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A CASH CROP COMBINATION FOR MAXIMUM NET INCOME: A CASE STUDY OF A SMALL-SCALE CASH CROP FARMER IN VHEMBE, LIMPOPO PROVINCE, SOUTH AFRICA

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ABSRACT

This paper investigates the optimal cash crop combination at a small-scale cash crop farm in Vhembe District, Limpopo Province, South Africa in which green maize, cabbages, tomatoes, spinach, mustard, butternut and sweet potatoes are grown. To get optimum farm outputs, decisions on crop combination and operational activities in crop production are crucial. Proper farm planning and resource allocation play a significant role in optimising farm revenues. It was observed that the farmer used traditional methods of allocating resources, which lead to a less profitable crop mix. In view of this, in this study, linear programming model was formulated using data collected from a farm concerning the past crop combinations and allocation of resources in crop planning and production to determine the best crop combination that maximizes net income given limited resources such as land, labour, capital, and others. The simplex method of linear programming works by first locating a feasible solution and then relocating to any vertex of the feasible set that improves the cost function. Eventually, a point is reached beyond which no further movement improves the cost function. The results of the developed linear programming model were compared to past farming practices based on experience, leading to the conclusion that crops and limited resources were not optimally allocated. The results clearly demonstrate the optimal crop combination and allocation of scarce resources that the farm could have considered to yield maximum returns. It is observed that the proposed linear programming model is appropriate for finding the optimal land allocation criteria for the cash crops in the study area. The optimal crop mix from the linear programming two phase simplex method show that the farmer should grow the following crop mix, 1.16 ha of green mealies, 2.64 ha of cabbages, 0.8 ha of tomatoes, 1.2 ha of mustard, 0.4 ha spinach, 0.4 ha of butternut and 0.4 ha of sweet potatoes with the gross income of R 740 800. The linear programming model resulted in a 37.8 percent increase in profit margin. Based on the results obtained from this study, it is recommended that the small-scale cash crop farmer should invest more in producing crops that give maximum profit. MATLAB software was used to determine the optimal values of the decision variables.

Key words: Cash crops allocation, crop combination, net income, linear programming (LP), resource allocation.

INTRODUCTION

The day to day business organisational operations and activities are based on the set goals and targets. To achieve the goals and the targets, major planning and decisions are needed to fully utilise the available resources to determine the best combination of products. Mainly the targets are to obtain maximum returns with minimum costs. Managers in different organisations are faced with complex decisions about how to combine the activities for maximum retains and allocate resources which are in short supply. Agriculture as a business enterprise contributes to the social and economic activities of any country. Worldwide, due to the increase in population, the demand for more food production and raw materials increases. This demands a careful agricultural planning which include crop planning and utilisation of the available resources. In South Africa, agricultural activities are mainly small-scale and commercial. The population relies on the consumption of the agricultural products. The increasing population in the country has resulted in high demand of land for household and agricultural activities. The farmers produce cash crops for consumption and for selling to the idle population. The population growth implies increasing demand in crop production and increasing area under cultivation [1]. The increasing demand in food stuff from the growing population will always be there even though farmers face increasing scarcity of farm resources. In addition, farmers are faced with a lot of challenges that affect their economic factors, social factors and lack of education [2]. This results in lack of resources and insufficient utilisation of resources which leads to reduced farm production, reduced farm incomes and affect the overall farmer's economic status. Farmers are forced to efficiently allocate the few available resources among their farming activities to be able to generate income. Optimal farm plans must be developed to assist farmers to allocate limited resources. Farmers, small-scale or commercial are faced with major decisions to make in the farming activities. The major challenge in decision making in farming is mainly to allocate resources to various farming activities to enhance maximum production for maximum returns. In most cases the farmers use past experiences, trial and error or make decisions based on comparing with neighbouring farmers in allocating resources [3, 4, 5] and this results in insufficiently allocating resources and crop combination plans which are not optimal.

Resource allocation and product combination problem in various activities has been an interesting active area of research in the last decades where vital decisions are required to ensure maximum returns with minimum costs. The problem of crop combination and allocation of resources in agricultural activities exists and affects cropping activities. The optimal allocation of limited resources to various crops has become a major challenge to yield maximum income especially using the traditional methods. Linear programming is a powerful modelling technique that has been widely applied to solve the product combination and resource allocation problem to improve performance which is measured through achieving maximum returns with minimum costs [6, 7]. The problem is based on how to decide on which resources would be allocated to obtain the best result, which may relate to profit or cost or both. This is best represented and solved by the mathematical model. This study seeks to find the optimal cropping pattern for the study area with the goal of developing a plausible optimal cropping plan for small crop farmers that maximizes returns. In this paper, the study is on the crop

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combination and resource allocation problem which is solved using linear programming model focussing on a case study of a small-scale cash crop farmer in Vhembe District, Limpopo Province, South Africa where different farming activities are carried out with some resources in short supply and the farm targets to get maximum production and returns. There is no such study known that has been conducted in this province. The results from this study can be extended to farms of different sizes and encourage the use of linear programming model in informed decision making process.

One of the major scientific developments in the 20th century is the development of linear programming as a standard tool whose application to different business enterprises, many production companies and agricultural sectors has saved a lot of money and has been applied to various production sectors of different sizes [8, 9]. Linear programming was founded by George. B. Danzig in 1947 through the simplex algorithm and is an optimization tool that is helpful in planning, allocation and has been widely used to make managerial decisions. The usual approach to solve such problems is either phase or Big-M method each of which involves artificial variables and the introduction of artificial variable brings artificiality in otherwise straightforward simplex method [10]. Linear programming is a powerful modelling technique that has been widely applied to solve the resource allocation problem. Linear programming has been extensively to solve resource allocation problem in agriculture and different application areas. For example, linear programming has been applied to solve the human resource allocation problem [11, 12, 13], optimal allocation of resources in the shoe production centre [14], Jain *et al.* [6] applied linear programming for profit maximization of the bank and the investor, application of linear programming to find the optimal allocation of classroom space [15] and Rajeiyan *et al.* [16] solved transportation problems using linear programming in a services company. The construction of the linear programming model has become an active area of research in agriculture to determine the optimal crop combination subject to the availability of scarce resources [1, 17, 18]. The successful agricultural crop activities depend on various resources like land, water, labour, capital among others. The linear programming model was successfully applied to determine crop mix to determine the optimal crop combination to increase the farm output and income [19]. Buzuzi and Buzuzi [19] have found that the linear programming approach has increased the profit margin by 76 percent compared to the traditional approach of determining crop mix and a linear programming crop mix was formulated to determine the optimum combination of crop farm enterprises in Marondera, Zimbabwe and income increased by 35 percent [4]. Patel *et al.* [18] applied the linear programming in getting the optimal crop pattern and agricultural land allocation in Patan District in India and showed that the farmer could get a maximum production. The allocation of resources and crop planning are the most important elements of crop production and the cornerstone for the farm maximum returns. The simplex method was recently used and the returns increased by 68 percent [1]. Hard decisions about crops to grow, land sizes and how to manage resources which are in short supply are faced by farmers at the onset of the cropping season. Linear programming was also applied to model effective farm enterprise combination and allocation of resources [2, 7, 9, 20]. A linear programming model was applied for farm resource allocation [4]. The results obtained from the use of the linear programming

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model and the traditional method of planning were compared. It was observed that the results obtained by using the linear programming model are more superior to that obtained by traditional methods. Kumari *et al.* [3] compared the linear programming models and a fuzzy multi objective fractional programming model and Igwe *et al.* [21] have applied linear programming to obtain optimum crop and livestock production in Nigeria. A linear programming model was used to determine the optimal crop mix of five different food crops with respect to factors like wages of labour and machine charges using simplex algorithm [9].

Linear programming model can be successfully utilised by rural and commercial farmers in South Africa, so that crop planning can be enhanced to ensure maximum farm returns for food security and personal incomes. This study seeks to find the optimal crop combination under the restrictions on the labour, space, capital, labour among others so that the farmer can realise maximum net income. The results from the linear programming model are compared with the known practised plans by the farm manager. A mathematical model of the problem was set up and converted into standard form of linear programming problem. Simplex method is the numerical solution process used to determining the optimal production proportion and profit margins. The simplex algorithm, is used to optimize the various combinations that allows the farmer to have optimal returns.

METHODOLOGY

The Linear Programming Problem

Linear programming problem is the mathematical technique that represents a problem objective function and a set of constraints which are formulated from the limited resources. The application of linear programming mainly is to find the feasible combinations that optimize a given linear objective function. The general mathematical formulation of linear programming is the analysis of a problem in which a linear function of several decision variables(n) is to be maximized (or minimized) subject to several constraints (m) in the form of linear inequalities and/or linear equalities. The general formulation of the linear programming problem is found in almost all the literature on linear programming. The linear programming problem may be stated mathematically in the following form:

Find the values of $y_1; y_2; \ldots; y_n$ that optimize the linear equation:

$$\text{Maximise/minimise: } S = c_1y_1 + c_2y_2 + \ldots + c_ny_n \tag{1}$$

subject to constraints:

$$a_{11}y_1 + a_{12}y_2 + \ldots + a_{1n}y_n \ \geq; =; \leq \ b_1 \tag{2}$$
$$a_{21}y_1 + a_{22}y_2 + \ldots + a_{2n}y_n \ \geq; =; \leq \ b_2 \tag{3}$$
$$. \ \geq; =; \leq \ . \tag{4}$$
$$. \ \geq; =; \leq \ . \tag{5}$$
$$. \ \geq; =; \leq \ . \tag{6}$$
$$a_my_1 + a_my_2 + \ldots + a_{mn}y_n \ \geq; =; \leq \ b_m \tag{7}$$

and

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$$y_1;\ y_2;\ \ldots;\ y_n \geq \quad 0 \tag{8}$$

where

- The equation (1) is the objective function in terms of the variables y_j's with the c_j's are constant which represent the unit contribution to the decision variable y_j to the objective function
- The constraints of system (2) - (7) represent the restrictions placed on the variables in the objective where:
  – the a_{ij} are the input showing the amount of the i^{th}resource used per unit decision variable y_j. The a_{ij} can be positive, negative or zero
  – The constant b_i positive is the total available of the i^{th} resource
- The equation (8) represents non-negative constraints that are consistent with most linear programming problems.
  The solution procedure of the LP model involves converting the problem to standard form then solve using the simplex (Big-M or the two phase) methods or other variations of the method. The solution process begins by transforming the linear problem's inequality constraints into an equality constraint by the addition of slack or the subtraction of surplus variables to the original inequality constraints. That is:

- if the constraints are of the form $\sum_{j=1}^{n} a_{ij}\ y_j\ \leq\ b_i$ then introduce and add a new slack variable $s_i\ \geq\ 0$ such that the constraint becomes equality $\sum_{j=1}^{n} a_{ij}\ y_j\ + s_i \leq\ b_i,\quad i\ = 1; \ldots; m$
- if the constraints are of the form $\sum_{j=1}^{n} a_{ij}\ y_j\ \geq\ b_i$ then introduce and subtract a new excess variable $e_i\ \geq 0$ such that the constraint becomes equality $\sum_{j=1}^{n} a_{ij}\ y_j - e_i \leq\ b_i,\quad i\ = 1; \ldots; m$

The cost coefficients in the objective function for the slack and surplus variables are given a value of zero. This enables the procedure based on Gauss-Jordan elimination to be used to solve linear programming problems.

Linear Programming Model of the Cash Crop Vegetable Farm

The government of South Africa during the past years has been encouraging young and unemployed people to be involved in income generating projects like cash crop farming, poultry and animal rearing among others. Most of the people have realised that there is money in producing crop vegetables for selling since very few people are involved in producing vegetables for family consumption. The objective of this study is to use the linear programming model to determine the optimal crop combination that ensures maximum gross income under some certain limitations on the available resources. The vegetable cash crop small-scale farmer was selected as a case study in this paper. The farming area is situated in Vhembe District in Limpopo Province, South Africa. The farm operates under the 7 hectares of land and specialises in producing the following cash crops: green mealies GM), cabbages, tomatoes, butternut, spinach, mustard and sweet potatoes (SP). The farmer produces these crops for selling to different markets like supermarkets, individual restaurants among others. The farmer explained that the crop production is affected by the usable land in hectares, availability

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of capital, which have a strong bearing on the labour used, seeds, fertilizers, chemicals and other input that are vital for the cropping activities. The farmer also believes that making profit is sometimes affected by the rising costs living and rising costs of crop production. Also, the farm activities are mainly affected by the rising cost of farm inputs and labour. The farming activities in the farm are mainly determined by the past experiences, market forces, climate and comparison with other neighbouring farmers. To cushion the farmer from the rising costs of production, the farmer needs to find ways to maximize profit. The formulation of the objective function is subject to the following adopted assumptions [2]:

- The crop prize and yields per hectare do not change during the planning period.
- The availability of resources does not change during the planning period.
- The land is equally suitable for all the selected crops. This means any hectare of land can be used for any crop.
- The crop combination depends only on the types of crops grown and not on methods of cultivation used.

Due to the demand for the vegetables from local communities and other various vegetable vendors, the farmer wants to increase production for the coming season. The farmer wants to allocate an amount of **R 140 000.00** to maximise crop production. The farmer's problem is to determine the vegetable and crop combination subject to the constraints on resources that can enhance maximum production and income. This study seeks to advice the farmer that despite all these challenges using the linear programming, the farmer can find the best possible crop combination that leads to the achievement of maximum possible income under those limitations. Linear programming model is used to address the farmer's allocation problems. The following data were collected for the farm's business plan for the coming season, which he uses to apply for a loan. The farmer's plan before optimisation for the cropping season **2019-2020** is presented in Table 1.

The farmer's targets and goals are to maximize the total gross income in the crop production activities while minimising the costs of the resources like labour, seed, fertilizer, pesticides, fungicides and other costs like transport, electricity, insurance, land preparation, maintenance and extension services. The data in Table 2 below are vital to find the production coefficients a_{ij}, the resource limits b_i and the contributions to the objective function, c_j. Table 1 presents the data obtained from the farmer for the season **2019 - 2020** where experience, trial and error were used to allocate the **7 ha** of available land as follows: **2 ha** of land under green mealies, **0.5 ha** land under cabbages, **0.5 ha** land under tomatoes, **0.5 ha** land under spinach**, 0.5 ha** land under mustard, **0.5 ha** land under butternut and **0.5 ha** land under sweet potatoes. The farmer was getting a gross income of **R 200 000.00** from the **2 ha** of green mealies, **R 70 000.00** from **1 ha** of cabbages, **R 80 000.00** from **1 ha** of tomatoes, **R 30 000.00** from **0.5 ha** of mustard, **R 22 000.00** from **0.5 ha** of spinach, **R 22 000.**00 from **1 ha** of butternut and **R 25 000.00** from **1 ha** of sweet potatoes. The total gross income of **R 449 000.00** was realised. The farmer indicated that he has a ready market for all the cash crops. He must produce all the crops. The farmer decided to allocate at least **1 ha**

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of land under green mealies, at least **1 ha** of land under cabbages and at least **0.8 ha** of land under mustard and tomatoes due to high from the customers. The other remaining crops were allocated between **0.4 ha** and **0.8 ha** of land. The farmer was faced with challenges of making decisions on how many hectares should be allocated to each crop to given maximum profit. The allocation is as follows: Let

- the number of hectares under green maize be x_1
- the number of hectares under cabbages be x_2
- the number of hectares under tomatoes be x_3
- the number of hectares under mustard be x_4
- the number of hectares under spinach be x_5
- the number of hectares under butternut be x_6
- the number of hectares under sweet potatoes be x_7

The Linear Programming Formulation

The data in Table 2 are represented in the linear programming formulation below which consist of the objective function, a set of constraints and the non-negative decision variables:

Objective function:

Maximise $Z = 100000x_1 + 140000x_2 + 160000x_3 + 60000x_4 + 44000x_5 + 44000x_6 + 50000x_7$ (9)

subject to:

$$x_1 + x_2 + x_3 + x_4 + x_5 + \text{x6} + x_7 \leq 7 \quad (10)$$

$$900x_1 + 9000x_2 + 8000x_3 + 4000x_4 + 4500x_5 + 1000x_6 + 4500x_7 \leq 40000 \quad (11)$$

$$4000x_1 + 4000x_2 + 4000x_3 + 3000x_4 + 4500x_5 + 4500x_6 + 5000x_7 \leq 30000 \quad (12)$$

$$200x_1 + 200x_2 + 300x_3 \leq 1000 \quad (13)$$

$$500x_1 + 200x_2 + 3000x_3 + 300x_4 + 400x_5 + 1000x_6 + 700x_7 \leq 7000 \quad (14)$$

$$4000x_1 + 4000x_2 + 4000x_3 + 4000x_4 + 4000x_5 + 4000x_6 + 4000x_7 \leq 30000 \quad (15)$$

$$5000x_1 + 4000x_2 + 4000x_3 + 1500x_4 + 1500x_5 + 2000x_6 + 5000x_7 \leq 30000 \quad (16)$$

$$14600x_1 1 + 21400x_2 + 29300x_3 + 14300x_4 + 16900x_5 + 12500x_6 + 19500x_7 \leq 140000 \quad (17)$$

$$x_1 \geq 1 \quad (18)$$
$$x_2 \geq 1 \quad (19)$$
$$x_3 \geq 0.8 \quad (20)$$
$$x_4 \geq 0.8 \quad (21)$$
$$x_5 \geq 0.4 \quad (22)$$
$$x_6 \geq 0.4 \quad (23)$$
$$x_7 \geq 0.4 \quad (24)$$

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$x_5 \leq 0.8$ (25)
$x_6 \leq 0.8$ (26)
$x_7 \leq 0.8$ (27)
$x_1;\ x_2; x_3;\ x_4;\ x_5;\ x_6; x_7 \geq 0$ (28)

RESULTS AND DISCUSSION

The linear programming model (9) - (28) was formulated to from the crop combination planning from the date in Table 2. The linear programming model was solved using the two-phase simplex method using MATLAB. Table 3 below gives the analysis of the farmer's expenditure, gross income and profit using the traditional allocation criteria.

The results from the linear programming two phase simplex method show that the farmer should grow **1.16 ha** of green mealies, **2.64 ha** of cabbages, **0.8 ha** of tomatoes, **1.2 ha** of mustard, **0.4 ha** spinach, **0.4 ha** of butternut and **0.4 ha** of sweet potatoes as shown in Table 4 below. Table 4 summarises the total optimal budget which the farmer must allocate for each cash crop in order to get the maximum net income.

Table 5 presents a comparison of the gross income, expenditure and the net income produced by the two approaches, linear programming and the traditional allocation. The farmer realised a gross income of **R 449 000.00** using the traditional methods that is using previous experience and comparing with other farmers. This translates to a profit of **R 375 000.00** from the **5 ha** of land utilised. The results in Table 4 show that the farmer realised a gross profit of **R 740 800.00** using the linear programming technique and total expenditure of **R 128 672.00**. This translates to a profit of **R 612 128.00** from the available farm land of **7 ha**. The increased income from an optimal plan agrees with the results in Ndip *et al.* [2] on their case study in Cameron that linear programming has increased income of US$124 from an optimal plan. This shows that the linear programming approach produced a net profit of **R 237 128.00** more than the traditional approach. This translates to a profit margin of **38.7 percent**. The results from this study show that linear programming is appropriate for finding the optimal resource allocation of the study area. This agrees with the results from Buzuzi and Buzuzi [19] that linear programming has increased the gross income by 76% and Majeke [4] found the income increasing by 35 % as compared to the farmer's plans, both studied case studies in Zimbabwe. Das *et al.* [11] and Taiwo [13] have shown that linear programming has helped in creating a proper human resource for the organisation.

The Table 6 gives comparison of the proportion of land used using the existing tradition allocation and the optimal allocation using the linear programming. The results show that the farmer's traditional method of allocation used **71.4 percent** while the optimal linear programming allocation enables the farmer to utilise **100 percent** of the available land. Optimal allocation of land gives **16.3 percent** of green maize land while the existing plan has **28.6 percent**. The land allocation of cabbages using the optimal allocation method increased to **37.7 percent** from **7.1 percent** allocated using experience as the traditional approach. The linear programming approach shows that growing spinach and sweet potatoes is less profitable while growing green maize and cabbages is more profitable.

SENSITIVITY ANALYSIS

The data and information collected about the farm plan are assumed to be accurate and perfect. The assumption is that the markets forecast, expected costs, estimated profit per one hectare, labour costs, fertiliser, seed, chemicals among others are known with accuracy. However, accurate or perfect data is rarely collected or exists. This means that the optimal solution to a linear programming model may not be taken as a final plan without carrying further tests on the stability of the solution by making changes in the input data to determine whether it depends on the actual values. In this section, sensitivity analysis is carried out to check how the input data for examples each crop (variables) profit per hectare and available resources of the farm can change without highly affecting the optimal solution. In all the scenarios, the effects of increasing and decreasing the quantities by 10 percent on the optimal solution were observed. The results of the sensitivity analysis in Table 7 show that low sensitivity was observed in all the variables except the variable (cabbages) which showed medium sensitivity. The results of the sensitivity analysis in Table 8 show that low sensitivity was observed in all the changes in the quantities of the available resources except the resource(chemicals) which showed medium sensitivity. This signifies that there are small changes in the optimal solution at the input data changes.

CONCLUSION

In this study, the focus was on solving the cash crop combination and resource allocation problems faced by a small-scale cash crop farmer in Vhembe District in Limpopo, South Africa. A mathematical linear programming technique was used and implemented. The farmer planned to have an optimal crop combination but was faced with limited resources such as land, capital, seed, fertilizer, crop protection chemicals and other resources that include transport, maintenance, irrigation and marketing. The results obtained from the formulated linear programming model were compared with those from the existing farming crop combination plan. The results show a significantly improved farmer's existing crop combination plan. This shows that using previous experience and intuition does not give an optimal crop combination and allocation of available resources. Though using the traditional approach the farmer was making profit, the linear programming model resulted in an increased profit margin of **37.8 percent**. The numerical results suggest that linear programming technique is the best tool for product mix, allocating, planning and managing of scarce resources. Finally, based on the results obtained from this study, it is recommended the cash crop small-scale farmer should focus more on the producing crops that maximize profit.

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Table 1: Farmers' Plans before optimisation for 2019-2020 farming season

Crop/Resources	GM	cabbages	Tomatoes	mustard	spinach	Butternut	SP	Available
Land(ha)	2	0.5	0.5	0.5	0.5	0.5	0.5	7
Gross income(R)	200000	70000	80000	30000	22000	22000	25000	449000
Seed (R)	1800	4500	4000	2000	2250	500	2250	17300
Fertiliser (R)	1800	2000	2000	1500	2500	2250	2500	18250
Chemicals R)	400	100	150					650
Fungicides(R)	1000	100	1500	150	200	500	350	3800
Labour (R)	8000	2000	1000	2000	2000	2000	2000	21000
Other(R)	2000	2000	2000	1500	1500	1000	2500	14500
Expenditure	21200	10700	10650	7150	8450	6250	9600	74000

Table 2: Farmers' Plans for 2020-2021 farming season

Crop/Resource	GM	cabbage	Tomatoes	Mustard	spinach	Butternut	SP	Available
Land(ha)	1	1	1	1	1	1	1	7
Seed (R)	900	9000	8000	4000	4500	1000	4500	≤40000
Fertiliser (R)	4000	4000	4000	3000	5000	4500	5000	≤30000
Chemicals(R)	200	200	300					≤1000
Fungicides(R)	500	200	3000	300	400	1000	700	≤7000
Labour (R)	4000	4000	4000	4000	4000	4000	4000	≤30000
Other(R)	5000	4000	4000	3000	3000	2000	5000	≤30000
Capital (R)	2000	2000	2000	1500	1500	1000	2500	≤140000
G. Income (R)	100000	140000	160000	60000	44000	44000	50000	

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Table 3: Farmers' Plans for the before optimisation for 2019-2020 farming season

Crop/Resource	GM	Cabbages	tomatoes	Mustard	Spinach	butternut	SP	Total
Land (ha)	2	0.5	0.5	0.5	0.5	0.5	0.5	**5**
Gross income(R)	200000	70000	80000	30000	22000	22000	25000	**449000**
Expenditure (R)	21200	10700	10650	7150	8450	6250	9600	**74000**
Net income (R)								**375000**

Table 4: Optimum crop combination using linear programming

Crop/Resource	GM	cabbages	tomatoes	Mustard	spinach	butternut	SP	Total
Land(ha)	1.16	2.64	0.8	1.2	0.4	0.4	0.4	**7**
Seed (R)	1044	23760	6400	4800	1800	400	1800	**40004**
Fertiliser (R)	4640	10560	3200	3600	2000	1800	2000	**27800**
Chemicals (R)	232	528	240					**1000**
Fungicides(R)	580	528	2400	360	160	400	280	**4708**
Labour (R)	4640	10560	3200	4800	1600	1600	1600	**28000**
Other(R)	5800	10560	3200	3600	1200	800	2000	**27160**
G. income(R)	116000	369600	128000	72000	17600	17600	20000	**740800**
Expenditure	16936	56496	18640	17160	6760	5000	7680	**128672**
Net income (R)	**99064**	**313104**	**109360**	**54840**	**10840**	**12600**	**12320**	**612128**

Table 5: Gross Income, Expenditure and Net income of the linear programming and traditional allocation methods

Method	Gross income (R)	Expenditure(R)	Net income(R)
Traditional	449 000	74 000	375 000
Linear Programming	740 800	128672	612128

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Table 6: Proportion of land allocated for each cash crop

Crop Mix	Size of farm(ha) (Farmer's plan)	Percentage	Size of farm(ha) Optimal allocation	Percentage
GM	2	28.6	1.16	16.6
Cabbages	0.5	7.1	2.64	37.7
Tomatoes	0.5	7.1	0.8	11.5
Mustard	0.5	7.1	1.2	17.1
Spinach	0.5	7.1	0.4	5.7
Butternut	0.5	7.1	0.4	5.7
SP	0.5	7.1	0.4	5.7
Used farm land	5	71.4	7	100
Unused farm land	2	28.0	0	0
Total	7	100	7	100

Table 7: Changes in the objective function coefficients

Test	**Variable to change**				**Model outcomes**			
	Variable to change	**Crop**	**Variable % change**		**Feasible Solution reached**	**Income Obtained(R)**	**Income % Change**	**Sensitivity**
0	No change	-	-		yes	740803	-	-
1	x_1	Maize	-10	90000	feasible	730228	-1.42	low
			10	110000	feasible	752385	1.56	low
2	x_2	Cabbages	-10	126000	feasible	708821	-4.32	medium
			10	154000	feasible	779333	5.20	medium
3	x_3	Tomatoes	-10	144000	Feasible	727980	-1.73	low
			10	176000	Feasible	758514	2.39	low
4	x_4	Mustard	-10	54000	Feasible	735506	-0.712	low
			10	66000	Feasible	748086	0.986	low
5	x_5	Spinach	-10	39600	Feasible	739020	-0.240	low
			10	48400	Feasible	742540	0.238	low
6	x_6	Butternut	-10	39600	Feasible	739020	-0.238	low
			10	48400	Feasible	743826	0.411	low
7	x_7	Sweet potatoes	-10	45000	Feasible	738780	-0.270	low
			10	55000	Feasible	742780	0.270	low

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Table 8: Changes in the right-hand side of constraints

Test	Constraint to change			Model outcomes			
	Constraint	**Variable % change**		**Feasible Solution**	**Income Obtained(R)**	**Income % Change**	**Sensitivity**
0	No change	-		feasible	740800	-	-
1	Seed	-10	36000	feasible	733452	-0.991	low
		10	44000	feasible	740800	0	none
2	Fertiliser	-10	27000	feasible	721027	-2.67	low
		10	33000	feasible	747200	0.863	low
3	Chemicals	-10	900	feasible	707200	-4.54	medium
		10	1100	feasible	767891	3.66	medium
4	Fumigation	-10	6300	feasible	740800	0	none
		10	7700	feasible	740800	0	none
5	Labour	-10	27000	feasible	730718	-1.36	low
		10	33000	feasible	740800	0	none
6	Other	-10	27000	feasible	740641	-0.02	low
		10	33000	feasible	740800	0	none
7	Capital	-10	126000	feasible	730523	-1.39	low
		10	154000	feasible	740800	0	None

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