Journal of Agriculture and Environment Vol. 5 Nos. 1 and 2, 2009: 1-9
ISSN 1595-465X

OPTIMAL FARM PLANS FOR CROP-LIVESTOCK FARMERS IN SOKOTO STATE, NIGERIA

A. L. Ala[1], I. Mohammed[1], K. M. Baba[1] and W. A. Hassan[2]

[1]Department of Agricultural Economics and Extension, Usmanu Danfodiyo University, Sokoto
[1]Department of Animal Science, Usmanu Danfodiyo University, Sokoto

ABSTRACT

The study was conducted to determine the optimal farm plans for crop-livestock production system in Sokoto State. In order to achieve this objective, one hundred and eighty farmers were randomly selected from six Local Government Areas of the State. Data collected were analyzed using linear programming models. The optimal total gross margin for the crop-livestock production system was ₦700,032.33 as against the existing farmers' total gross margin of ₦411, 562.03. The shadow prices of capital and man-days were ₦5.64 and ₦80.96, respectively. Sensitivity analysis reveals that if the farmer decides to use all the slack variables, the objective function would be increased by ₦27,959.54 (4 %) over that of the optimal plan. The level of resource use was 2.50 ha for millet/sorghum/cowpea mixture, 2.05 ha for millet/sorghum/groundnut, 0.5 ha for millet, sorghum and groundnut each, while cattle, sheep and goats were one each. It was recommended that farmers should reorganize their resources according to the optimum plan as this will greatly enhance their income.

Keywords: Crops; Livestock; Optimal plan; Gross margin

INTRODUCTION

The most fundamental issue in economics is the allocation of the scarce resources among competing ends in order to maximize satisfaction. Therefore, any attempt to increase the level of production in traditional agriculture should accentuate on the introduction of new and appropriate technology so as to ensure the efficient utilization of these scarce resources and thus attain the stated objectives (Schultz, 1964). The traditional agricultural production systems in Nigeria as well as the semi-arid, arid and sub-humid zones of sub-Saharan Africa - shifting cultivation and pastoralism are under increasing pressure (Powell *et al.*, 1996) due to rapid rise in population (2-3 %). In fact, in most of the semi-arid and sub-humid zones, the area of range and crop lands required to achieve high productivity in both systems (crop and livestock production systems) is no longer adequate (Mohammed-Saleem, 1996).

Therefore, the pastoral system of production, which is an aspect of segregated livestock and crop production, may be inefficient in the farming system as a whole and may lead to waste of resources- manure, milk, crop residues and draft power. This problem becomes even more accentuated, especially, now that the traditional free grazing areas are fast reducing due to increasing population pressure and changes in land use for structural development and crop production (McIntire and Gryssels, 1986). Due to these emerging challenges in the face of a rapidly changing external environment, this trend has to a large extent reduced the size of land on which the farmer can graze his animals and grow his crops.

However, if the farmer were to produce both crops and livestock together, a competition will emerge for common resources such as land, labour, capital, management and water. Land is needed for both forage and grain production, the additional labour required for improved livestock production may also compete with what is required for cropping operations. Capital, management and water resources also have to be allocated to both enterprises. Therefore, the possibility of the farmer keeping large herd alone or cultivating large area of land is becoming very slim.

Now the questions are, how is the farmer going to handle and manage this problem? Is he to reduce his herd size so as to cope with the emerging scarce land resource? Will he combine both crop and livestock production together so as to reap the benefits provided by the two enterprises? What should be the appropriate level of integration between crop and livestock production enterprises? What is the optimum enterprise combination(s) the farmer should evolve so as to maximise his productivity and income? These are the questions that this research seeks to answer.

A frequently used model in determining optimum resource combination at the farm level is mathematical programming. This method is used to determine the optimum allocation of land, labour and capital given a goal (usually maximization of income) and a set of constraints and possible activities (Van Rheenen, 1995; Baker and Lightfoot, 1988; Sisoko, 1998). Such model may be used to advise the farmer on how to organize his farm in view of one or more of his goals. The standard methods used in the analysis of agricultural decision making under risk are reviewed in Henderson and Quandt (1979) and Broussard (1979). The usual way in which the trade off between the mean yield and variance in yield between crops is modelled is the technique of stochastic dominance, using cumulative distribution functions for yield (Muchow and Bellamy, 1991). Stochastic dynamic programming has been used extensively in behavioral ecology (Mangel and Clark, 1988). Mace and Houston (1989) applied it to the pastoralists' decision about the proportion of camels and goats to combine in their herds.

Milner-Gulland *et al.* (1996) developed a model of household decision making in dry land agro-pastoral system in order to find optimal combination of crops and livestock that a farmer would choose to keep. In this study, the farmer could choose to plant a high-risk crop such as maize, a low-risk crop such as millet, and keep goats or cattle. An interaction between these components was modelled involving the use of cattle for drought power. It was shown that very poor farmers chose to plant maize, whereas cattle were kept only if they were to be used for draught power, and only by wealthier farmers. Besides linear programming, several other models such as the production function, multi objective and goal programming have been used to solve the problem of resource allocation and enterprise combination.

MATERIALS AND METHODS

Sokoto State is located in the Sudan savanna zone in the extreme north-western part of Nigeria between longitudes 4^0 8' and 6^o 54'E and latitudes 12^o 0' and 13^o 58'N (Mamman *et al*., 2000). The target population for the study was settled farmers growing crops and keeping livestock together in Sokoto State. Sokoto State comprises of 23 Local Governments Areas. Among these, six Local Government Areas were randomly selected. These included Tambuwal (Barkeji, Sanyinna and Nabaguda), Rabah (Maikujera, Rara and Rabah), Wamakko (Gumbi, Gwiwa and Sire), Tangaza (Sononi, Gidan-madi and Sabro), Illela (Amarawa, Ambarura and Sabaru) and Tureta (Tsamiya, Lamba and Yargwalli). In each of the Local Government Areas, three villages were selected and in each of the villages, ten farmers were selected using multi-stage sampling technique. This gave a total of 180 farmers who were randomly selected. In this study, linear programming model was used to determine the optimum combination of crop and livestock enterprises. The model was specified as follows:

Maximize $Z = \sum c_j X_j$ (1)

Subject to:

Land: $\sum_{aij} X_j \leq b_i$ (2)

Labour: $\sum_{aij} X_j \leq b_2$ (3)

Capital: $\sum_{aij} X_j \leq b_3$ (4)

$X_j \geq 0$

Where:

Z = the objective function to be maximised, that is the total gross margin.

C_j = net price per hectare of the j^{th} activity.

X_j = the decision variable of the activity engaged in

a_{ij} = the amount of the resource 'i' used in the production of a unit of the j^{th} activity.

b_1, b_2, b_3 = quantities of resources available.

Algebraic Formulation

The problem is to maximize Z defined as the sum of returns over variable costs:

$$Z = c_1X_1 + c_2X_2 + c_3X_3 + c_4X_4 + c_5X_5 + c_6X_6 + c_7X_7 \quad (5)$$

Subject to:

$1x_1 + 1X_2 + 1X_3 + 1X_4 + 1X_5 + 1X_6 + 1X_7 + 1X_8 + 1X_9 + 1X_{10} + 1X_{11} + 1X_{12} + 1X_{13} + \leq \beta_1$ hectares of land (6)

$a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + a_7X_7 + a_8X_8 + a_9X_9 + a_{10}X_{10} + a_{11}X_{11} + a_{12}X_{12} + a_{13}X_{13} \leq \beta_2$ hours of labour (7)

$b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + b_{13}X_{13} \leq \beta_3$ capital (in naira) (8)

And non-negativity constraints:

$X_1 \geq 0, X_2 \geq 0, X_3 \geq 0, X_4 \geq 0, X_5 \geq 0, X_6 \geq 0, X_7 \geq 0$

Where

X_1 = Unit of millet + sorghum produced
X_2 = Unit of millet + cowpea produced
X_3 = Unit of millet + groundnut produced
X_4 = Unit of millet + sorghum + cowpea produced
X_5 = Unit of millet + sorghum + groundnut produced
X_6 = Unit of sorghum + cowpea produced
X_7 = Unit of sorghum + groundnut produced
X_8 = Unit of millet produced
X_9 = Unit of sorghum produced
X_{10} = Unit of groundnut produced
X_{11} = No. of sheep sold
X_{12} = No. of cattle sold
X_{13} = No. of goats sold
C_1 = Net price of millet + sorghum
C_2 = Net price of millet + sorghum produced
C_3 = Net price of millet + cowpea produced
C_4 = Net price of millet + groundnut produced
C_5 = Net price of millet + sorghum + cowpea produced
C_6 = Net price of millet + sorghum + groundnut produced
C_7 = Net price of sorghum + cowpea produced
C_8 = Net price of sorghum + groundnut produced
C_9 = Net price of millet produced
C_{10} = Net price of sorghum produced
C_{11} = Net price of groundnut produced
C_{12} = Net price of sheep sold
C_{13} = Net price of cattle sold
C_{14} = Net price of goats sold

The system of inequalities in equations 6, 7 and 8 are now changed to equalities by adding slack variables. This is because any of the resources may go unused. The slack variables are as follows:

$X_{\alpha 1}$ = the quantity of unused land
$X_{\alpha 2}$ = the quantity of unused labour
$X_{\alpha 3}$ = the quantity of unused capital

Adding the slack variables to equations 6, 7 and 8 we now have

$$1X_1 + 1X_2 + 1X_3 + 1X_4 + 1X_5 + 1X_6 + 1X_7 + 1X_8 + 1X_9 + 1X_{10} + 1X_{11} + 1X_{12} + 1X_{13} + 0X_{\alpha 1} + 0X_{\alpha 2} + 0X_{\alpha 3} = \beta_1 \text{ hectares of land} \quad (9)$$

$$a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + a_7X_7 + a_8X_8 + a_9X_9 + a_{10}X_{10} + a_{11}X_{11} + a_{12}X_{12} + a_{13}X_{13} + 0X_{\alpha 1} + X_{\alpha 2} + 0X_{\alpha 3} = \beta_2 \text{ man-days of labour} \quad (10)$$

$$b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7\ b_8X_8 + b_9X_9 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + b_{13}X_{13} + 0X_{\alpha 1} + 0X_{\alpha 2} + X_{\alpha 3} = \beta_3 \text{ Naira of capital} \quad (11).$$

In programming, the values of 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} $X_{\propto 1}$, $X_{\alpha 2}$, and $X_{\propto 3}$ that will maximize the sum of the products of these quantities and their net prices were determined.

RESULTS AND DISCUSSION

Optimal Farm Plans

The results of the optimum and existing farmer's plans are shown in Table 1. The table reveals that given the land resources available to the smallholder farmer, 8.25 ha is the optimal farm size which should be devoted to crop-livestock production system. A breakdown of the activities (enterprises) showed that the optimum farm size for millet/cowpea was 1.5 ha, millet/sorghum/cowpea 2.50 ha and millet/sorghum/groundnut 2.05 ha. Similarly, sorghum/cowpea was 0.85 ha, millet, sorghum and groundnut had 0.50 ha each. Millet/sorghum, millet/groundnut, sorghum/groundnut were not as competitive as other enterprises and could not enter into the optimum plan.

The optimal total gross margin for the crop-livestock production system was ₦700,032.33 as against the existing farmers' total gross margin of ₦411,562.43. This increase in the total gross margin induced by the optimal plan represents an increase of 70 % over that of the existing farmers' total gross margin. This therefore, means that farmers could increase their income to this level (70%) by adopting the optimum plan. Dipeolu *et al*. (2000) in their study of the optimum farm plans for sustainable environmental and economic resource use for food crop farmers in Ogun State found that the gross margin per hectare of the actual existing farms was ₦16,621.99, while the optimum plan showed an increase of 108 % over that of the existing farm plan (₦34,634.61). Similarly, the optimum farm plan recommended an area of 2.08 ha to be put into cassava/maize cultivation as opposed to 0.9 ha actually used. Sanni *et al.* (2004) also reported that the optimum gross margin for crop-livestock farmers in Katsina State showed an increase of 21 %, 12 % and 19 % for zones 1, 2, and 3, respectively over that of specialized crop production. Similarly, increases in the average returns to the limiting resources of land, labour and operating capital were also recorded.

The average return per ha for the optimum plan was ₦84,852.40, return per man-day, ₦1,515.98, return to capital and management ₦591,856.99 and return per operating capital was ₦2.22. In the case of farmers' existing system, return per ha was ₦49,348.00; return per man-day, ₦636.60; return to capital and management, ₦303, 373.44, while the return per operating capital was ₦1.30. The difference between optimum plan and farmers' plan represented an increase ranging between 72 % for return per ha and 138 % for return per man-day. This reveals that farmers could improve the utilization of their limited resources and thus income by adopting the optimum farm plan.

Sensitivity Analysis

The results of the sensitivity analysis of the optimal solutions to the net prices (₦ /ha) and the values of the constraints are presented and interpreted. Sensitivity analysis shows the range in which the coefficients could vary while the optimal level remains the same. Optimality is realized between the lower and upper boundaries provided by the results of this study.

Table 1: Summary of optimum and existing farmers' plan.

Item	Unit	Optimum plan	Farmers' Plan
Millet + sorghum	Ha	0.00	1.80
Millet + cowpea	Ha	1.50	1.50
Millet + groundnut	Ha	0.00	0.50
Millet + sorghum + cowpea	Ha	2.50	2.55
Millet + sorghum + groundnut	Ha	2.05	0.99
Sorghum + cowpea	Ha	0.85	0.75
Sorghum + groundnut	Ha	0.00	0.06
Millet	Ha	0.50	0.05
Sorghum	Ha	0.44	0.08
Groundnut	Ha	0.50	0.06
Cattle	No.	1.00	1.00
Sheep	No.	1.00	2.00
Goats	No.	1.25	4.00
Total land	Ha	8.25	8.34
Total labour	Man-days	640.97	646.61
Total operating capital	₦	314,664.22	325,323.01
Total gross margin (TGM)	₦	700,032.33	411,562.45
Economic value (shadow price of land)	₦	-	-
Economic value (shadow price of labour)	₦	5.64	-
Economic values (shadow price of capital)	₦	90.96	-
Return/ha	₦/ha	84,852.40	49,348.00
Return/Man- days	₦/Man-	1,515.98	636.49
Return to capital and Management	day₦	591,856.99	303,373.44
Return/Operating Capital	₦	2.22	1.30

Therefore, a farmer whose goal is to maximize profit should adopt the optimal plan and thus fix net prices and levels of constraints within the stipulated ranges given by the results of this study.

Sensitivity Analysis of the Optimal Solutions to Changes in the Net Prices

The sensitivity analysis of the optimal solution to the net prices attributable to each activity is shown in Table 2. The table indicates that the average net prices have allowable decreases of 0.269 ha for millet/sorghum/cowpea, 0.0284 ha for sorghum and 0.0279 ha for sorghum/cowpea. The shadow price indicates that increasing the right hand size by one unit

Table 2: Results of the sensitivity analysis of the optimal solution to changes in net prices for the different crop-livestock production activities.

Activity	Lower Limit	Current Value	Allowable Decrease	Shadow Price (₦)	Value for the Allowable Decrease (₦)
Mi + So	0.000	0.000	0.000	1878.310	0.000
Mi + Co	1.274	1.50	0.226	280.666	63.431
Mi + Gn	0.000	0.000	0.000	3752.438	0.000
Mi + So + Co	2.231	2.500	0.269	893.757	240.420
Mi + So + Gn	0.000	2.050	2.050	6645.837	13623.970
So + Co	0.571	0.850	0.279	1964.090	547.980
So + Gn	0.000	0.000	0.000	0.000	0.000
Millet	0.282	0.500	0.218	2130.328	464.410
Sorghum	0.156	0.440	0.284	2641.929	750.310
Groundnut	0.260	0.500	0.240	33736.075	8096.650
Cattle	0.000	1.000	1.000	4172.355	4172.355
Sheep	1.125	2.000	0.875	0.000	0.000
Goats	0.000	4.000	4.000	0.000	0.000

Mi = Millet, So = Sorghum, Co = Cowpea, and Gn = Groundnut

(i.e., requiring an additional unit of production) for each of the enterprise, increases the objective function by the value indicated against each activity.

Therefore, from the table it could be said that if the farmer decides to use all the slack variables (allowable decreases), the objective function would be increased by ₦27, 959.54. This increase represents 4 % over that of the initial total gross margin of ₦700, 032.33. The implication of this is that if the farmer utilizes all the inputs he would earn an additional income of ₦27, 959.54. Gordon and Pressman (1978), in their study for optimal machines to be used by a company in order to make optimal profit determined that $22,200, could be made if zero regular machines, 10 deluxe machine and 10 super machines were used. However, a slack variable of 100 units were left unutilized. When the company further utilized the additional units (100), an additional profit of $4440 was made over that of the initial total gross margin of $22,200. These results reveal the range within which the net prices can vary, while optimality levels remain the same. The implication of this is that the average net prices can only be increased or decreased by the stipulated range provided in the optimal solution.

Therefore, fixing average net prices outside the range will lead to the failure to achieve optimal solution by the farmer. In essence, if optimality is to be achieved, the farmer has to operate within the stipulated range. Ayokanmi (2004) observed that farmers could only remain within the optimal level if they operate within the range stipulated by the optimal plans. The results of the sensitivity analysis of the optimal solution to the changes in the values of the constraints for crop-livestock production system are shown in Table 3. This shows that labour and capital have surpluses in the optimum farm plan. The implication of this is that the original level of the constraints could be adjusted without affecting the optimum plan.

Table 3: Sensitivity analysis of the optimal solution to changes in the values of the constraints for crop-livestock production system

Constraint	Lower Limit	Current Values	Upper Limit	Allowable Increase	Allowable Decrease
Land (ha)	8.251	8.34	No limit	No limit	0.089
Labour (man-day)	461.772	646.61	651.462	4.852	184.834
Capital (₦)	314, 664.022	325, 323.01	No limit	No limit	10, 658.988

Dipeolu (2000) in his studies on optimum farm plans for food crop farmers in University of Agriculture, Abeokuta model extension villages found that farmers had surpluses of capital and labour. He further explained that farmers could reorganize their resources and make these surpluses of capital and labour available for investment in other productive ventures. In the case of no limit, all the inputs were utilized.

CONCLUSION

The optimal total gross margin for the crop-livestock production system was ₦700,032.33 as against the existing farmers' total gross margin of ₦411,562.43. This increase in the total gross margin induced by the optimal plan represents an increase of 70 % over that of the existing farmers' total gross margin. This, therefore means that farmers could increase their income to this level (70%) by adopting the optimum plan.

Though farmers have reported inadequate land and capital as some of their problems, if they could reorganize their resources according to the optimal plan, it will go a long way in solving their problems of land and capital allocation. Optimal farm plans proffered by this study if adopted by the farmers will enhance profitability of the enterprises.

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