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INCORPORATING CROP ROTATION REQUIREMENTS IN A LINEAR PROGRAMMING MODEL: A CASE STUDY OF A RURAL FARMER IN BINDURA, ZIMBABWE

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ABSTRACT

Communal farmers are always confronted with the problem of finding the combination of enterprises that will provide them with the highest amount of income through the best use of the farm's limited resources. Linear programming is a mathematical technique that can be used to find the optimal combination of enterprises. The assumption is that the farmer simply seeks to maximize income. However, in reality, the production options open to a farmer may be restricted by the need to observe sound husbandry practices such as crop rotations. Crop rotations are important for pest and disease control and maintaining soil fertility. In this study, a linear programming model that incorporates crop rotations requirements was developed for a rural farmer in Bindura, Zimbabwe. Crops considered were maize, soya beans and tobacco. The results show that maize gained acreage by 108 percent and tobacco by 108 percent compared to the farmer's plan. The model suggests no production of soya beans. The crop acreage decreased by 17 percent compared to the farmer's existing plan. Income obtained from the optimal crop combination was 36.89 percent higher than that obtained from the farmer's existing plan.

Keywords: Linear Programming; Rural Farmer; Crop Rotations; Maximizing Income; Crop Combination

1. INTRODUCTION

Communal farmers are always confronted with the problem of finding the combination of enterprises that will provide them with the highest amount of income through the best use of the farm's limited resources. Linear programming (LP) is a mathematical technique that can be used to find the optimal combination of enterprises. Igwe *et al* (2011) says, "Linear programming technique is relevant in optimization of resource allocation and achieving efficiency in production planning particularly in achieving increased agricultural productivity". The efficient utilization of resources and the optimal combination of enterprises in the food sub-sector is of paramount importance (Igwe *et al*, 2011). Many studies have been conducted in different farming systems in different countries to optimize farm plans using LP. Nedunchezhian and Thirunavukkarasu (2007) developed an LP model to optimize farm plans in different farming systems in Orathanadu block of the Thanjavur district in Tamil Nadu. The income increase in the optimal plans was 223.5 per cent for large scale farmers, 192.7 per cent for small farmers, 180.1 per cent for marginal farmers and 116 per cent for landless households. Ibrahim and Omotesho (2011) in their study determined an optimal enterprise combination for vegetable production in north central Nigeria. Their optimal plan achieved 88 per cent of the goals considered. Scarpari *et al* (2010) developed an optimized planning model for sugarcane farming using an LP tool. Their results support their planning model as a very useful tool for sugarcane management. Mohamad and Said (2011) developed an LP crop mix model for a finite-time planning horizon. The objective of their model was the maximization of total returns.

Dey and Mukhopadhyay (2010) formulated an LP model to find the optimum allocation of resources. The net return earned from the optimal plan was found to exceed the net return obtained from existing allocation of resources by 43 per cent. Abdelaziz *et al* (2010) applied LP to optimize the cropping pattern in North Darfur State, Sudan. The models gave a cropping pattern different from the farmers' production plan. The solution gave a profitable objective function while the farmers' plan gained them a loss. An LP model was formulated by Kaur *et al* (2010) to suggest the optimal cropping pattern for maximizing net returns and to ensure significant savings of groundwater use in Punjab. The optimal production plan increased returns by 4 per percent along with groundwater savings of 26.55 per cent. Bamiro *et al* (2012) actualized by LP model the optimal cassava based combination. The resulting crop combinations resulted in increased gross margin.

In modeling the economic aspects of the farm, we assume that the farmer simply seeks to maximize income (Hazel & Norton, 1986). However, in reality, the production options open to a farmer may be restricted by the need to observe sound husbandry practices such as crop rotations (Hazel & Norton, 1986). Crop rotations are important for pest and disease control and maintaining soil fertility (Hazel & Norton, 1986). In this study, a linear programming model that incorporates crop rotation requirements is developed for a rural farmer in Bindura, Zimbabwe.

2. THE LINEAR PROGRAMMING FORMULATION

The farm modeled in this study has 8 hectares of land that was meant for maize, soya beans and tobacco production for the period 2011/12. The expected gross income was, $285 per ton of maize, $1,325/ha from soya beans, $5,250/ha from tobacco. The farmer had $4,500 as capital. The farmer's existing plan was to allocate 1 ha for maize, 3 ha for soya beans and 1 ha for tobacco. The question was whether this plan was optimal, that is, does it produce maximum income. We are assuming that the farmer seeks to maximize income. However, Hazel & Norton (1986) argue that, in reality, the production options open to a farmer may be restricted by the need to observe sound husbandry practices such as crop rotations. Crop rotations are important for pest and disease control and maintaining soil fertility (Hazel & Norton, 1986). Thus, in this study, the LP developed incorporated crop rotation requirements. We adhered to a rotation in which maize, if grown, must be alternated with tobacco. The maize consumption constraint was incorporated into the LP model. The resources constraints were land, labor and capital.

The decision variables are:

$$x_1 = hectares\ allocated\ for\ maize\ production.$$

$$x_2 = tons\ of\ maize\ produced\ for\ sale.$$

$$x_3 = tons\ of\ maize\ stored\ for\ family\ consumption.$$

$$x_4 = hectares\ allocated\ for\ soya\ bean\ production.$$

$$x_5 = hectares\ allocated\ for\ tobacco\ production.$$

The goals of the objective function are to maximize cash income.

Table 1. Linear Programming Matrix

	Activities	Maize	Sell Maize	Transfer Maize	Soya Beans	Tobacco	
Resources	**Units**	ha	ton	Ton	ha	ha	RHS
Crop Land	ha	1			1	1	≤ 8
Labor	days	30			30	40	≤ 305
Maize Accounting	ton	-8	1	1			≤ 0
Maize Consumption	ton			-1			≤ -1
Operating Capital	dollars	936			767	1,230	≤ 4,500
Rotational Requirement	ha	-1				1	≤ 0
Gross Income	dollars		285		1,325	5,250	

Table 1 represents the LP matrix and the right hand side represents the constraints on the resources.

The LP model is given by:

$$Max\ z = 285x_2 + 1325x_4 + 5250x_5, \qquad (objective\ function)$$

$$subject\ to$$

$$x_1 + x_4 + x_5 \leq 8, \qquad (crop\ land\ constraint)$$

$$30x_1 + 30x_4 + 40x_5 \leq 305, \qquad (labor\ constraint)$$

$$-8x_1 + x_2 + x_3 \leq 0, \qquad (maize\ accounting)$$

$$-x_3 \leq -1, \qquad (maize\ consumption)$$

$$936x_1 + 767x_4 + 1230x_5 \leq 4500, \qquad (cash\ constraint)$$

$$-x_1 + x_5 \leq 0, \qquad (rotational\ requirement)$$

$$x_1, \dots, x_5 \geq 0, \qquad (non-negativity\ constraint)$$

3. RESULTS AND DISCUSSION

The LP model is solved using MS Excel and the cropping pattern obtained is presented in Table 2. Maize gained acreage by 108 percent and tobacco by 108 percent. The LP model suggests no production of soya beans. The crop acreage decreased by 17 percent compared to the farmer’s plan.

Table 2. Cropping Patterns

Crops	Farmer's plan (ha)	LP solution (ha)	% of Farmer's plan
Maize	1	2.08	208
Soya Beans	3	0.00	0
Tobacco	1	2.08	208
Total	5	4.16	83

The cropping production obtained from the LP model is presented in Table 3.

Table 3. Cropping Production

Crops	Farmer's plan ($)	LP solution ($)	% of Farmer's Plan
Maize	1,995.00	4,451.00	223
Soya Beans	3,975.00	0.00	0
Tobacco	5,250.00	10,907.20	208

The income levels are presented in Table 4. The results show that income would increase from $11,220.00 to $15,359.04 showing an increment of 36.89 percent. The optimal solution suggestions increase income.

Table 4. Income Levels

Income		
Farmer's Plan ($)	LP solution ($)	% of Farmer's Plan
11,220.00	15,359.04	136.89

4. CONCLUSION

In this study, an LP model that incorporates crop rotations requirements was developed for a rural farmer. The LP model solved the problem of finding the optimal combination of enterprises and at the same time observing the sound husbandry practice of crop rotations. The results show that income obtained from the optimal crop combination is 36.89 percent higher than that obtained from the farmer's existing plan.

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