A Mathematical Programming Technique to Crop Mix Problem on a Farm in Mutasa, Manicaland Province, Zimbabwe

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Abstract

In this study we assess the economic activity on a small scale farm in Mutasa district of Manicaland province of Zimbabawe in which maize, cabbages, potatoes and tomatoes are grown. An operation research model, in particular linear programming was used to optimize the net profit given the limited resources namely land, labour and capital. By comparison with the farmer's farming practices based on intuition and experience the Linear programming method developed showed that the available resources were not optimally allocated. By implementing the linear programming model using Microsoft excel solver 2017, the optimal crop pattern revealed a rise in the profit margin by 76%.The results were analyzed and discussed in tabular and graphical form.

Keywords: *Linear programming, Optimum allocation, small scale farm, profit margin*

I. INTRODUCTION

Linear programming(LP) technique was founded by George B. Danzig in 1947 and successful application of it in agriculture was first proposed by Waugh in 1951 who determined the least-cost combination for the feed stuffs and livestock rations that would meet the specific nutritional requirements [1, 12]. Linear programming is a standard tool that has saved millions of dollars of many production companies and agricultural sectors [5, 12]. An LP crop mix was formulated to determine the optimum combination of crop farm enterprises in Mazowe, Zimbabwe and income increased by 35% [7]. Also [3] used LP technique to determine the optimal enterprise combination for vegetable production in North Central Nigeria and the LP model increased the profit by 88%. A linear programming approach to combination of crop, monogastric farm animals and fish enterprises in Ohafia agricultural zone, Nigeria was studied by [4] and the optimum gross margin rose by 72.90% compared to the existing plan then. A farm resource allocation problem using LP was also investigated by [2] who used LP to determine the optimal crop allocation plan for women farmers under land, labor and capital constraints. The LP showed a 13.6% increase in the gross income.

In Zimbabwe the majority of the population depends on agriculture for their livelihood [9]. The bulk of the land allocated to new farmers in Zimbabwe are underutilized because of a number of reasons which among them are, the use of traditional farming methods which may not follow the optimal path, insecure land tenure system which incentivize investment, limited access to input and output market, credit and off farm employment [9, 10]. Linear programming is an effective technique to produce optimal solutions in rural farms in Zimbabwe [7, 9].

The planning of crop farming entails consideration of resources such as land, accessibility to irrigation water, labour, capital, cropping patterns, cropping intensity, topography and climate [11, 12]. Of the several optimization techniques available the Linear Programming (LP) model is the most used because of its proportionate allocation characteristic [12]. Most small scale farmers rely on experience to allocate the farm resources available [6, 7]. In this paper we want to demonstrate that using the Linear programming models gross income returns are optimal.

Using LP model, this study seeks to determine the optimal crop pattern under labor, land and capital constraints allowing the farmer to have optimal profit margin.

II. METHODOLOGY

The study was conducted at a farm in Mutasa, located in Manicaland province of Zimbabwe. The 4 ha small farm grows maize, potatoes, cabbages and tomatoes. The farmer was realizing profits in his farming activity but the rising costs of living in the country has prompted the farmer to find ways of maximizing profits so as to cushion the ever rising inflation in the country.

The following simplifying assumptions were adopted in the formulation of the LP model [8]:

- The prize of the crop and its yield per ha does not change during the planning period.
- Availability of farm land, irrigation water,fertilizer, technology, management, labour, and seed does not change during the planning period.
- The land is equally suitable for all the selected crops. You can substitute any one crop with another for any hectare piece of land on the farm.

- The crop-mix depended only on the type of crops that were grown and not the methods of cultivation applied.

A. The linear Programming Model

The objective of formulating the LP model is to maximize gross income or total returns at the end of the planning horizon. The objective function, z in a Linear Programming Problem (LPP) reads

$$\text{Maximize} \qquad z = \sum_{i=1}^{i=n} c_i x_j \qquad x_j \geq 0,$$

$$j = 1,2 \ldots\ldots, n$$

Subject to the constraints

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \ldots a_{1n}x_n \leq b_1$$
$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \ldots a_{2n}x_n \leq b_2$$
$$a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + \ldots a_{3n}x_n \leq b_3$$
$$\vdots$$
$$a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + \ldots a_{mn}x_n \leq b_m$$
$$x_i \geq 0, i = 1,2,\cdots n$$

The Linear Programming Problem (LPP) may be written in a more compact way as

Maximize

$$z = \sum_{i=1}^{n} c_i x_j \quad x_j \geq 0,\ j = 1,2,\ldots,n$$

Subject to

$$\sum_{i=1}^{i=n} A_{ij} x_j \leq b_i \quad i = 1,2,\ldots m;\ j = 1,2,\ldots,n; x_j \geq 0.$$

where the input variables are represented by x_j the cost coefficients of the objective function z are represented by c_i, the constraints are bounded above by b_i and the coefficients of the constraints equations, referred to as the 'production coefficients' are represented by a_{ij} and the coefficient matrix for the constraints inequalities is given by A_{ij} .

The farm under study has 4 ha of available farming land. The farmer grows a variety of crops which includes maize, potatoes, cabbages and tomatoes. The farmer's plan prior using LP technique is depicted in **Table 1**.

Table 1:Farmer's plan before optimization for the period 2015-2017

	Maize	Cabbages	Potatoes	Tomatoes	Available
Land (ha)	2	1	8 000	0.5	4.0
Gross Income(US$)	400	10 000	600	244	24 414
Tractor and/or Labour (US$)	792	450	300	275	3 000
Pesticides,Fungicides/Fertilizer(US$)	200	250	2 200	200	2 000
Other Operations (US$)	986	4 700	3 100	774.50	13 000
Total Expenses (US$)	1978	5 400	5 400	1249.50	11 727.50

Table 2: Farmer's plan per hectare of each crop

	Maize	Cabbages	Potatoes	Tomatoes	Available
Land (ha)	1	1	1	1	≤ 4
Gross Income (US$)	2 000	10 000	20 000	4 828	
Tractor and/or Labour (US$)	396	450	1 500	550	≤ 3 000
Pesticides/Fungicides/Fertilizer(US$)	100	250	750	400	≤ 2 000
Other Operations(US$)	493	4700	5 500	1 549	≤ 13000

To determine the production coefficients, a_{ij} it is necessary to find the amount of particular input x_j required to produce 1ha of maize, cabbage potatoes and tomatoes. A matrix of these coefficients

including the expected output per hectare is shown in **Table 2**.

From experience over the years 2015 - 2017 the farmer allocated the **4** ha of land as follows: **2** ha for maize production, **1** ha for cabbage production, **0.4** ha for growing potatoes and **0.5** ha for growing tomatoes. The farmer was getting **US$4 000** from **2** ha of maize, **US$10 000** from **1** ha of cabbage, **US$8 000** from **0.4** ha of potatoes and **US$2 414** from **0.5** ha of tomatoes. The farmer realized a gross income of **US$ 24 414**. The size of land allocated for maize and tomatoes were determined by the immediate neighborhood demand and so the farmer had to grow at least **1** ha of maize and **0.4** ha of tomatoes.

In order to apply the LP technique the farmer had to decide on the size of land allocated to each crop. The decision or input variables are:

x_1 = hectares of land allocated for maize production

x_2 = hectares of land allocated for cabbage production

x_3 = hectares of land allocated for potatoes production

x_4 = hectares of land allocated for tomatoes production

The farmer's objective is to maximize total gross margin of producing the crops less costs of transport, fertilizer, pesticides, fungicides, insecticides, seed, irrigation, labour and other

operational costs such as electricity, insurance and marketing. The LP model is derived from **Table 2** which depicts the farmer's gross income, expenses and limitations per hectare ofeach crop type. The LP model is given by

Max

$$z = 200\ x_1 + 10000\ x_2 + 20000\ x_3 + 4828\ x_4 + 5000\ x_5$$

(Objective function)

Subject to,

$x_1 + x_2 + x_3 + x_4 \leq 4$ (Land constraint)

$100\ x_1 + 250\ x_2 + 750\ x_3 + 400\ x_4 \leq 2000$

(Pesticides/fungicides/fertilizer)

$396\ x_1 + 450\ x_2 + 1500\ x_3 + 550\ x_4 \leq 3000$

(Tractor and/or labour)

$493\ x_1 + 4700\ x_2 + 5500\ x_3 + 1549\ x_4 \leq 13000$

(other operations)

$x_1 \geq 1.0$ (maize land constraint)

$x_4 \geq 0.4$ (tomatoes land constraint)

$x_1, x_2, x_3, x_4 \geq 0$ (Non-negativity constrain**t)**

III. RESULTS AND DISCUSSION

The crop planning scheme was formulated as a Linear Programming Problem and solved using simplex method using a software package found in Microsoft excel 2017. The farmer's plan without optimization is depicted in **Table 1.** The expenditure, gross income and profit realized by the farmer using the existing traditional approach are shown in **Table 3.**

Table 3: Expenditure, gross income and profit before optimization

	Maize	**Cabbages**	**Potatoes**	**Tomatoes**	**Total**
Land (ha)	2	1	0.4	0.6	4
Gross Income (US$)	4 000	10 000	8 000	2414	**24 414**
Expenditure (US$)	1 978	5 400	3 100	11 727.50	**11 727.50**
Net Income/Profit (US$)					**12 686.50**

Using intuition and experience (traditional approach) the farmer was realizing a net profit of **US$12 686.50.Table 4** shows the crop planning scheme as suggested by the LP model. The LP approach suggests that the farmer should grow **1ha** of maize, **1.03ha** of cabbages, **1.28ha** of potatoes and

0.4ha of tomatoes.

In the optimal plan **20%** of the available plan is reserved for growing maize compared to **40%** in the

***Table 4:* Optimum farming pattern using LP approach**

	Maize	**Cabbage**	**Potatoes**	**Total**
Land (ha)	1	1.03	0.4	4
Labour (US$)	396	463.50	220	3 000
Pesticides/Fertilizer(US$)	100	1257.50	160	2 000
Other Operations(US$)	493	4 841	619.60	13 000
Expenditure (US$)	989	5 562	**999.60**	17 470.60
Gross Income (US$)	2 000	10300	**1 931.20**	39 831.20
Profit (US$)	**1 011**	**4 738**	**931.60**	**22 360.60**

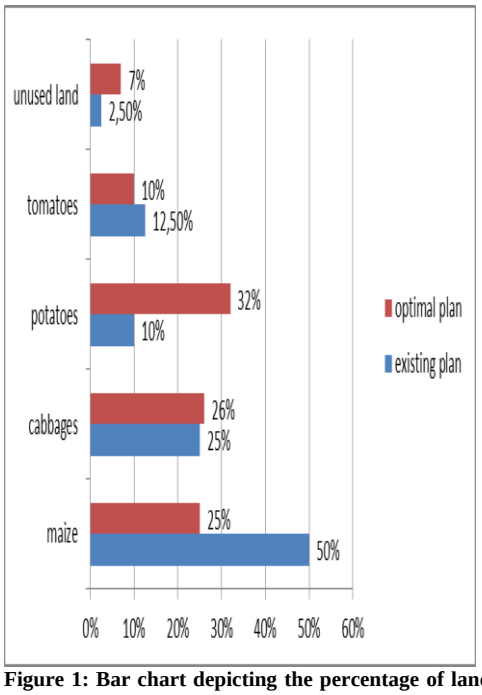

Figure 1: Bar chart depicting the percentage of land allocated for each of the crops in both the existing and optimal plan

***Table 5:* The proportion of land allocated for each of the crops in both the existing and optimal plan.**

Cropping pattern	**Existing Plan (ha) Size of farm**	**%**	**Optimal plan (ha) size of farm**	**%**
1. maize	2	50	1	25
2. cabbages	1	25	1.03	26
3. potatoes	0.4	10	1.28	32
5. Tomatoes	0.5	12.5	0.4	10
6. unused farm land	0.1	2.5	0.29	7
Total	4	100	4	100

It is deduced from **Table 5** that the farmer was using **97.5%** of the available farm land in the existing plan whereas in the optimal plan (LP model) the farmer should use **92.8%** of the available land.

existing plan. Although maize is a staple food in Zimbabwe whose demand can never be exhausted the LP technique suggests that growing cabbages and potatoes and less maize is more profitable.

Information displayed in **Table 5** also shown in **Figure 1** shows the proportion of land allocated for

Table 6: Comparison of the Gross income, expenditure and net income of the traditional and LP approaches

	Gross income(US$)	Expenditure(US$)	Net income/profit (US$)
Traditional approach	24 414	11 727.50	12 686.50
LP approach	39 831.20	17 470.60	22 360.60

each of the crops in both the farmers plan and the LP optimal plan by percentage.
Using the optimal approach (LP) the gross income is **US$39 831.20** compared to **US$24 414** realized using the existing approach. Less expenses the optimal approach has increased the profit margin by **76%**. **Table 6** gives a comparison of the gross income, expenditure and profit of the traditional and approaches.

IV. CONCLUSION

The objective of this study was to implement the Linear programming model to the optimal allocation of farm resources which are subjected to labor, land and capital constraints so as to maximize the profit margin by a small scale farmer in Mutasa district in Manicaland province of Zimbabwe.

The study revealed that the existing farming plan which is based on previous experience has resulted in suboptimal allocation of available resources. Although the farmer was making some profit a comparative analysis of results obtained using the LP model and the existing farming method showed that the LP model increased the profit margin by **76%.**The results of the study reveal the superiority of the LP model compared to the existing farming method.

REFERENCES

[1] Adres, W., & Romero, C. (2006). Operation Research Models and the Management of Agriculture and Forestry Resources: A Review and Comparison, INFORMS, 36(5): 446-457

[2] Antwi, K.D. (2016). Optimal Resource Allocation Decision Among Women Farmers in the Northern Region of Ghana, African Journal of Agriculture and Food Security: International Scholars Journals, 4(3):161-166.

[3] Ibrahim, H.,Alamu, J.F., & Ahmed, B. (2004). Optimal Farm Plans in Cotton Production: A Linear Programming Approach, Journal of Resources in Agriculture, 1(1):21-26.

[4] Igwe, K.C., Onyenweuku, C. E, & Tanko, L.(2013). A Linear Programming Approach to Combination of Crop, Monogastric Farm Animal and Fish Enterprises in Ohafia Agricultural Zone, Abia State, Nigeria, Global Journal of Veterinary Sciences, 13(3): 23-31.

[5] Ion, R.A., & Turek, R.A.,(2012). Linear Programming in Agriculture: Case Study in Region of Development South – Mountenia, International Journal of Sustainable Economic Management, 1(1):51-60.

[6] Kumari, P.L., Reddy, G.K., & Krishna, T. G. (2014). Optimum Allocation of Agricultural Land to the Vegetable Crops under Uncertain Profits using Fuzzy Multiobjective Linear Programming, IOSR Journal of Agriculture and Veterinary Science, 7(2): 19-28.

[7] Majeke, F (2013). Optimum Combination of Crop Farm Enterprises: A Case Study of a Small- Scale Farm in Marondera, Zimbabwe, The International Research Journal: International Researchers, 2(1): 61-65.

[8] Mohamad, N., Said, F. (2011). A Mathematical Programming Approach to Crop Mix Problem, African Journal of Agricultural Research, 6(1): 191-197.

[9] Mugabe, D.,Chipunza, N., Mupaso, N., Munyati, V.T., Makarudze, F. V. (2014). Estimation of Optimal Land Use Allocation Among Small Holder (A1) Farm Allocation Among Small Holder (A1) Farm Households in Zimbabwe. A Case Study of Long Croft Farm, in Mazowe District. Journal of Agricultural Science, 6(2): 170-181.

[10] Rukuni, M., Eicher, C.K. (2006). Zimbabwe's Agricultural Revolution Revisited. UZ pubications, Harare, Zimbabwe

[11] Sarker, R.A. & Quaddus, M.A., (2002). Modelling a Nationwide Crop Planning Problem using a multiple criteria decision Making tool. Computers and Industrial Engineering, 42:541-553.

[12] Sofi, N. A., Ahmed, A., Ahmad, M., & Bhat, B. A. (2015). Decision Making in Agriculture: A Linear Programming Approach, International Journal of Modern Mathematical Sciences, 13(2): 160-169.