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# Optimising Land Allocation for Paddy Varieties Using Linear Programming: A Case Study of Pawaga, Tanzania

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## ABSTRACT

Farmers often operate with limited resources, making strategic and scientifically informed decision-making essential. Linear programming is one such analytical tool that can support optimal resource allocation. A case study was conducted in Pawaga, Iringa District, Tanzania, with the aim of evaluating the gross profit of growing four paddy varieties, namely Shingo yamwali, Faya, Saro 5 and Zambia, using linear programming. Farmers in the area typically select crop varieties based on intuition or peer influence, which can lead to suboptimal profitability. A study was conducted to determine the gross revenue per acre for different paddy varieties, assess their variable production costs, and compute their gross profits. Linear programming was then applied using Microsoft Excel Solver to identify the best land allocation that would maximise overall farm profit. A farmer should allocate the 4 acres of land by growing 2.7 acres of paddy Shingo yamwali and 1.3 acres of paddy Saro 5 so as to generate a gross profit of 7,680,400 shillings under the operating cost of 4,167,000 shillings. The results show that the gross profit obtained through the LP model is superior to that obtained through the traditional method by 6%. This suggests that, by reallocating the same land and operating under the same budget constraints, farmers could increase their gross profit compared to their current practices. The study concludes that scientific tools such as linear programming can significantly improve crop planning and encourages farmers to transition from experience-based decision-making to data-driven strategies for enhanced profitability.

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## 1.0 Introduction

Paddy is a staple food for the majority of people around the world, and many different paddy varieties are cultivated globally (Handayani, 2022). In Pawaga, Iringa District, Tanzania, four varieties – Shingo ya Mwali, Faya, Saro 5, and Zambia – are predominantly grown. These varieties differ in their production requirements, associated costs, taste, flavour, and aroma, which can influence farmers' choices and profitability.

This study analysed the gross profit of cultivating four paddy varieties using a Linear Programming (LP) approach. Data were collected on total revenue per acre, variable production costs, and the resulting gross profit for each variety. The objective was to use this information within the LP model to determine the land allocation that would maximise total farm profit.

Farmers customarily rely on intuition, experience and comparisons with their neighbours to make decisions concerning land allocation to different crops, which in many cases do not guarantee the optimal profit (Jawla *et al.,* 2018).

Linear programming is a useful tool for addressing such resource allocation problems, as it enables the identification of the most efficient combination of decisions under given constraints (Ganesh Nayak & Ananthi, 2024). In this research, a linear programming model is formulated to guide farmers in selecting an optimal mix of paddy varieties that maximises profitability while efficiently utilising available land.

## 2.0 Materials and Methods

### *2.1 Study Area*

This study was conducted at the Pawaga irrigation scheme in the Iringa district, Tanzania, about 80 km from Iringa town, famous for paddy production. The scheme is on the west bank of the Little Ruaha River. The average annual rainfall in the area is 375 mm; consequently, agriculture mainly depends on irrigation in this area (TEEB, 2020). Soils in the region are generally fertile, and local farmers cultivate multiple paddy varieties, including Shingo ya Mwali, Faya, Saro 5, and Zambia, based on field observations and information provided by participants.

### *2.2 Sampling Design and Procedures*

The participants of this study were all extension officers from six villages, namely Itunundu, Magombwe-Kisoloka, Kisanga, Isele, Kimande and Mbuyuni-Ndolela, together with two ward extension officers (WEO) (Itunundu and Mlenge) and scheme leaders. The extension officer was selected because they are the ones with agronomy science, which is the science and technology of producing plants. They are knowledgeable about plant genetics, physiology, meteorology, and soil science. The relevant information concerning crop production activities in the study area was obtained from them. The scheme leaders were involved primarily in administrative matters and provided support during the field observations.

### *2.3 Methods of Data Collection*

Primary data and secondary data were all used in this study. Primary data was collected from the study area by onsite observation and pre-tested semi-structured questionnaires to extension officers using the Delphi technique. The primary data gathered is based on the existing farm plan, including the number of acres cultivated, which is a unit they prefer more than hectares; the types of crops grown; the amount and price of resources used (fertiliser, seeds, labour, and capital); the yield of each crop per acre; and the average price of each crop in the market in Tanzanian shillings per kilogram.

The primary data for this study was collected from extension officers rather than farmers because many farmers are not consistently implementing scientifically recommended practices, which could affect the accuracy of the results. Farmers also do not have a habit of record keeping (Biswas *et al.,* 2023). The data collected is from field classes or other farms that are under the supervision of extension officers.

Secondary data was gathered from different literature reviews, both published and unpublished. Sources for secondary data include books, journals, articles, and annual reports from various sources, such as regional libraries. Data analysis was conducted using Microsoft Excel.

### *2.4 Case Study Design*

This research adopts a case study approach, focusing on a single 4-acre paddy farm managed by an extension officer. The farm was selected to allow a detailed analysis of land allocation and profitability across the four dominant paddy varieties. Supporting information was collected from multiple extension officers to contextualise local production practices, input costs, and market prices.

### *2.5 Gross Profit Calculation*

Profitability is the ability of the business, in this case, the farm, to earn a profit (Rahaman *et al.,* 2022). Farm profit is calculated as the difference between the total revenue earned by the farm and the cost incurred (Basnet *et al.,* 2022). Various profitability ratios are commonly used to assess firms' performance and efficiency, including gross profit margin, net profit margin, return on equity (ROE), and return on assets (ROA) (Kryszak *et al.,* 2021).

Among these, the gross margin analysis is particularly useful for cash flow planning and evaluating the relative profitability of different farm enterprises (Kuznietsova *et al.,* 2024). Gross margin estimates can help to determine which crops are more profitable than others. This profitability ratio is different from other ratios since it includes variable costs such as seeds, fertilisers, pesticides, material cost and labour cost and excludes fixed costs (Castillo *et al.,* 2021). Gross margin analysis uses basic mathematical techniques to estimate yields and calculate profit or loss, helping farmers achieve economic stability (Mukherjee, 2005). The higher the gross profit, the more profitable the crop (Popescu, 2012).

Let $i$ denote the paddy variety,
where $i = 1,2,3,4$ corresponds to Shingo ya Mwali, Faya, Saro 5, and Zambia, respectively.
The gross profit for crop $i$ is defined as:

$$Gross\ profit(GP_i) = Revenue - cost\ of\ good\ sold(cogs) \quad (1)$$

Equivalently

$$Gross\ profit(GP_i) = Revenue - Variable\ cost \quad (2)$$

Thus $GP_i = (TR_i - VC_i)$ (3)

Where total revenue is given by price times yield:

$$GP_i = (P_iY_i - VC_i) \quad (4)$$

Where $i$=Index representing the paddy variety
$GP_i$=Gross Profit of crop i
$TR_i$=Total Revenue of crop i
$VC_i$=Variable Cost per acre of crop i
$P_i$ = Price per unit Kg of crop i
$Y_i$=Yield per acre of crop i

### *2.6 Linear Programming Model*

A linear programming model is a mathematical representation of a real-world problem using linear equations and inequalities to be solved by the linear programming technique. A problem is said to be a linear programming problem (LPP) when it possesses the four essential characteristics, which are linearity (proportionality), additivity, divisibility (continuity) and certainty (Chatare, 2023).

In crop production, the LP models aim to optimise gross profit (which is the focus of this research) or sometimes cost minimisation and are obtained by following the optimal plan generated from the solution of the LP.

In model formulation, our base is a farmer who owns 4 acres of land and uses his land to grow paddy. Each paddy variety produces different amounts of yield using different amounts of resources and variable costs and sells for different prices. Therefore, a farmer must decide which paddy variety to choose and how much of each variety to produce to maximise profits. The general structure of a linear programming model typically comprises the following key elements:

i. Decision variables/control variables
ii. Objective function
iii. Constraints

In this study, our concern is in maximising the profit for farmers, so the general maximising formulation as by Sofi *et al.* (2015) will be of the form:

$$\max Z = c_1x_1 + c_2x_2 + c_3x_3 + \cdots + c_nx_n \quad (5)$$

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq b_1 \quad (6)$$

$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq b_2 \quad (7)$$

$$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq b_m \quad (8)$$

$$x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0$$

Where $x_1, x_2, x_3 \ldots x_n$ are decisions variables,they represent the quantity of each paddy variety to plant per acre.

$c_1 \ldots c_n$are coefficients in the objective function, they represents the gross profit per acre for each paddy variety.

$b_1, b_2, \ldots b_m$areright hand side values, they represent the amount of available resources.

$a_{ij}$, these indicate how much of each resource is used per unit of decision variable.

The usual approach for solving this kind of problem is to use the Simplex method (Patel *et al.,* 2017). This study will use the simplex method, which is a mathematical technique for solving linear programming problems by first locating a feasible solution and then working iteratively until the optimal solution is obtained.

There are several software which can be used in solving LP models, including EXCEL SOLVER, MATLAB, LINDO, LINGO, TORA, AMPL, PYTHON, etc. (Alotaibi & Nadeem, 2021). The modelled problem was solved using the Microsoft Excel Solver (2010). This software is a very popular and easily accessible tool, which can enable even small farmers to obtain quantitative solutions in their daily lives.

The 4-acre farm from Pawaga, Iringa, was selected as a case study in this paper. The data was collected from an extension officer in Pawaga, Iringa, Tanzania. The total revenue and production variable costs of four paddy varieties in the area were surveyed, which is owned by the extension officer, who provided the data through documents and unstructured interviews. Based on this data, the gross profit of each paddy variety was calculated using Equation (2), and the linear programming model was formulated.

Table 1

*Farming Plan before Optimization per Acre*

| | SHINGO YA MWALI | FAYA | SARO 5 | ZAMBIA | TOTAL |
|---|---|---|---|---|---|
| PROFIT | 1,794,000 | 1,608,600 | 2,182,000 | 1,666,000 | 7,250,600 |
| TOTAL COST | 1,022,000 | 1,041,000 | 1,082,000 | 1,022,000 | 4,167,000 |
| REVENUE | 2,816,000 | 2,649,600 | 3,264,000 | 2,688,000 | 11,417,600 |

Table 1presents the data based on experience and intuition that were used to allocate the 4 acres of available land by allocating 1 acre to each paddy variety. The farm generates total revenue of 11,417,600 shillings under the operating cost of 4,167,000 shillings, hence the gross profit of 7,250,600 shillings.

Table 2

*LP Formulation*

| | SHINGO YA MWALI | FAYA | SARO 5 | ZAMBIA | Resource Available |
|---|---|---|---|---|---|
| GROSS PROFIT | 1794000 | 1608600 | 2182000 | 1666000 | |
| LAND | 1 | 1 | 1 | 1 | 4 |
| LAND PREPARATION | 100000 | 100000 | 100000 | 100000 | 400000 |
| SEEDS | 15000 | 15000 | 15000 | 15000 | 60000 |
| PLANTING | 120000 | 120000 | 120000 | 120000 | 480000 |
| WEEDING | 60000 | 60000 | 60000 | 60000 | 240000 |
| FERTILIZER | 142000 | 142000 | 142000 | 142000 | 568000 |
| FERTILIZER APPLICATION | 20000 | 20000 | 20000 | 20000 | 80000 |
| CHEMICALS | 15000 | 15000 | 15000 | 15000 | 60000 |
| CHEM APPLICATION | 10000 | 10000 | 10000 | 10000 | 40000 |
| CROP PROTECTION | 150000 | 150000 | 150000 | 150000 | 600000 |
| HARVESTING | 160000 | 160000 | 160000 | 160000 | 640000 |
| TRANSPORT | 70000 | 80000 | 100000 | 70000 | 320000 |
| STORAGE | 60000 | 69000 | 90000 | 60000 | 279000 |
| OTHER | 100000 | 100000 | 100000 | 100000 | 400000 |
| OPERATING COST | 1022000 | 1041000 | 1082000 | 1022000 | 4167000 |

In formulating the linear programming model, the decision variables are defined as follows:

$X_1 = Acres\ for\ Shingo\ ya\ mwali$

$X_2 = Acres\ for\ Faya$

$X_3 = Acres\ for\ Saro5$

$X_4 = Acres\ for\ Zambia$

The present study measured farm profitability in terms of farm gross margin; hence, the objective function of the LP model was used to maximise overall farm gross profit by selecting the optimal crop combination. The data from Table 2 is used to generate the following system of equations (LP model):

Objective function

$$\max Z = 1{,}794{,}000X_1 + 1{,}608{,}600X_2 + 2{,}182{,}000X_3 + 1{,}666{,}000X_4$$

Constraint 1 land constraints

$$X_1 + X_2 + X_3 + X_4 \leq 9$$

Constraint 2 land preparation budget

$$100{,}000X_1 + 100{,}000X_2 + 100{,}000X_3 + 100{,}000X_4 \leq 400{,}000$$

Constraint 3seeds cost

$$15{,}000X_1 + 15{,}000X_2 + 15{,}000X_3 + 15{,}000X_4 \leq 60{,}000$$

Constraint 4 planting cost

$$120{,}000X_1 + 120{,}000X_2 + 120{,}000X_3 + 120{,}000X_4 \leq 480{,}000$$

Constraint 5weeding cost

$$60{,}0000X_1 + 60{,}000X_2 + 60{,}000X_3 + 60{,}000X_4 \leq 240{,}000$$

Constraint 6 fertilizer budget

$$142{,}000X_1 + 142{,}000X_2 + 142{,}000X_3 + 142{,}000X_4 \leq 568{,}000$$

Constraint 7 fertilizer application labour cost

$$20{,}000X_1 + 20{,}000X_2 + 20{,}000X_3 + 20{,}000X_4 \leq 80{,}000$$

Constraint 8 insecticide cost

$$15{,}000X_1 + 15{,}000X_2 + 15{,}000X_3 + 15{,}000X_4 \leq 60{,}000$$

Constraint 9 insecticide application labour cost

$$10{,}000X_1 + 10{,}000X_2 + 10{,}000X_3 + 10{,}000X_4 \leq 40{,}000$$

Constraint 10 crop protection cost

$$150{,}000X_1 + 150{,}000X_2 + 150{,}000X_3 + 150{,}000X_4 \leq 600{,}000$$

Constraint 11 harvesting cost

$$160{,}000X_1 + 160{,}000X_2 + 160{,}000X_3 + 160{,}000X_4 \leq 640{,}000$$

Constraint 12 transportation cost

$$70{,}000X_1 + 80{,}000X_2 + 100{,}000X_3 + 70{,}000X_4 \leq 320{,}000$$

Constraint 13 storage cost

$$60{,}000X_1 + 69{,}000X_2 + 90{,}000X_3 + 60{,}000X_4 \leq 279{,}000$$

Constraint 14 miscellaneous cost

$$100{,}000X_1 + 100{,}000X_2 + 100{,}000X_3 + 100{,}000X_4 \leq 400{,}000$$

Constraint 14 total variable cost

$$1{,}022{,}000X_1 + 1{,}041{,}000X_2 + 1{,}082{,}000X_3 + 1{,}022{,}000X_4 \leq 4{,}167{,}000$$

Non negativity constraints

$$X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9 \geq 0$$

## 3.0 Results

Table 3 gives the analysis of the operating cost and gross profit per acre for each paddy varieties.

Table 3

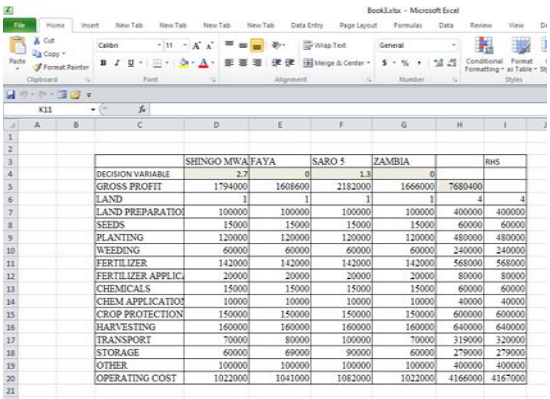
*Operating Cost and Gross Profit Per Acre*

| | SHINGO YA MWALI | FAYA | SARO 5 | ZAMBIA |
|---|---|---|---|---|
| GROSS PROFIT | 1794000 | 1608600 | 2182000 | 1666000 |
| LAND PREPARATION | 100000 | 100000 | 100000 | 100000 |
| SEEDS | 15000 | 15000 | 15000 | 15000 |
| PLANTING | 120000 | 120000 | 120000 | 120000 |
| WEEDING | 60000 | 60000 | 60000 | 60000 |
| FERTILIZER | 142000 | 142000 | 142000 | 142000 |
| FERTILIZER APPLICATION | 20000 | 20000 | 20000 | 20000 |
| CHEMICALS | 15000 | 15000 | 15000 | 15000 |
| CHEM APPLICATION | 10000 | 10000 | 10000 | 10000 |
| CROP PROTECTION | 150000 | 150000 | 150000 | 150000 |
| HARVESTING | 160000 | 160000 | 160000 | 160000 |
| TRANSPORT | 70000 | 80000 | 100000 | 70000 |
| STORAGE | 60000 | 69000 | 90000 | 60000 |
| OTHER | 100000 | 100000 | 100000 | 100000 |
| OPERATING COST | 1022000 | 1041000 | 1082000 | 1022000 |

From the Table (3) the costs of many items are similar for all paddy varieties except for transport cost and storage which depend on the yield.

Figure 1

*Microsoft Excel Solver Results*



| | SHINGO MWA | FAYA | SARO 5 | ZAMBIA | | RHS |
|---|---|---|---|---|---|---|
| DECISION VARIABLE | 2.7 | 0 | 1.3 | 0 | | |
| GROSS PROFIT | 1794000 | 1608600 | 2182000 | 1666000 | 7680400 | |
| LAND | 1 | 1 | 1 | 1 | 4 | 4 |
| LAND PREPARATIO | 100000 | 100000 | 100000 | 100000 | 400000 | 400000 |
| SEEDS | 15000 | 15000 | 15000 | 15000 | 60000 | 60000 |
| PLANTING | 120000 | 120000 | 120000 | 120000 | 480000 | 480000 |
| WEEDING | 60000 | 60000 | 60000 | 60000 | 240000 | 240000 |
| FERTILIZER | 142000 | 142000 | 142000 | 142000 | 568000 | 568000 |
| FERTILIZER APPLIC. | 20000 | 20000 | 20000 | 20000 | 80000 | 80000 |
| CHEMICALS | 15000 | 15000 | 15000 | 15000 | 60000 | 60000 |
| CHEM APPLICATIO | 10000 | 10000 | 10000 | 10000 | 40000 | 40000 |
| CROP PROTECTION | 150000 | 150000 | 150000 | 150000 | 600000 | 600000 |
| HARVESTING | 160000 | 160000 | 160000 | 160000 | 640000 | 640000 |
| TRANSPORT | 70000 | 80000 | 100000 | 70000 | 319000 | 320000 |
| STORAGE | 60000 | 69000 | 90000 | 60000 | 279000 | 279000 |
| OTHER | 100000 | 100000 | 100000 | 100000 | 400000 | 400000 |
| OPERATING COST | 1022000 | 1041000 | 1082000 | 1022000 | 4166000 | 4167000 |

The results from the linear programming solution obtained by the simplex method as presented in Figure (1) from Microsoft Excel Solver show that the farmer should allocate the 4 acres of land by growing 2.7 acres of paddy Shingo yamwali and 1.3 acres of paddy Saro 5. The farm can generate a gross profit of 7,680,400 shillings under the operating cost of 4,167,000 shillings.

Table 4
*Comparison of Traditional vs LP model*

| Method | Operating Cost (Tanzania shillings) | Gross Profit (Tanzania shillings) |
|---|---|---|
| Traditional | 4,167,000 | 7,250,600 |
| Linear Programming | 4,167,000 | 7,680,400 |

Table 4 presents a comparison of the operating cost and gross profit of the two approaches, LP and the traditional allocation. Using traditional methods based on experience and intuition, a farmer generates a profit of 7,250,600 shillings from the four acres of land by incurring an operating cost of 4,167,000 shillings. On the other hand, using an LP technique, from the same farm (4 acres) and the same operating cost of 4,167,000 shillings, the farm generates a profit of 7,680,400 shillings.

The gross profit obtained from the linear programming (LP) allocation was 7,680,400 shillings, while the gross profit from the traditional allocation was 7,250,600 shillings. The increase in profit was calculated as follows:

$$increase\ in\ profit = \frac{7{,}680{,}400 - 7{,}250{,}600}{7{,}250{,}600} \times 100 = 6\% \qquad (9)$$

## 4.0 Discussion

The results show that the gross profit obtained through the LP model is superior to that obtained through the traditional method by 6%. While this increase may appear modest, it is due to the fact that these paddy varieties have similar variable cost and profit contributions, that is why optimizing mix yields only small shifts—and thus modest gains.

However, the LP model still identifies a more economically efficient combination — favoring Shingo ya Mwali and Saro 5, which provide relatively higher returns when compared to Faya and Zambia. This suggests that farmers can maximize income by adopting an optimization approach rather than relying solely on intuition and experience.

These findings support the use of mathematical decision tools in agricultural planning, especially when working with limited resources.

## 5.0 Conclusion

In this study, the focus was on solving the problem of deciding how to select and allocate four paddy varieties in a farm of 4 acres so as to obtain the maximum profit faced by farmers in Pawaga, Iringa, Tanzania. An applied mathematical technique, belonging to a class of operational research called linear programming, was used and implemented in Microsoft Excel Solver. The results obtained from the formulated LP model were compared with those from the existing farming plan, which uses experience. It shows that using previous experience and intuition does not provide an optimal result. LP model results are always superior, as it can be seen that there is an increased gross profit of 6%.

## 6.0 Recommendations

Based on the results obtained from this study, it is recommended that the farmer should use the scientific method (LP) in selecting and allocating crops so as to achieve maximum profit. Farmers are encouraged to transition from experience-based decision-making to data-driven strategies for enhanced profitability.

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## 9.0 Declaration of Conflicting Interests

The authors declare no conflict of interest.

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