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RESEARCH NOTES

Revenue Maximising Combination of Crop Enterprises in Bayelsa State of Nigeria: A Linear Programming Application

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I

INTRODUCTION

Studies have shown that mixed and inter-cropping are more advantageous in terms of resource productivity and output, as well as in profitability than sole cropping. This is particularly the case in most parts of Africa, Asia and Central America (Papendrick *et al.,* 1976; Beets, 1982; and Francis, 1986). For example, Nji and Nkwain (1987) and Peter and Range-Metzger (1994) have reported the practice of mixed and inter-cropping among peasant farmers in Cameroun and other parts of Africa. These practices are said to have prevailed over the years because of the benefits the peasant farmers have continued to derive from these cropping systems.

The foregoing analysis suggests that farmers in Africa should, for now and in the near future, accord greater priority to mixed or inter-cropping than sole cropping. The questions that readily come to mind are: what is the optimum mixture of crops that a farmer should cultivate? What crops should be in the mixture? The problem of the farmer therefore is to select combinations or levels of particular crop production activities which will maximise his/her motive of farm enterprise. In doing this, he/she is not completely free because the production inputs available to him/her are limited. The sum of the i-th input that he/she uses to support the crop enterprises cannot exceed his/her resources endowment b_i. He/she therefore needs to maximise his/her motive of enterprise (farm profit, household subsistence needs, etc.) subject to their resource constraints.

Small-holder crop farmers in Bayelsa State are known to have intuitively made rational decisions in matters of choice and combinations of crops to cultivate subject to their level of experience and available information (Allison-Oguru *et al.,* 1999). However, there has not been any empirical analysis of what crop farmers do in this regard. Yet analysis and information on optimum crop mixture is vital in promoting crop production activities in the area. It is for this reason that this study was undertaken to determine the optimum crop enterprise mixture consistent with

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maximum farm revenue, identify the limiting resources in the cropping system practiced by farmers in the areas, and assess the level of resource use and efficiency.

II

CONCEPTUAL FRAMEWORK AND METHODOLOGY

2.1 Conceptual Framework

During the last three decades, farm business management experts have made very frequent use of linear programming (LP) models in analysing farm planning and related problems both at the micro and macro-economic levels in Africa and Asia (Sankayan and Cheema, 1991). Though the theory of mathematical programming from which LP evolved had been known for a long time, its application to agricultural production economics is relatively recent dating back only to the middle of the 20th century (Aromolaran, 1993). Since then, LP models have been employed in the diagnosis, analysis and solution of various farm business problems.

In its simplest form LP is a mathematical technique by which the allocation of limited resources to maximise a desired quantifiable objective can be determined under the assumptions that there is no risk involved and that all the relations between relevant variables are linear and continuous (Charry *et al*., 1992). Thus, LP is no more than a form of budgeting which by making use of mathematics, ensures that the optimum budget is found.

Structurally, an LP model has three essential components: an objective function, competitive enterprises with possible alternative methods of producing each; and constraints to attainment of the set objective (Heady and Candler, 1958; Thiam and Ongs, 1979; Olayemi and Onyenwaku, 1999). The objective function of an LP model can take one of several forms. It can be the maximisation of the revenue or gross margin from one or a combination of farm enterprises, minimisation of productions costs, etc.

In linear programming, a process denotes the method of transforming farm inputs into outputs and is indicated by input-output coefficients. Input-output coefficients refer to the quantities of resources required to produce a unit of an activity or output. Different processes are associated with different methods of product transformation, e.g., battery cage and deep litter systems of broiler production. Activity refers to any enterprise being undertaken. However, the same enterprise or farm product produced by different method or process constitutes different activities for the purpose of LP modeling. In general, we have real, intermediate, disposal and artificial activities in a typical LP model.

One of the advantages of LP is that the dual solution to the primal provides a direct measure of the shadow prices or marginal value productivities (MVP) of the resources. In general, only limiting resources or excluded activities have shadow prices greater than zero. Shadow prices in a maximisation problem are income penalties which show by how much the value of an objective function or programme will increase by increasing the level of resource by one unit (Osuji, 1978; Noori-Naini, 1978).

2.2 Methodology of the Study

2.2.1 Sources and Types of Data

The data for this study were obtained from small-holder crop farmers drawn from 3 of the 8 local government areas (LGAs) in Bayelsa State, Nigeria. The data comprised farm land availability and endowment, farm labour availability and endowment, farm capital availability and the inputs-output coefficients of the various resources endowment and the crop production activities involved.

2.2.2 Method of Data Collection

A three-stage sampling technique was used in collecting the data for this study. The first stage involved the purposive selection of 3 of the 8 LGAs in the study area, based on preponderance of crop production activities. The second stage involved random selection of 14 farming communities from a list of such communities in the LGAs. Lastly, in each farming community so selected, 5 farm households were randomly selected and studied. This gives a sample size of 210 farm households during the first phase of the study which was focused primarily on reconnaissance survey of farm and farm household in the area.

The cost-route data collection procedure was used in the second phase of the study which involved an in-depth study of 100 out of the 210 farm households surveyed in the earlier phase. The basis of selection of the 100 farm households included in the in-depth study was farmers' willingness to participate in the study. With the aid of trained enumerators drawn from the Agricultural Projects and Extension Services of Shell Petroleum Development Company of Nigeria Limited (SPDC), the Bayelsa State Ministry of Agriculture and Natural Resources, data concerning weekly crop farming activities were collected from the 100 farm households surveyed for a period of 15 months using pre-designed questionnaire.

2.2.3 The Linear Programming Model

The data for this study were analysed using a linear programming model of the type specified below:

$$\text{Max.}Z = \sum_{i=1}^{m} CX_i \qquad \ldots (1)$$

subject to the following constraints:

$$\sum_{i=1}^{n} a_{ik} X_i \leq b_k \qquad \text{....(2)}$$

$$X_i \geq 0 \qquad \text{....(3)}$$

Where Z = Sum of the net annual returns of the activities in the crop year surveyed,
C_i = Net annual return per hectare of the i-th activity in the crop year surveyed,
X_i = Hectarage devoted to the i-th activity in the crop year surveyed,
n = Total number of activities in which crop appears,
m = Total number of activities,
a_{ik} = Per hectare requirement of the k-th resource by the i-th activity in the crop year surveyed,
b_k = Level of k-th resource available in the crop year surveyed.

The LP model specified in equation (1) has eleven crop production activities and ten resource constraints. The crop production activities in the model are: cassava sole (C); plantain sole (P); yam sole (Y); swamp rice sole (R); cassava/cocoyam/plantain (CCyP); cocoyam sole (Cy); cassava/maize (CM); plantain/yam/vegetables (PYV); plantain/sugarcane/vegetables (PSV); and plantain/cassava/vegetables (PCV).

The ten resource constraints in the LP model are respectively: 1st quarter family labour (FLAB 1); 2nd quarter family labour (FLAB 2); 3rd quarter family labour (FLAB 3); 4th quarter family labour (FLAB 4); 1st quarter hired labour (HLAB 1), 2nd quarter hired labour (HLAB 2); 3rd quarter hired labour (HLAB 3); 4th quarter hired labour (HLAB 4); capital (CAP), and farm land (LD).

The data requirements for the LP model specified in equations (1) through (3) were collated and presented in Excel format and analysed using SLP 88 linear programming routine. The LP model specified in equations (1) through (3) was aimed at economic analysis which would yield information on optimum crop mixtures, programme value, shadow prices of resources employed, income penalties, and marginal opportunity costs of limiting resources in the cropping system of the study area (Allison-Oguru, 2004).

III

RESULTS AND DISCUSSION

3.1 Matrix of Input-Output Coefficients

A major requirement in the specification of conventional LP model is the formation of a matrix of input-output coefficients. This matrix specifies the amount of different inputs such as land, labour and capital and net farm return per unit of activity included in the LP model. As mentioned earlier, there are 11 different crop production activities in the LP model used in this study. The information on per hectare use of the different production inputs for each crop, net return per hectare of each activity, level of resource endowment, etc., are shown in Table 1.

3.2 Mechanics of Programming

With the aid of the empirical information furnished in Table 1, the LP model specified in this study is presented empirically as follows:

$$\text{Max } Z = 62{,}853X_1 + 76{,}331X_2 + 41{,}152X_3 + 76{,}662X_4 + 44{,}872X_5 + 27{,}442X_6 + 42{,}715X_7 + 1{,}12{,}523X_8 + 88{,}980X_9 + 95{,}900X_{10} + 94{,}666X_{11} \quad \ldots(4)$$

Subject of the following input constraints

(a) $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} \leq 2$ ha ….(5)

(b) $31X_1 + 23X_2 + 48X_3 + 22X_4 + 28X_5 + 40X_6 + 27X_7 + 31X_8 + 26X_9 + 11X_{10} + 60X_{11} \leq 55.2$ mandays ….(6)

(c) $52X_1 + 47X_2 + 36X_3 + 16X_4 + 28X_5 + 59X_6 + 29X_7 + 25X_8 + 22X_9 + 34X_{10} + 105X_{11} \leq 55.2$ mandays ….(7)

(d) $23X_1 + 25X_2 + 29X_3 + 17X_4 + 26X_5 + 70X_6 + 24X_7 + 18X_8 + 29X_9 + 13X_{10} + 41X_{11} \leq 45.6$ mandays ….(8)

(e) $15X_1 + 47X_2 + 68X_3 + 14X_4 + 45X_5 + 67X_6 + 15X_7 + 17X_8 + 12X_9 + 45X_{10} + 39X_{11} \leq 62.4$ mandays ….(9)

(f) $8X_1 + 6X_2 + 10X_3 + 6X_4 + 6X_5 + 8X_6 + 5X_7 + 8X_8 + 6X_9 + 3X_{10} + 13X_{11} \leq 13.8$ mandays ….(10)

(g) $13X_1 + 10X_2 + 8X_3 + 4X_4 + 7X_5 + 15X_6 + 7X_7 + 5X_8 + 5X_9 + 9X_{10} + 26X_{11} \leq 17.6$ mandays ….(11)

(h) $5X_1 + 5X_2 + 7X_3 + 4X_4 + 6X_5 + 15X_6 + 5X_7 + 4X_8 + 6X_9 + 3X_{10} + 9X_{11} \leq 11.4$ mandays ….(12)

(i) $3X_1 + 12X_2 + 14X_3 + 4X_4 + 9X_5 + 17X_6 + 4X_7 + 4X_8 + 3X_9 + 9X_{10} + 10X_{11} \leq 15.6$ mandays ….(13)

(j) $16X_1 + 18X_2 + 17X_3 + 17X_4 + 13X_5 + 23X_6 + 19X_7 + 42X_8 + 21X_9 + 18X_{10} + 32X_{11} \leq 42$ naira ….(14)

TABLE 1. LINEAR PROGRAMMING INPUT-OUTPUT COEFFICIENTS OF THE CROP ENTERPRISES SURVEYED

Activities	C	P	Y	CCyP	R	Cy	CM	PYV	PCyV	PSV	PCV						Value of
Constraints	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	constraints
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Objective function (Net Farm Income Unit = ₦'000)	63	76	41	76	45	27	65	133	86	95	96						67.54 Naira
Land	1	1	1	1	1	1	1	1	1	1	1						2.00 hectare
Family Labour Period 1 (FLAB 1)	30.8	23.04	47.5	22.08	27.66	40.46	25.65	31.33	26.42	11.4	60.13	-1					55.20 mandays
Family Labour Period 2 (FLAB 2)	52.44	46.48	35.98	16.32	28.33	59.0	28.72	24.6	22.12	34.08	105.32		-1				70.40 mandays
Family Labour Period 3 (FLAB 3)	22.75	24.27	29.32	16.73	25.96	69.70	23.77	18.32	28.58	13.21	41.0			-1			45.6 mandays
Family Labour Period 4 (FLAB 4)	14.88	46.72	68.24	14.40	45.30	67.0	15.27	16.66	12.0	44.74	38.66				-1		62.40 mandays
Hired Labour Period 1 (HLAB 1)	7.72	5.76	9.72	5.52	5.67	8.28	5.25	7.83	5.79	2.50	13.19	1					13.8 mandays
Hired Labour Period 2 (HLAB 2)	13.11	9.52	7.89	4.08	7.08	14.75	7.18	5.40	4.53	8.52	26.33		1				17.60 mandays
Hired Labour Period 3 (HLAB 3)	4.66	11.68	13.68	3.60	9.27	16.75	3.81	4.16	3.00	9.16	9.66			1			11.40 mandays
Hired Labour Period 4 (HLAB 4)	3.27	5.33	5.33	7.33	3.67	15.30	4.86	3.75	5.85	3.30	9.0				1		15.60 mandays
Capital (Unit = ₦ '000)	16	18	17	17	13	23	19	42	21	18	32					-1	42.00 Naira

Source: Allison-Oguru (2004).

3.3 Programming Results and Optimum Farm Plan

The results of the LP model indicate that only 2 of the 11 basic crop production activities specified in the model entered the feasible solution. The two activities are: plantain/yam/vegetables (PYV) (Table 2). This suggests that the average farmer in the study area who wishes to maximise net farm return, irrespective of whether or not farm household foods consumption requirements are met should allocate his farm resources in such a manner that these crops enterprises are cultivated at the level of the optimum hectarage indicated. This would enable the farmer generate optimum net annual return of ₦211,727.60 per cropping season as against the current average net annual income of ₦106,644.02.

TABLE 2. BASIC OPTIMAL RESOURCE USE AND ALLOCATION PATTERN OF THE CROP ENTERPRISES SURVEYED

Basic Activity		Fully utilised resources		Unused Resources	
Crop Mixture (1)	Hectarage (2)	Resource (3)	Shadow Price (4)	Resource (5)	Surplus (6)
Plantain/yam/vegetables (PYV)	1.63	Land	82,645.28	FLAB 2	17.70
				FLAB 3	10.85
Plantain/sugarcane/vegetables (PSV)	0.37	FLAB 1		FLAB 4	18.72
				HFLAB 2	5.65
		HLAB 2	673	HFLAB 3	4.07
Programme value (₦)	2,11,727.60	Capital	0	HFLAB 4	5.44

Source: Computer Printout of Linear Programming Model No.1 in Allison-Oguru (2004).

It is advisable that farmers in the area do away, for now, with the crop enterprise not included in the optimal farm plan shown in Table 2. These enterprises are cassava sole (C); plantain sole (P); yam sole (Y); cassava/cocoyam/plantain (CCyp); cocoyam sole (Cy); cassava/maize (CM); plantain/cocoyam/vegetables (PCyV); and plantain/cassava/vegetables (PCV).

Forcing any of the aforementioned crop enterprises not included in the optimal farm plan into the programme would lead to reduction in programme value, and by implication, the net annual return the farmer would earn. The marginal opportunity cost of capital (MOC) reported in Table 3 measures by how much the programme value will reduce if any of the non-basic activities, which erstwhile did not enter the programme, is forced into it.

TABLE 3. MARGINAL OPPORTUNITY COST (MOC) OF NON-BASIC ACTIVITIES IN THE LP MODEL

Non-Basic activity (1)	Marginal Opportunity Cost (MOC)(₦) (2)
Cassava Sole (C)	₦48,569.28
Plantain Sole (P)	30,027.71
Yam Sole (Y)	80,154.40
Cassava/Cocoyam/Plantain (CCyP)	23,220.11
Rice Sole (P)	60,076.41
Cocoyam Sole (Cy)	90,447.35
Plantain/Cocoyam/Vegetable (PCyV)	41,441.01
Plantain/Cassava/Vegetable (PCV)	₦66,104.12

Source: Computer Printout of Linear Programming Model No.1 in Allison-Oguru (2004). ₦ - Naira, the Nigerian currency.

For example, if cassava sole (C) is forced into the optimal farm plan, net annual return will decrease by ₦48,569.28 while net annual return will decrease by ₦30,027.71; ₦80,154.40 and ₦23,220.11 if plantain sole (P), yam sole (Y), and cassava/cocoyam/plantain (CCyP) respectively are forced into the optimal farm plan. The corresponding figures for rice sole (R); cocoyam sole (Cy); cassava/maize (CM); plantain/cocoyam/vegetables (PCyV); and plantain/cassava/vegetables (PCV) can be similarly interpreted. The most detrimental of all the excluded activities is cocoyam sole (CY) while the least detrimental is plantain/cocoyam/vegetables (PCyV).

It could be argued that if the recommended cropping pattern is followed by many crop farmers in the study area, it could lead to over-supply of the food crops concerned thus giving rise to marketing and price risks. Theoretically, this is a possibility. However, it would not occur automatically because most of the farmers concerned are resource poor. It would therefore require external intervention by either government or non-government agencies to enable them garner the additional resources required for adoption of the recommended cropping pattern.

The perceived lag in time could be used by the government or non-government agencies concerned to put in place a marketing arrangement for the food crops concerned such that any supply in excess of the absorptive capacity of the local market in the study area are shipped to areas of deficit outside of the immediate area of production. This would help to forestall any possible adverse effects of over–supply of the food crops concerned in the immediate and long run.

An examination of the resource use pattern in the crop enterprises surveyed reveals that only 4 of the 10 specified farm resources are fully utilised at the satisfying solution. These are farm land, family labour for period I (January-March), hired labour for period II (April – June), and capital. The shadow price for these fully utilised resources are ₦82,645.28 for land, and ₦673.00 each for family labour in period I and hired labour in period II. It can therefore be argued that the net annual return will be increased by these amounts if additional units of these resources are employed in farm production. These results further suggest that farm land, family labour for the period January – March, and hired labour for the period April – June are the most limiting resource faced by farmers in the area. The shadow price of capital is zero implying that this resource has not been limiting under the existing conditions relative to land, family labour and hired labour.

About 17.7 man-days of family labour for the period April – June, 10.85 man-days for the period July – September and 18.72 man-days for the period October-December, as well as 5.65 man-days, 4.07 man-days and 5.44 man-days respectively of hired labour for the periods April-June, July-September and October-December, were left unused. This suggests that there are not enough of the other complementary resources on the farm to be combined with these unused resources and thereby increase farm production and income. Consequently, the farmer is not willing to pay anything for any additional unit of these unused farm inputs.

The farmers in Bayelsa State and elsewhere in the Niger delta are known to engage in other natural-resource-based secondary economic activities during off-farm seasons in order to earn supplementary income. Such activities in the area include: artisanal fishing, lumbing, game and snail trapping, hunting, forest fruits gathering, weaving, etc. (Allison-Oguru *et al.,* 1999). Consequently, the excess man-days of family labour indicated in the feasible farm plan for the periods April-June, July-September and October-December could be redeployed to such secondary economic activities in aid of farm household's subsistence, as well as to earn supplementary income.

With regard to the unused man-days of hired labour indicated in the optimal farm plan, they could be used up through reduction of family labour employed if the complementary resources on the farm to be combined with the said unused resources could be mobilised.

IV

CONCLUSION

The study has shown that mixed cropping in the central Niger Delta of Nigeria is superior to mono-cropping in terms of income generated. Out of eleven crop production activities included in the LP model, only two entered the basic feasible solution and none of these two are mono-cropping enterprises. Given the prices of farm inputs and outputs, the prevailing farming technology and the farmers' experience, the cultivation of 1.63 hectares of plantain/yam/vegetables (PYV) in combination with 0.37 ha of plantain/sugarcane/vegetables (PSV) is the revenue maximisation combination of crop enterprises in the area.

In addition, the study has shown that farm land, family labour for the period January-March and hired labour for the period April-June are the most limiting agricultural resources faced by the farmers in the area, *ceteris paribus*. This is evident in the positive values of the shadow prices of these farm resources. It can therefore be argued that farmers in the area who wish to maximise farm revenue and by extension farm profit, should be encouraged to continue the practice of mixed cropping. In doing so, they should be guided in their choice and combination of crop enterprise by the optimal farm plan resulting from this study. However, policy makers and agricultural development programmers and planners should take proactive actions to avert the possible adverse effects which the limiting resources such as farm land and farm labour could have on the growth and development of crop farming activities in the area. They should also take proactive measures to put in place an effective marketing system that would minimise the anticipated risks associated with over-supply of the recommended food crops. It is therefore suggested that further studies be conducted on the availability, suitability and mode of agricultural land use in the area as well as the pattern of seasonal labour supply and demand with a view to addressing the likely problems that could be posed by their limiting nature.

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