' committee who will oversee the management of the system. This will reduce corruption for example during the award of plots. By controlling their own activities they also minimize the chances of forest fires emanating from careless farmers, such as during plot clearing. They will also help in curbing cases of some farmers renting out their plots to third parties.

REFERENCES

- [1] Cheboiwo, J.K. (1997). Evolution of Forestry Policy in Kenya: Forestry and Forest Development Between 1800 and 1994. Socio-economics and Policy Research Programme. Working Paper no. 9. Kenya Forestry Research Institute, Nairobi, Kenya
- [2] KFMP, (1994). Kenya Forestry Master Plan, Ministry of Environment and Natural Resources, Government of Kenya, Nairobi.
- [3] Johnson, K. N. and Scheurman, H.L., (1977). Techniques for Prescribing Optimal Timber Harvest and Investment under Different Objectives – Discussions and Synthesis. *Forest Science Monograph 18*, 31.
- [4] GOK, (2000). Statistical Abstract, Central Bureau of Statistics. Ministry of Finance and Planning, Nairobi.
- [6] GOK, (1997). Kiambu District Development Plan. Government of Kenya, Nairobi.
- [7] GOK, (1994). National Development Plan, Government of Kenya, Nairobi.
- [8] Oduol, P.A. (1987). The Shamba System: An Indigenous System of Food Production from Forest Areas in Kenya. *Agroforestry System 4*: 365-373.
- [9] Johnson, K. N. and Scheurman, H.L.(1977). Techniques for prescribing opti-mal timber harvest and investment under different objectives – Discussion and Synthesis, *Forest Science Monograph 18*.
- [11] Wanyeki, F.H.M. (1981). Agroforestry Practices in High Potential Areas of Kenya. In Buck, L.(Ed.), *Proceeding of the Kenya National Seminar on Agroforestry*. ICRAF, Nairobi.
- [12] Verinumbe,I., Knipscheer, H.C. and G.E. Enabor 1984. The Economic Potential of Leguminous Tree Crop in Zero Tillage in Nigeria: A Linear Programming Model. *Agroforestry Systems 2: 129-138*.
- [13] Raintree,J.B., Turray F. (1980). Linear Programming Model of an Experimental Leucaena-Rice Alley Cropping System. *IITA Research Briefs 1(4)*
- [14] Sharma, J.K (1989). *Mathematical Models in Operations Research*. Tata McGraw-Hill Publishing Company Ltd, New Delhi.