Optimal Crop Combinations under Limited Resource Conditions: Application of Linear Goal Programming (LGP) Model to Smallholder Farmers in the Drier Savannah Zone of Nigeria

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Abstract

Efficient allocation of resources through an optimal crop enterprise combination by smallholder farmers among their usually multiple goals of providing food for the family throughout the year, accumulating monetary income and ensuring minimum use of paid labour (in other words improve on the utilization of family labour) has been evasive in smallholder farm economy in sub-Saharan Africa. Food-crop production remains a major component of the farm-family economy and these smallholder farms represent as much as 95% of the total food-crop farming units in the country and produces about 90% of the total food output.

Using a data collected from 400 households selected in the rural areas of Kebbi State, in the drier Savannah agro ecological zone of Nigeria, We applied a Linear Goal Programming (LGP) technique to model the farm-family crop production enterprise in the study area with a view to developing an optimal crop enterprise combination that would enable the smallholder farmers meet their most important goals earlier identified.

The goal programming results revealed that only 4 out of the 18 basic cropping activities identified in the study area entered the programme. The 4 activities and their Hectarage allocations were Millet/Maize/Rice (1.20 ha), followed by Maize/Guinea corn/Cowpea (0.94 ha), then by Millet/Cowpea (0.16 ha), and lastly by Maize/Cowpea/Millet (0.04 ha). A striking feature of this plan is that there is no sole cropping enterprise included in the model. This plan will utilize the minimum cost of ₦6485.16/ha to produce the minimum food required, minimum income and would ensure minimum use of paid labour. The result further revealed that some household resources such as land were in excess of actual household requirements.

Effective extension programmes that will educate the farmers on efficient allocation of their resources are pivots upon which the various smallholder development programmes initiated by the government should be built.

Introduction

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In Nigeria, food-crop production remains a major component of all production activities in the agricultural sub-sector. Food-crop production comes under different agricultural systems, most commonly as mixed faming, mixed cropping or mono cropping. Furthermore, activities in the food-crop sub-sector have continued to dominate the category of farms variously referred to as smallholder farms, small-scale farms, low-resource farms or small farms (Olayide et. al., 1980).

This category of farms represents as much as 95% of the total food-crop farming units in the country and produces about 90% of the total food output (Okuneye and Okuneye 1988). These farms are characterized by low level of operation, illiteracy of operators, and a labour intensive production technology with hired labour cost constituting about 60% of the total cash cost of production (Olayemi, 1980; Aromolaran, 1992). There is also complete reliance on household resources, for instance about 75% of the total labour requirement is from family sources. It is also believed that a sizeable proportion of farm output is retained for family consumption and planting purposes and they often cultivate marginal lands.

However, in small-scale agriculture, the farming system is embedded in the household economy, which integrates both production and consumption, and it shaped by the multiple goals that are operative in the system (Norman et. al, 1982). More often than not the goals or objectives are conflicting. It was assumed that the main objectives pursued by the farmers in the study area include provision food for his family throughout the year, accumulation of monetary income and ensuring minimum use of paid labour (in other words improve on the utilization of family labour).

This paper therefore seeks to analyze the resource allocation patterns of crop farmers in the drier Savannah zone of Nigeria, with a view to suggesting an optimal crop enterprise combination that will meet the aforementioned goals of the farm family.

Methodology

Theoretical/Conceptual Framework

Peasant Farmer Resource Allocation Model

The theoretical model of the peasant farmer resource allocation has some basic assumptions concerning the objective function of the farmers. These assumptions include the following among others:

(i) Farmers are assumed to have specified utility functions.

(ii) The objectives or goals of the farmer are many, which are conflicting, or not.

(iii) The objectives in turn assumed to be functions of the model decision variables.

(iv) The objective of production is to achieve satisfactory levels of specified objectives subject to the limitations imposed by the system and the environment.

The theory of production economics is concerned with optimization of the objectives or goals and optimization implies efficiency (Baumol, 1977). Decision-makers are presumed to be concerned with maximization of some measure of achievement such as profit or utility.

Resource allocation according to Heady (1969) refers the technical concept of efficiency, which brings about great product to the society from given resources.

The equimarginal principle otherwise called the principle of equal marginal returns is the neoclassical economic criterion for efficiency in resource use and allocation in multiproduct firms such as smallholder economy. It simply states that, for a multiproduct firm to be said to have allocated its resources optimally among its feasible production enterprises, it must do it in such a way that the Marginal Product (MVP) of every variable input is equal in all enterprises in which it is employed and also equal to price of the input. Mathematically, the equimarginal principle is represented by expression below.

Given a production function $Yj = f(Xi)$………………. (1)

$MVPi1 = MVPi2 = --- = MVPin \leq Pi$,

For all I, (I = 1----n; j = 1---m)……………………… (2)

Where,

MVPij = Marginal value product of i^{th} input (X) used in the j^{th} product Y and

Pi = Unit price of the input i.

Following the frameworks discussed previously on the resource allocation models; the estimation model developed to determine an optimal enterprise combination for the households was the linear goal-programming (LGP) model.

Study area, Sampling design and data collection

Study area

The study was carried out in Kebbi State in the North Western Nigeria, which falls in the dry savanna region comprising of Sokoto, Kebbi, Zamfara, Kano, Kaduna and Jigawa States. The area falls into the dry savanna ecological zone of Nigeria with an average annual rainfall of between 650mm and 1100mm. The vegetation largely comprises of drought resistant grasses, legumes and shrubs. There are two distinct seasons: the rainy and the dry season; with the dry season longer than the rainy season. Dry season is usually accompanied by very dry air known as the harmmerttan.

The commonly practiced religion is Islam, although a few Christians are still in the state. Largely dominated by families which are polygamous in nature, and they reside in huts. Commonly cultivated crops in the State include maize, sorghum, millet, and rice. Others include pepper, tomatoes, cowpea, and so on.

Sampling design and data collection

The sampling method employed in the study was the multi-stage stratified random sampling approach. The Agricultural Development Project zones formed the first stratum for sampling. Ten Local Government Areas were selected from all the zones and these formed the second stratum. The third stratum was the village level, where 100 villages were randomly selected and the last stratum was the household level, where 4oo households were randomly selected.

Largely, primary data were used for this study; a few secondary data were also collected from Food Basket Foundation of Nigeria. The primary data were collected from the rural household through the use of pretested and structured questionnaires with the help of trained ADP enumerators under the supervision of a team of researchers from the International Institute of Tropical Agriculture (IITA). The household livelihood, economic and demographic data constitute the bulk of the data collected. Some farm specific data were also collected. Most of the data were collected on weekly, monthly or three-monthly basis.

Empirical models

Since the main objective of this paper was to determine the farmers' optimal crop enterprise combination to meet a set of objectives or goals, the following linear goal-programming model was developed. The model was also used to generate constrained optimal solutions to the resource allocation problem of the farmer. The model is expressed as follows, following Njiti and Sharpe

(1994).

Minimize Z = $\overset{n}{\underset{i?1}{?}} ?W_i^{?} d_i^{?} ? W_i^{?} d_i^{?} ?$ ……(3)

Subject to: AX – Id+ + Id-

BX (= = =) C

Xij = 0 (j = 1, 2, …, m)

di+, di- = 0 (i = 1, 2, …, n)

In which:

Z = function of objectives

Wi+, Wi- = the numerical differential weights assigned to the deviational variables di+, di of goal i.

di+, di = the vectors (n.1) of the negative and positive deviations of goal i.

A = the (n.m) matrix which represents the relationship between the decision variable vector, X (m.1) and the goal vector, G (n.1). Practically, the decision variables vector represents inputs, which are transformed by matrix 'A' to produce desired outputs.

I = the identity matrix.

B = the (c.m) matrix of coefficients which relate the decision variables to constraint vector, C (c.1).

n = number of goals.

m = number of decision variables

c = number of constraints.

The deviational variables (di+, di-) were derived from the households' characteristics. It was assumed that the main objectives pursued by any household in the study area are as follows:

i. to provide adequate food to ensure at least minimum calorie for the household throughout the year.
ii. to earn adequate monetary income to at least meet minimum household financial needs.
iii. to maximize utilization of family labour through minimum use of paid labour.

It was on the basis of these objectives that the optimality of the system was assessed. The production system was said to be optimal only if it is capable of providing an adequate caloric intake for the family throughout the year, and producing adequate monetary surplus to allow the household to acquire goods that were not produced on the farm. These were the assumed minimum requirements for taking household out of poverty (Manyong et. al., 1995).

For the three objectives assumed, the indicators were as follows:

(i) The indicator for adequate caloric intake came from the WHO/FAO recommendations, which gave some indicators for adequate caloric intake (FAO, 1974; Food Basket, 1995).
(ii) The monetary income indicator corresponded to a minimum of 56% of the average household expenditure in the study area.
(iii) The labor saving indicator was represented by desired level of cash expenditure on paid labor in the study area.

The structure of the objective function is further described in Table 3.2. The objectives were priotized based on the view of households in the study area. The households were of the opinion that food security in terms of adequacy comes first, followed by balanced diet. The third and the last on the priority ranking were accumulation of monetary income and limited expenditure on paid labour through efficient utilization of family labour. Pre-emptive weights were also attached to these objectives based on the ranking with the first objective carrying the highest weight.

Minimize

Z=(?i.ni+?i.pi) ……(3)

Subject to: ? AijXj+ni-pi=ai for all i.

? AkjXj= bk for all k

Xj, ni, pi= 0 for all j and i

In which:

Z = function of objectives

ni = negative deviation if ai is under achieved

pi = positive deviation if ai is over achieved

a = weight or relative importance attached to deviation pi or ni

Aij = matrix of aij

Xj = matrix of xij

aij = marginal contribution of xij to satisfying ai

ai = indicator of sustainability i

akj = coefficient of use of bk

bk = resource k

The indicators of sustainability (ai) and the deviational variables (ni, pi) will be derived from the households' characteristics. It was assumed that the main objectives pursued by the farmers in the study area are as follows:

i. to provide food for his family throughout the year;
ii. to accumulate monetary income and
iii. to ensure minimum use of paid labour (in other words improve on the utilization of family labour).

It was on the basis of these objectives that the optimality and sustainability of the system was assessed. The production system is said to be sustainable only if it is capable of providing an adequate balance diet for the family throughout the year, and producing a monetary surplus to allow the household to acquire goods not produced on the farm (in other words take the household out of poverty) Manyong and Degand (1995).

For the three objectives assumed, the indicators are as follows:

(iv) The indicator for a good diet came from the WHO/FAO recommendations, which give some nutritional indicators for a balanced diet (FAO 1974).

(v) The monetary income indicator corresponded to 70% of the average household expenditure derived for the study area.

(vi) The labor saving indicator was represented by desired level of cash expenditure on paid labor.

Basic activities included in the model are as follows:

1. Maize and Rice
2. Millet and Guinea corn
3. Millet and Cowpea
4. Guinea Corn and Maize
5. Maize, Cowpea and Rice
6. Guinea Corn and Groundnut
7. Millet, Guinea Corn, Cowpea and Groundnut
8. Millet, Maize and Rice
9. Maize, Guinea corn and Cowpea
10. Rice, Sorghum and Groundnut
11. Sorghum, Rice, Millet and Onions
12. Cowpea, Rice and Groundnut
13. Guinea corn, Cowpea and Rice
14. Millet, Guinea corn and Rice
15. Millet, Groundnut and Guinea corn
16. Millet, Rice and Vegetable
17. Sorghum, Groundnut, Pepper, Maize
18. Millet, Maize, Bambaranut and Sugarcane

Table 1. Tabular Representation of The Objective Function Structure of the Basic Linear Goal Programming Model for the Average Farm Family.

Objective of Farm Production	Goal Statements: Achievement of	Objective Function Statement: To minimize	Deviation Variable in Objective Function	Priority Level	Preemptive Weights
1. Farm Household Food Security	i. Min. Maize intake	Underachievement	d_	1	4
	ii. Min. Millet intake	Underachievement	d_	1	4
	iii. Min. Cowpea intake	Underachievement	d_	1	4
	iv. Min. Rice intake	Underachievement	d_	1	4
2. Limited Cash Expenditure on Labor	i. Specified level of expenditure on labour	Overachievement	d+	4	1
3. Gross Farm Income	i. Desired level of farm income	Underachievement	d_	3	2
Nutritional Well being	i. Min. Calorie intake	Underachievement	d_	2	3
	ii. Min. Protein intake	Underachievement	d_	2	3

Source: Constructed after field survey by ranking goals and attaching weights

Input Coefficients

The input coefficients refer to the requirements of a crop activity in respect of the inputs of different resources measured on per hectare basis. He input coefficients for all the crop activities on all the selected farms were calculated on the basis of the actual quantities of different resources used for those crop activities.

Resource Constraints

The resources on the farm consist of land, labour, fertilizers, other chemicals and capital. The availabilities of these resources act as constraints within which the feasible planning needs to be optimized. Some of these constraints through borrowing/hiring, other can not be. These constraints were:

i. Land
ii. Labour (family and hired) in two different periods i.e. early planting season (April-July) and late planting season (August-October).
iii. Working capital

Results

This section presents the optimal farm plan generated under the assumption that cost minimization is the underlying behavioural principle guiding the farmers in their resource use and allocation decisions. Out of the 18 basic activities included in the model only 4 of them enter the programme. The 4 activities include:

i. Millet and Cowpea mixed
ii. Maize, Cowpea and Millet mixed
iii. Millet, Maize and Rice mixed, and
iv. Maize, Guinea corn and Cowpea mixed

Table 2 presents the result of the goal programming, which is constrained to use minimum cost possible to produce the minimum household food requirement as defined earlier. The programme value of 6485.16, which means that for the optimum farm plan got to be executed, the farmer will incur a cost of N6485.16. The most advisable thing to do is to do away with the non-basis; if they were not done away with, the margin would increase by forcing any of them into the programme.

Table 2 Basic Cropping Activity and their Hectarage Allocations

Basic Activity	Hectarage (ha)
Millet/Cowpea	0.16
Maize/Millet/Cowpea	0.04
Millet/Maize/Rice	1.20
Maize/Guinea corn/Cowpea	0.94

Source: Computer printout of Goal Programming model

From the farm plan shown in Table 2, the average farmer should allocate his resources in such a way that the 4 crop enterprises shown in the Table are produced according to their Hectarage allocations. The recommended allocation pattern depicts the most important enterprise that enters the model is Millet/Maize/Rice (1.20 ha), followed by Maize/Guinea corn/Cowpea (0.94 ha), then by Millet/Cowpea (0.16 ha), and lastly by Maize/Cowpea/Millet (0.04 ha). A striking feature of this plan is that there is no sole cropping enterprise included in the model because one could hardly find a smallholder farmer in Kebbi who practiced sole cropping.

An examination of the resource utilization pattern in Table 3 reveals that only 4 of the specified resources were fully utilized in arriving at the optimal solution. These resources included: family labour for period one, hired labour for period one, family labour for period two, and cash on material input. The shadow prices for the fully utilized resources were 10.44, 11.53, 5.11 and 16.00 respectively; this implies that the cost of production will decrease by N10.44, N11.53, N5.11 and M16.00 respectively if additional units of such resources are used.

Table 3 Resource Allocations and Use Pattern

Resource	Use status	Slack	Shadow price (MVP)
Land	Not fully utilized	2.33 ha	-
Family labour I	Fully utilized	-	10.44
Hired labour I	Fully utilized	-	11.53
Family labour II	Fully utilized	-	5.11
Hired labour II	Not fully utilized	44.65 mandays	-
Cash paid labour	Not fully utilized	₦275.00	-
Cash on material input	Fully utilized	-	16.00

Source: Computer printout of Goal programming Models

The non-fully utilized resources include land (2.33 ha), hired labour for period II (44.65 mandays), as well as the cash paid labour (₦275.00). These show that these resources were in excess of the actual needs of the household in the study area. Though there are evidences of land fragmentation in the study area due to land tenure system that is a prominent feature of land in Africa, however, land is not yet a constraining factor to households' agricultural (crop) production in the study area.

The non-basic activities include the following: maize/rice, millet/groundnut, guinea corn/maize, guinea corn/groundnut, millet/guinea corn/cowpea/groundnut, rice/sorghum/groundnut, sorghum/rice/millet/onion, cowpea/rice/groundnut, guinea corn/cowpea/rice, millet/guinea corn/rice, millet/groundnut/guinea corn, millet/rice/vegetables, sorghum/groundnut/pepper/maize, and millet/maize/Bambaranut/sugarcane. The non-basic activities have the marginal opportunity cost (MOC) of N3672.46, N1796.35, N2426.04, N2481.97, N398.34, N2770.48, N2785.61, N192.69, N681.37, N688.65, N3096.77, N1825.68, N4831.60, and N3912.99 respectively.

The MOC signifies by how much the programme value will increase if any of the non-basic activities, which erstwhile did not enter the programme, is forced into the programme. That is, the optimal cost of production will increase by the margin equal to the MOC value of the excluded activities. The most detrimental of all the excluded activities was sorghum/groundnut/pepper/maize with an MOC of N4831.60, while the least detrimental was cowpea/rice/groundnut, with an MOC of N192.69.

Conclusion

The optimum farm plan showed that an average rural household should allocate his resources in such a way that 4 crop enterprises are produced according to their hectarage allocations. The recommended allocation pattern depicted the most important enterprise as Millet/Maize/Rice (1.20 ha), followed by Maize/Guinea corn/Cowpea (0.94 ha), then by Millet/Cowpea (0.16 ha), and lastly by Maize/Cowpea/Millet (0.04 ha). A striking feature of this plan is that there is no sole cropping enterprise included in the model because one could hardly find a smallholder farmer in the study area, who practiced sole cropping. These crop combinations were also unique in the sense that they are all cereal-based, usually laced with legume (cowpea).

Further, the resource use allocation in the study depicted that since the household held some resources in excess, it is an indication of inefficiency in actual resource use by the households in their crop production enterprise. Finally, the results suggested that an average household could not achieve full satisfaction of its production goals with the present structure of its available farm production resources.

Recommendation

For the goals of food security, increased income, and reduced farm production costs in terms of labour as identified by the rural households in the study area to be accomplished, they should produce 1.20 ha of Millet/Maize/Rice, 0.94 ha of Maize/Guinea corn/Cowpea, 0.16 ha of Millet/Cowpea, and 0.04 ha of Maize/Cowpea/Millet. That is the average farm holding should be 2.34 ha.

It is also recommended that, effective farm advisory services on the efficient allocation of farm resources and appropriate cropping patterns are important and should be built into programs promoting increased agricultural productivity among farmers in a cereal-based cropping system. Farmers should economize on the use of hired labour and embrace a mixed cropping pattern particularly cereal-legume based cropping.

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