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Farm profit maximizing food crops and tree combination in Mufindi district: A multi-period programming approach

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Abstract

Optimal agricultural land use is vital for improved productivity, maximized profitability, and efficient utilization of resources. The study aimed to determine the optimal combination that maximizes profit from the production of food crops and trees. A multi-period profit maximization programming model was used. The study used both primary and secondary data. Primary data involved the collection of information on average crop/tree prices and production costs through the focus group discussion and key informants such as VEO and other village leaders. Secondary data was collected from the National sample census of agriculture 2007/08, Iringa region report. From the study findings, it can be concluded that the initial allocation done by farmers was not optimal. Moreover, the study found capital and land were binding. Therefore, the government should promote low-interest credit to farmers to enable them to increase their capital base and also rent more land to increase profit.

Keywords: Crops; Multi-period; Optimization; Profit; Trees.

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1. Introduction

Optimal agricultural land use is vital for improved productivity, maximized profitability, and efficient utilization of resources (Sainio *et al*., 2019; Hassan *et al.,* 2005). This is more thoughtful for production resources such as land which is fixed in nature while its use demand increases over time due to increased human activities; and capital which is a scarce resource and therefore requires efficient allocation. Lucey (2002) reported that allocation of resources ensures proper utilization of limited resources to the best advantage. However, studies on optimality that could guide farmers in allocating limited production resources at their disposal for maximized benefits are rarely available and therefore not accessible to smallholder farmers who are particularly the major producers of crops in developing countries. Therefore, maximizing profits from agricultural production may not be achieved as farmers are not fully aware of how to optimize land use.

Land expansion to other uses such as mineral explorations, biofuels, conservation, urbanization, and the current expansion of tree plantations has been one of the major challenges that limit agricultural activities in Tanzania. The challenge is an outcome of inadequate implementation of the Village Land Act, 1999, and the Land-use planning Act, 2007 (Kimaro & Hieronimo, 2014). The Act among others insists on the allocation of land for various uses including cropland and forestland to facilitate efficient and orderly management of land use and empower users to make better and more productive use of their land (URT, 2007), hence profitability in the production. For decades, Smallholder farmers in Tanzania specifically in Mufindi District and the Southern highlands in general have been allocating land at their disposal to both food crops and trees (PFP, 2016; FDT, 2015). This allocation is meaningful to smallholder farmers, as food is required by households on daily basis, and food crops are also vital for the provision of income in the short run while trees provide income in the long run. However, it is not known if the food crops/trees allocation they make is optimal for ensuring that their profits are maximized.

An innovative solution for efficient allocation of their land may be finding an optimal land allocation that maximizes farmers' profit through modeling (Hassan *et al.,* 2005). Moreover, Igwe and Onyenweaku, (2013) elucidate that; the modeling approach for optimal combination of agricultural enterprises has remained underdeveloped globally. In Tanzania for example smallholder farmers are prevalent and own small plots of land ranging between 0.25 –3 acres in which multiple crops are grown. In such a situation, studies on optimal land use allocation between various crops grown by farmers could help them maximize their benefit.

1.1. Theoretical Framework: Multi-Period Profit Maximization Model

Multi-period profit maximization programming assumes that a producer aims at maximizing net profit over the time horizon through the allocation of resources that are constrained in the production process. The net profit is obtained as a sum of discounted revenue less discounted total variable costs for the entire production period. Revenue is a function of yield and prices, and costs are a function of the number of inputs and prices. The discounting is inevitable because revenue is realized and costs are incurred over years, and therefore, they have to be put on a common basis for comparison purposes.

As related to this study, revenue from trees becomes available after ten years while costs are incurred on yearly basis, therefore, to compare the revenue and costs over years and then find an optimal combination of both annual food crops and trees, discounting of revenue and costs over ten years is necessary. To take into consideration the time preference, this study has used a current discount rate of 17 percent, the rate recommended by the central bank of Tanzania (BoT) to discount cash flows. The multi-period profit maximization model has been used in the manuscript to establish an optimal combination between food crops and trees.

Basic assumptions of the multi-period profit maximization model

i) Prices of agricultural goods and outputs per acre – the study assumes average prices over the previous five years and constant outputs throughout the production period of ten (10) years.

ii) The study assumes that each crop is grown in a pure stand.

iii) Profit maximization is confined to the following crops: maize, beans, round potatoes, wheat, green peas, and finger millet (food crops), and Pine trees.

iv) Land allocation to each crop is fixed for the entire planning period.

1.2. Related Studies

There are numerous studies on crop optimization (Johansson and Azar, 2006; Mugabe *et al.,* 2014; Igwe *et al.,* 2015; Chukwuigwe *et al.,* 2006; Igwe and Onyenweaku, 2013; Drafor *et al*. 2013). These studies offer useful information on the optimization of land use. However, the focus has been on the optimum combination of annual food crop production without due consideration of the combined land for both tree plantations and food crops. The production of perennial trees is an activity that is growing fast at the global level and in Tanzania in particular.

A more recent study by Alexandra and Scott (2016) in Kenya used a multi-period programming technique to find an optimum combination between food crops and trees to maximize profit. However, the study considered trees that regenerate after harvesting (grevilia and Eucalyptus) which ensures continuous revenue to farmers after planting, which is different from Pines (*Pinus Patula*)—a plantation tree grown by smallholder farmers in Tanzania. Once planted, Pines are harvested after ten years, and those wanting to continue with their production must replant the trees. Therefore, this implies a different modeling approach from that of Alexander and Scott (2016) who assumed regeneration of the trees once planted. While there are scenarios where a farmer can produce only trees or food crops from which to maximize profit, this study assumes that a representative farmer in Mufindi can maximize profit from the production of both food crops (annual) and Pine trees (Perennial) as this is a common practice.

1.3. Purpose of study

Therefore, this study aims to establish an optimal food crops/tree combination that maximizes farmer profit while meeting households' food consumption requirements. The findings from this study are useful in informing policymakers on how farmers can maximize profits from their production by allocating resources at their disposals such as land, labour, and capital efficiently.

2. Materials and Methods

2.1. Participants and context of the study

The present study was conducted in Mufindi, a leading District in timber plantations expansion in Tanzania, based on acreage (PFP, 2016). Mufindi is one of the five District authorities of the Iringa Region located 80 km South of Iringa Municipal. It is bordered by Njombe Region to the south, Mbarali District (Mbeya Region) to the West, and Iringa Rural District to the North. To the Northeast lies Kilolo District. In terms of location coordinates, the district lies between latitudes 8^{o}.0' and 9^{o}.0' south of the Equator and between longitudes 30^{o}.0' and 36^{o}.0' east of Greenwich. Mufindi is divided into five divisions namely Ifwagi, Kibengu, Kasanga, Malangali, and Sadani. It has 30 wards, 125 villages, and 608 hamlets. The district is mostly occupied by the forest (10 411.3 sq. km) leaving only 2 427.6 sq. km. for human settlement and other economic activities. The climatic conditions vary within the district with the first three divisions (Ifwagi, Kibengu, and Kasanga) having favorable climates for timber tree plantations. According to the 2012 National census, the population was about 317,731 people of which more than 90% were engaged in agriculture, which provides more than 85% of the income.

2.1.1. Description of Smallholder Farmers and Tree Growers in Tanzania

According to National Agriculture Policy (URT, 2013), Smallholder farmers are those cultivating between 0.2 and 2.0 hectares of land, while in forestry farming, FDT (2015) reports categories of tree growers as follows; smallholders (< 5 acres), medium (5 – 20 acres), and large (> 20). This study has however focused on smallholder farmers and tree growers as they are the most affected when land-use changes occur.

2.1.2. Population and Sampling

To gain a general view of production activities and tree growing, key informants comprising Village Chairpersons, Village Executive Officer (VEO), and Ward Agricultural Extension Officer were interviewed in each selected village. Focus group discussions (FGDs) were conducted to have a better understanding of community-wide activities to collect information about the types and costs of inputs as well as outputs from crops and trees. Based on the geographical location of the study villages and similarities in terms of production activities, the eight villages were divided into two groups, hence two focus group discussions comprising eight (8) members were conducted. The FGD is comprised of four village leaders and four representatives, one from each village. The members of the FGD were purposefully selected based on their knowledge and involvement in crop/tree production and crop output prices.

2.2. Data collection

The study used both primary and secondary data. Secondary data entailed the collection of information on average yield for crops such as maize, beans, round potatoes, wheat, green peas, and finger millet in the Mufindi District. This information was collected from the National sample census of agriculture 2007/08, Iringa region report (URT, 2012) as farmers had not yet harvested most of the crops at the time of data collection. Thus, it was difficult for them to memorize the crop yield of previous years since they don't keep records. Therefore, the average yield per acre measured in kilograms of various crops as reported in the national census of agriculture 2007/08, was used as a standard for Mufindi District and its villages.

Moreover, primary data involved the collection of information on average crop/tree prices and production costs through the focus group discussion and key informants such as VEO and other village leaders as these are community-wide information. Moreover, acreages of trees were collected from respondents by using a structured questionnaire. Data on land allocation to various crops and/or trees were collected using a structured questionnaire involving 413 randomly selected households.

Resources in the linear programming model were land, labour, and working capital. The total amount of land available to the household for different allocations was computed as the maximum amount of land the household was possessing. Where household annual income obtained from different sources was used as a proxy for total working capital available for different production activities.

2.3. Analysis

In the context of this study food crops are crops planted and harvested within a year, after which can be replanted again in the next farming season. At the household level, these crops serve dual purposes like food and a source of income. These crops include maize, beans, round potatoes, wheat, green peas, and finger millet. Moreover, the production of pine trees is another activity undertaken by smallholder farmers, whereby once planted, harvesting can be done after ten (10) years, and this is the time when revenue is realized. After harvesting the trees do not regenerate but can be replanted again. This study is only confined to Pines (*Pinus Patula*) as they are the most grown timber trees by smallholder farmers.

To compare on the same ground, the revenue from trees and that of annual food crops, a net profit from each crop is computed per acre by subtracting total variable costs from revenue which is a function of yield per acre multiplied by the farm gate price. Net profit is then discounted for ten (10) years using a 17% discount rate and added together to get the net present value for each crop which is used in the multi-period model to find an optimal combination of food crops/trees.

Thus, the multi-period profit maximization programming model is as shown in equations 1 - 5:

$$Max\ \pi = \sum_{i=1}^{n} \sum_{t=1}^{T=10} \frac{P_{jt}X_{jt}}{(1+r)^t} \quad \text{……(1)}$$

Subject to:

$b_{11}X_1 + b_{12}X_2 + b_{13}X_3 + \ldots + b_{1n}X_n < c_1$ (Land constraint)……(2)

$b_{21}X_1 + b_{22}X_2 + b_{23}X_3 + \ldots + b_{2n}X_n < c_2$ (Labour constraint) ……(3)

$b_{31}X_1 + b_{32}X_2 + b_{33}X_3 + \ldots + b_{3n}X_n < c_3$ (capital constraint) ……(4)

$X_i \geq 0$ (non-negativity) …… (5)

$\Sigma Y_{ij}X_{ij} \geq f_j$ (Subsistence consumption requirement for maize and beans)

Where: π = Net Profit to be maximized (Tshs). P_{jt} = Net profit of the j^{th} farming activity in the year *t* (Tshs/acre). X_{jt} = Acres of land devoted to the production of j^{th} crop during the survey period; r = Discount rate of capital (17%); t = the year in which the crop is cultivated (t = 1). Y_{ij} = Yield of the j^{th} crop for the i^{th} grower. f_j = Subsistence food requirement for maize and beans. T = the end of the year of the planning period (10). b = per acre requirement of the i^{th} resource (land, labour, capital) by the i^{th} activity during the survey period. c = Level of k^{th} resource available during the survey period. Table 1 shows the different types of food crops and trees produced by smallholder farmers in the study areas; Yield obtained and profit per acre and the production requirements. Data in Table 1 are the inputs in the excel problem solver for the optimization process.

Table 1: ***Yield, profit per acre and the production requirements***

Variables	Yield/ Acre (Kg)	Price (Tshs/kg / Tree)	Revenue/ Acre (Tshs)	Variable Cost/Acre (Tshs)	Profit/Acre (Tshs)	Land (Acres)	Working capital (Tshs)	Labour (Man-Days /Acre)
Maize (X_1)	644	663	427 000	300 000	127 000	2.05	300 000	57
Beans (X_2)	272	1737	472 500	275 000	197 500	0.5	275 000	55
R/Potatoes (X_3)	2505	400	1 001 900	325 000	676 900	0.7	345 000	57
Wheat (X_4)	476	1400	667 000	205 000	471 900	0.22	205 000	41
Green Peas (X_5)	263	1540	405 000	180 000	225 000	0.07	180 000	55
Finger millet (X_6)	407	1400	570 000	205 000	365 000	0.03	180 000	41
Pine Trees(X_7)	650	35 000	22 750 000	270 000	22 480 000	4.28	270 000	35
Available Resources						8.25	1 330 725	714.1

Source: Field data, 2017

2.3.1. Objective Function

Max π = 591642.2X1+920073.5X2+3153406.34X3+2152273.2X4+1 048185X5+1 700 389X6+ 4 169 811X7……(6)

Subject to:

$2.05X1 0.8X2 + 0.7X3 + 1.13X4 + 0.42X5 + 0.46X6 + 4.20X7 \leq 8.2$ Land constraint) ……………………(7)

250000X1+275000X2+345000X3+205000X4+180000X5+205000X6+ 270000X7 $\leq$ 1330725 (working capital constraint)……………………………………………………………(8)

$57X1 + 55X2 + 57X3 + 41X4 + 55X5 + 41X6 + 35X7 \leq 714.1$ (Labor constraint) ………………………….(9)

$644X1 \geq 365$ (Maize – subsistence food consumption constraint) … … … … … … … … … … … … … . (10)

272X2 $\geq$ 96.5 (Beans - subsistence food consumption constraint) ……………………………………………(11)

X1- Xn ≥ 0 $(Non - negativity)$ … (12)

2.3.2. Solving the LP model

To find the optimal land allocation solutions that maximize the Net profit, the variables in the objective functions and constraints were entered into excel problem solver software 2010 for analysis (Adekunle & Tafamel, 2016).

2.4. Ethical consideration

Before data collection, permission was requested from the Deputy Vice-Chancellor (Academics) of the Sokoine University of Agriculture. It was then submitted to the Local government authorities concerned such as District Executive Director, Ward Executive Officer, and Village authorities. During data collection, the following ethical issues were highly observed; informed consent, that is a person knowingly, voluntarily, and intelligently, and clearly and manifestly, gives his consent; respect for anonymity and confidentiality; respect for privacy and consideration of vulnerable groups of people.

3. Results

3.1. Descriptive statistics

Descriptive statistics were computed to summarize and explain the household land resource, labour, and land allocation to various food crops and trees in the study areas.

3.1.1. Household's Land

The land is an important production resource from which decisions to allocate it to food crops and/or trees are made. In the study areas, total land available to the household was assessed based on total land owned for the crop; land rented in for crop production, total land owned for trees, land rented in for trees, and fallowed land. Results in Table 1 show that on average a household had a total land size of 8.25 acres.

Table 2: Household Land Resource (acres)

Land category	n	Min	Max	Mean	Std. Error	Std. Deviation
Total land owned for crop	413	0.5	15	2.92	0.10	2.01
Land rented in for crop	413	0	10	0.65	0.08	1.52
Total land owned for trees	413	0	42	3.75	0.27	5.53
Land rented in for trees	413	0	12	0.53	0.08	1.55
Total fallowed land owned	413	0	15	0.39	0.08	1.58

Total land size	413	0.5	47	8.25	0.37	7.53

3.1.2. Farm Labour

The amount of labour (Man-days) used in the production of each crop was calculated based on the number of man-days required to perform and complete each farm operation for each crop within eight hours, and then total man/days were added together. In the study areas, farmers were found to mostly use family labour (Table 3).

Table 3: Farm Labour (Man-days)

		Labour availability				
Labour category	Persons in the HH	Year working days	Total days	Hours/ day	Conversion factor	Total man-hours/year
Age of Males (years)						
1 - 6 years	154	0	0	0	0	0
7 - 14 years	205	52	10660	8	0.516	44004.5
Other Students	100	52	5200	8	1	41600
15 - 55 years	427	313	133651	8	1	1069208
> 55 years	64	313	20032	8	0.59	94551.0
Females						
1 - 6 years	127	0	0	0	0	0
7 - 14 years	197	52	10244	8	0.406	33272
Other Students	127	52	6604	8	0.84	44378.9
15 - 55 years	446	313	139598	8	0.84	938098.6
> 55 years	67	313	20971	8	0.562	94285.6
Total man-hours/year						2359399
Total man-days/year						294925
Household average total labour/year (man-days)						714.1

The total amount of farm labour available was computed based on the amount and type of family labour available and was found to be 714.1 man-days. On average, a household in the study area was found to have a size of 4.5 persons just above the average of 4.2 persons found in the year 2012 in the district (URT, 2013; NBS, 2013). Conversion to man-days took into consideration the age and sex of an individual.

3.2. Land allocation by crop/Trees across the village

Results in Table 4 show the average land allocated per different use in each village. Overall results show that, on average, households allocated about 2.05, 0.54, 0.71, 0.22, 0.07, 0.03, and 4.28 acres for maize, beans, round potatoes, wheat, green peas, finger millet, and pine trees respectively. Based on Table 4, households have been allocating more land to tree plantations, followed by maize which is a staple food crop.

Table 4: ***Land allocation by crop/Trees across village (acres)***

	Maize	Beans	Round potato	Wheat	Green peas	Finger millet	Pine Trees
Vikula (n = 28)	2.05	0.46	0.71	0.21	0.07	0.04	4.37
Ikwega (n = 57)	2.06	0.60	0.72	0.23	0.07	0.04	4.28
Ludilo (n = 36)	2.04	0.71	0.72	0.22	0.08	0.03	4.58
Luhunga (n = 48)	2.05	0.54	0.69	0.24	0.07	0.03	4.27
Ifwagi (n = 48)	2.06	0.57	0.69	0.25	0.07	0.04	4.29
Nundwe (n = 50)	2.07	0.46	0.72	0.20	0.09	0.03	5.18
Igoda (n = 50)	2.03	0.50	0.72	0.30	0.04	0.02	3.38
Mninga (n = 96)	2.01	0.51	0.69	0.23	0.07	0.04	3.91
Average (413)	**2.05**	**0.54**	**0.71**	**0.22**	**0.07**	**0.03**	**4.28**

Results in Table 5 shows that the optimum combination of food crops and trees that maximizes net present value is attained when a farmer allocates 1.81 acres to round potatoes and 1.74 acres to Pine trees, while also allocating 0.57 and 0.35 acres of land for maize and beans to meet household's food demand for subsistence. Given this allocation, the maximum profit the farmer can get is Tshs 13 592 440. Moreover, Table 5 shows that the original land allocation made by farmers, was not optimal, and therefore was not maximizing the farmers' profit.

Table 5: Food crops/Tree optimum combination

The objective function and decision variables				
Objective Cell (Max)				
	Cell	**Name**	**Original Value**	**Final Value**
	$I$10	Profit (Tshs)	12,984,700.60	13592440.53
Variable Cells				
	Cell	**Decision variables**	**Original Value (Acres)**	**Final Value (Acres)**
	$B$2	Maize	2.05	0.57
	$C$2	Beans	0.5	0.35
	$D$2	Round potato	0.7	1.81
	$E$2	Wheat	0.22	0
	$F$2	Green peas	0.05	0
	$G$2	Finger millet	0.05	0
	$H$2	Pines Tree	4.20	1.74

Table 6 also shows that land and working capital constraints, are binding; implying that land and working capital are fully utilized in the final solution. The labour constraint is not binding and has a slack value of 498.5 man-days not used in the final solution. Therefore, in the study area, labour is not fully utilized in the activities considered in optimization while land and capital are binding.

Table 6: Constraints status in the model

Cell	Name	Cell Value	Formula	Status	Slack
$I$4	Land (Acres)	10	$I$4<=$K$4	Binding	0

$I$5	Capital (Tshs)	1330725	$I$5<=$K$5	Binding	0
$I$6	Labour (M/days)	215.46	$I$6<=$K$6	Not Binding	498.5
$I$7	Maize (Kgs)	365	$I$7>=$K$7	Binding	0
$I$8	Beans (Kgs)	96.5	$I$8>=$K$8	Binding	0
$I$9		0	$I$9>=$K$9	Binding	0

3.3. Sensitivity Report

The sensitivity report shows how changes in the coefficients of the objective function affect the optimal solution, and also, how changes in the constants on the right-hand side (RHS) of the constraints affect the optimal solution. The allowable increase/decrease associated with the original coefficient of a decision variable expresses the range in which the coefficient of a given decision variable in the objective function may be increased/decreased without changing the optimal solution, where all other data are fixed. The reduced cost of a given decision variable shows the rate at which the value of the objective function will worsen for each unit change in the optimized value of the decision variable with all other data held fixed.

From the sensitivity report in Table 7, it can be deduced that, if the objective coefficient on round potatoes is raised to Tshs 5 328 091.83, or decreased to Tshs 3 030 457.44, the optimal plan of allocating 1.81 acres of round potatoes and 1.74 acres of pine trees will be met ceteris paribus. Also, if the objective coefficient on Pine trees is raised to Tshs 18 920 438, or decreased to Tshs 3 892 371.21, the optimal plan remains constant.

Table 7: Model coefficients

Cell	Name	Final Value (Acres)	Reduced Cost (Tshs)	Objective Coefficient (Tshs)	Allowable Increase (Tshs)	Allowable Decrease (Tshs)
$B$2	Maize	0.57	0	591 642.2	2 412 364.3	1.00E+30
$C$2	Beans	0.35	0	920 073.5	1 706 297.8	1.00E+30
$D$2	Round potato	1.81	0	3 153 406.34	2 174 685.5	122948.9
$E$2	Wheat	0	-54 243.9	2 152 273.2	54 243.88	1.00E+30
$F$2	Green peas	0	-622 599	1 048 185	622 599.4	1.00E+30
$G$2	Finger millet	0	-193 905	1 700 389	193 905.38	1.00E+30
$H$2	Pines Tree	1.74	0	4 169 811	14 750 627	277439.79

Therefore, this means that if the net present value per acre of round potatoes varies between Tshs 5 328 091.83 and Tshs 3 030 457.44 or the net present value per acre of Pine trees varies between Tshs 18 920 438 and Tshs 3 892 371.21, the optimal production plan of using 1.81 acres for round potatoes and 1.74 acres for Pine trees under the planning period, will still be achieved, while also allocating 0.57 and 0.35 acres of land for maize and beans to meet households' food demand for subsistence. This result is in line with Mpogole and Kadigi, (2012) who reported that round potatoes in the Southern Highlands of Tanzania were more profitable than other food crops. Also, Scott *et al*. (2000) reported that trees were profitable in Kenya. Moreover, results in Table 7 show that forcing wheat, green peas, and finger millet into the model from 0 to 1 acre, will result in reduced cost from the objective function by Tshs 54 243.9, 622 599, and 193 905 respectively.

3.4. Shadow Price

The shadow price of a given constraint is the rate of increase or decrease in the optimal objective function value, as the RHS of that constraint increases or decreases with all other data held fixed. Results on shadow price are presented in Table 8.

Table 8: Shadow Price

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$I$4	Land (Acres)	10	466 004	10	8.42	6.34
$I$5	Capital (Tshs)	1 330 725	8.19	1 330 725	2 922 984.4	54 548.98
$I$6	Labour (M/days)	215.47	0	714	1.00E+30	498.53
$I$7	Maize (Kgs)	365	-3 745.9	365	2 646.43	365
$I$8	Beans (Kgs)	96.5	-6 273.2	96.5	658.86	96.5
$I$9		0	0	0	0	1.00E+30

Results in Table 8 show the shadow price for the land constraint is Tshs 466 004, indicating that if the land is increased by 1 acre (in a range of 10 to 11 acres), the corresponding net present value at the optimal solution will increase by Tshs 466 004, and also will decrease by the same amount if decreased by 1 acre (from 10 to 9 acres). Regarding working capital, results show its shadow price equal to Tshs 8.19, indicating that if working capital is increased by Tshs 1 (in a range of Tshs 1 330 725 to 1 330 726), the corresponding net present value at the optimal solution will increase by Tshs 8.19, and also will decrease by the same amount if decreased by Tshs 1 (from Tshs 1 330 725 to Tshs 1 330 724). Results also show that the shadow price for maize and beans land constraints are negative, that is -3745.91 and -6273.15 respectively. This shows that; any change by one acre in the constants on the RHS of the constraint will reduce the optimal solution by the amount equivalent to the respective shadow price. Moreover, the above changes are valid only for a range as indicated by the allowable increase and decrease columns. For example, from Table 5 as far as the RHS remains within 18.42 to 3.7 acres, the shadow price (Tshs 466 004) remains valid for land constraint, while for capital constraint, the shadow price will remain valid as far as constants in the RHS remain within the range of Tshs 4 253 709 to 789 176.

4. Discussion

From the study findings, farmers are advised to combine food crops and trees within the optimal plan for maximized profit. This is similar to the findings of Ibrahim, Oformata, Jirgi, & Adewumi (2019). It is also related to the findings of Fontanilla-Díaz, Preckel, Lowenberg-DeBoer, Sanders & Peña-Lévano, (2021). Also, land and working capital are found to be fundamental in maximizing farmer profit (Aytac, Hoang, Lahiani & Michel, 2020); however, they are binding as opposed to labour which is found to be slack in the study area.

The study, therefore, recommends that farmers be financially enabled by the government through the provision of low-interest credits to enable them to rent and also buy more land, as well as agricultural inputs for investment in round potatoes and pine trees for increased profit while producing maize and beans for subsistence food consumption. Moreover, the study recommends that farmers create off-farm activities to curb rural unemployment as a result of slack labour existing.

5. Conclusion

This study aimed to establish an optimum combination between food crops and Pine trees that maximizes farm profit, subject to land, working capital, and labour constraints available to smallholder farmers. A multi-period profit maximization model was used to determine the optimal combination. Results showed that a farmer can maximize profit by allocating between 0.72 hectares of land for round potatoes and 0.70 hectares of land for Pine trees, while also allocating 0.23 and 0.14 hectares of land for maize and beans to meet households' food demand for subsistence. From this allocation, the maximum profit the farmer can get was Tshs 13 592 440. Other crops such as wheat, finger millet, and green peas were found to have no contribution to the optimal solution. Moreover, land and working capital were found to be binding, while labour was slack.

Finally, Sensitivity analysis was conducted to identify how changes in constraints can affect the optimal solution, and hence guide the decision-makers in making correct decisions. Results showed that maintaining the objective coefficient within the range of Tshs 5 328 091.83 to 3 030 457.44 for round potatoes, and Tshs 18 920 438 to 3 892 371.21 for Pine trees, ensures that the optimal plan is met. Moreover, results show that an increase or decrease by one-acre land for round potatoes is likely to increase or decrease the net present value by the shadow price (Tshs 466 004). Also, an increase or decrease in working capital by Tshs 1 is likely to increase or decrease the net present value by Tshs 8.19.

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