which could increase farmers' profits by 264%. The study recommends that government bodies and stakeholders provide more financial support and resources to help farmers in Balanga LGA adopt this optimal strategy. Farmers are advised to focus on growing beans and guinea corn in the recommended ratio for commercial purposes, while limiting the cultivation of other crops for personal use.

Key words: Optimality, farm yields, Balanga, Beans, Guinea corn, government visibility

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Introduction

Agriculture plays a vital role in both human sustenance and the economic development of nations. Besides providing food and raw materials, it generates direct and indirect employment for a large segment of the population. As noted by Varrella (2020), agriculture is a crucial sector in Nigeria's economy after oil, providing livelihoods to many, unlike oil wealth, which benefits only a small portion of the population. According to the Food and Agricultural Organization (FAO, 2021), agriculture contributed 22.35% to Nigeria's Gross Domestic Product (GDP) between January and March 2021, and in 2022, this figure rose to 23.69%. However, this is a significant drop compared to the 40% contribution reported by the National Bureau of Statistics (NBS) in 2012, as cited by Ibrahim, Oformata, Jirgi, and Adewumi (2019). While the percentage of agriculture's contribution to GDP has declined, the proportion of Nigerians involved in agriculture increased to 70% in early 2021, up from 60% in 2012 (FAO, 2021; NBS, 2012).

Despite its importance, Nigeria's agricultural sector faces numerous challenges that hinder productivity, including poor land tenure systems, low levels of irrigation, climate change, land degradation, limited access to inputs and financing, high post-harvest losses, and inadequate market access (FAO,

2021). This has resulted in declining food sufficiency and rising food imports, exacerbated by population growth. For instance, between 2016 and 2019, Nigeria's agricultural imports amounted to N3.35 trillion, more than four times the agricultural export value of N803 billion during the same period (FAO, 2019). Moreover, Varrella (2020) reported that between 2017 and 2019, around 9% of Nigerians experienced days without food due to financial constraints, while the Consumer Price Index (CPI) continues to rise.

Several government initiatives have been launched to address these issues, such as the Agriculture Promotion Policy (APP), Nigeria–Africa Trade and Investment Promotion Programme, Presidential Economic Diversification Initiative, and others aimed at increasing agricultural productivity and reversing environmental degradation (FAO, 2019). These efforts, along with policies like the 2019 ban on rice imports, are designed to boost food production, enhance food security, and promote sustainable land management.

With Nigeria's population projected to reach 400 million by 2050, the FAO (2019) emphasizes the need for increased agricultural productivity through the adoption of innovative techniques to ensure food security and nutrition. Collaboration between government, private stakeholders, and international partners will be essential in achieving these goals.

Operational research, particularly linear programming, is one method that has proven effective in agricultural management. Vico and Bodiroga (2017) note that linear programming is widely used to solve agro-management problems at various levels, including farm, regional, and national levels. In practical terms, farmers face challenges in resource allocation, crop selection, and water management, which impact decision-making and overall productivity. Bhatia and Bhat (2019) suggest that linear programming can optimize the use of farm resources such as labor, fertilizers, seeds, and capital to maximize returns. Specifically, farm planning based on linear programming can assist farmers in determining the best combination of crops and resource allocation for optimal productivity. For small-scale farmers, this approach can also enhance the sustainability of mixed cropping systems, which integrate livestock and crop cultivation (Bhatia & Bhat, 2019). Mellaku, Reynolds, and Woldeamanuel (2018) further recommend linear

programming-based land allocation strategies to improve smallholder farmers' profitability while promoting sustainable resource use.

Problem Statement/Justification

According to Nairaland (2018), Gombe State primarily produces rice and groundnut, which are examples of cereal and leguminous crops, respectively. Although agriculture dominates Gombe State's economy, a significant portion of the population also engages in trade and commerce. As noted by Yusuf, Abbas, Husain, and Mohammed (2017), while some residents work in the civil service, many combine their professions with arable farming. Their study in Gombe State revealed that the majority of respondents—232 (58%)—are arable farmers, followed by 72 (18%) traders, 60 (15%) civil servants, and 36 (9%) involved in other livelihoods, such as blacksmithing, traditional barbing, Islamic scholarship, tanning, water vending, and mat and cap making.

Despite the importance of agriculture, farmers in Gombe State face several challenges that affect productivity and income. Bakoji (2014) identified insufficient credit facilities, high input costs, pests and diseases, and reliance on manual labor as key constraints to farmers. He suggested that improved access to credit, timely provision of inputs, early pest control, labor-saving technologies, and better farm management practices could significantly enhance production outcomes.

Given these constraints, as well as various efforts to improve agricultural productivity in Nigeria and Gombe State, applying optimization techniques like linear programming for resource allocation is crucial for maximizing farm returns. The Gombe State Agricultural Development Programme (GSADP, 2023) reported that Balanga Local Government Area ranks sixth in cereal and leguminous crop production in the state and first in the Southern Senatorial Zone, highlighting the area's agricultural significance.

Objective(s) of the Study

The main objective of this study is to maximize the farmers' returns by allocating the resources available to them in Balanga Local Government Area of Gombe State optimally. The specific objectives are:

1. To establish the optimum crop production plan for a farmer in Balanga local government area of Gombe State.
2. To evaluate the profitability vis-à-vis the optimum solution for a farmer in Balanga local government area of Gombe State.
3. To examine the optimum land use vis-à-vis the optimum crop production plan for a farmer in Balanga local government area of Gombe State.
4. To uncover the optimum capital rationing plan for a farmer in Balanga local government area of Gombe State.
5. To find out if there is any difference in operating at optimum crop production plan and operating at existing production plan for a farmer in Balanga local government area of Gombe State.

Literature Review

Linear Programming (LP) has been defined in various ways by different scholars, including Bhatia and Bhat (2019), Sankheerth et al. (2010), Soumendra (2005), and Wiley (2002). According to Bhatia and Bhat (2019), LP is an optimization technique commonly used to allocate resources efficiently in order to enhance production. Soumendra (2005) described LP as a minimization problem, where the goal is to minimize a given linear function subject to one or more linear inequality constraints; the linear function is also referred to as the objective function. Sankheerth et al. (2010) defined LP as a mathematical modeling technique that helps allocate limited resources—such as labor, materials, time, and warehouse space—across various competing activities, such as products, services, jobs, or projects, based on a criterion of optimality. Similarly, Wiley (2002) defined LP as a model that seeks to either maximize or minimize a linear function, which is subject to a set of linear constraints, and involves key components: decision variables, an objective function, and constraints.

In essence, all these definitions highlight that LP involves optimizing a linear function by adjusting decision variables, which are subject to constraints, to achieve the objective of maximizing or minimizing the desired outcome.

A general linear programming problem involving “n” decision variables and “m” constraints can be mathematically modeled as outlined by Taha (1975), Zeleny

(1982), Winston (1995), and Higle and Wallace (2003), as cited in Khan et al. (2011, p. 207).

$$MAXIMIZE\,Z : C_1X_1 + C_2X_2 + ------ + C_nX_n$$

$$S.t$$

$$a_{11}X_1 + a_{12}X_2 + ---------- + a_{1n}X_n \le b_1$$

$$a_{21}X_1 + a_{22}X_2 + ---------- + a_{2n}X_n \le b_2$$

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$$a_{n1}X_1 + a_{n2}X_2 + ---------- + a_{mn}X_n \le b_m$$

$$X_1, X_2 ---------- X_n \ge 0$$

This can be written as,

$$Max\,Z = C^t x$$

$$S.t.,$$

$$a_x \le b$$

$$X \ge 0$$

Vico and Bodiroga (2017) identified several key objectives in the agricultural sector, which include: maximizing total production, maximizing revenue or income, minimizing costs, minimizing labor usage, reducing fertilizer and water consumption, and minimizing the total travel distance for transporting goods. Additionally, they highlighted several constraints commonly considered in maximization problems, such as available arable land, agro-technical requirements (e.g., crop rotation), available labor, agricultural machinery resources, barn or storage capacity, available capital, and market limitations. Vico and Bodiroga (2017) noted that linear programming is a widely used technique for addressing such challenges in both crop and livestock production.

Empirical Literature

Ibrahim, Oformata, Jirgi, and Adewumi (2019) conducted a study titled "Optimum Production Plan for Maize-Based Crop Farmers in Niger State, Nigeria." Utilizing a survey research design and descriptive statistics, they analyzed the data and used Excel Solver for calculating optimal solution quantities and conducting sensitivity analysis. Key findings included that the average age of the farmers was 37 years, with a mean household size of five and an average of 20 years of farming experience. The majority of the farmers (99.25%) were male, with only 0.75%

being female. Most of the respondents (90.98%) were married, while 8.27% were single. The findings also revealed that most farmers had some level of education, and the average farm size was 1.88 hectares. Off-farm income was estimated at ₦13,684.21 per year. While 21.80% of the farmers cultivated maize as a sole crop, 79.20% practiced mixed cropping, with the most common combinations being maize/sorghum (27.82%) and maize/groundnut (17.29%). The optimum cropping pattern suggested 1.1988 hectares for maize/soybeans and 0.0468 hectares for maize/cowpea. Labor and capital were identified as the binding constraints, with shadow prices of ₦1,076.90 and ₦2.75, respectively, while land, seed, fertilizer, and agrochemicals were surplus resources. The gross margin under the existing plan was ₦120,122.73, whereas the optimal plan yielded a gross margin of ₦211,555.70, reflecting a 76.12% increase in profitability.

Mellaku, Reynolds, and Woldeamanuel (2018) investigated the "Role of Linear Programming-Based Cropland Allocation to Enhance Performance of Smallholder Crop Production" in Abaro Kebele, Shashemene Zuria District, Ethiopia. Their findings indicated that conventional cropland allocation did not meet household consumption needs. Profitability under the current practice was significantly lower than the optimal levels estimated through linear programming. The study concluded that low crop production performance hindered households' efforts to engage in environmental and natural resource management.

In another study, Bakoji (2014) examined the "Economic Analysis of Maize/Cowpea Intercrops in Akko Local Government Area of Gombe State, Nigeria." Using regression analysis, the research found that 77.8% of maize/cowpea farmers were male, and 71.4% were aged between 31 and 50 years. Additionally, 87.3% were married, 54% had formal education, and most farmers had over 10 years of farming experience. The study also revealed that 65% of farmers relied on personal savings for capital, while the remainder obtained loans from family, friends, banks, and cooperatives. The net return per hectare was ₦20,605.09, with a total cost of ₦22,135.85 and total returns of ₦42,743.93 per hectare.

Oladokun and Johnson (2012) applied optimization techniques to Nigerian poultry farms and found that using a mathematical model for feed formulation resulted in a 9% cost savings compared to the existing method. Igwe et al. (2013) used linear programming to develop an optimal combination of crops and livestock enterprises, finding that optimized plans increased gross margins by 72.90%. This demonstrated that farm resources were not being optimally allocated under the existing plans.

Khan et al. (2011) applied linear programming and sensitivity analysis to determine optimal production planning for Ici Pakistan. They found that the company could increase its profit by Rs30,300 compared to the current operating level. The study identified that polyester, paints, and chemicals were binding constraints, while Soda Ash contributed the most to the company's objective function.

Agarana et al. (2014) explored the application of linear programming to optimize banks' loan portfolios, finding that reducing unsecured loans could help minimize bad debts. Similarly, Okoli et al. (2012) applied linear programming in production scheduling for plastic products, resulting in an optimal profit of ₦4,898,182.

Lastly, Wirnkar (2020) examined the product mix of foam manufacturing companies in Gombe State, Nigeria. The study revealed that these companies were not operating optimally, and applying an optimization model could increase weekly revenues by 817% and 922% for two separate companies.

Methodology

The study employed both survey and exploratory research designs. According to the Gombe State Agricultural Development Programme (GSADP) (2023), Balanga Local Government Area ranked sixth in cereal and leguminous crop production in Gombe State and was first in the Southern Senatorial Zone. The study population was considered infinite, comprising all farmers within Balanga Local Government Area. A multi-stage random sampling technique was applied to determine the sample size. In the first stage, all villages in the local government area were listed, and five villages were randomly selected. From each village, 30 respondents were chosen, resulting in a total sample size of 150 (5x30). Data were collected primarily through questionnaires. Construct validity was enhanced by conducting a pilot study.

Once the data were collected, it was cleaned to remove any outliers and then analyzed using both descriptive and inferential parametric statistics. Descriptive statistics such as percentages, frequencies, and mean values were employed. In addition, linear programming (optimality analysis) and sensitivity analysis (post-optimality analysis) techniques were used with Excel Solver to determine the optimal solution quantities, maximum profit, and the ranges of optimality and feasibility. The analysis also identified binding constraints, non-binding constraints, shadow prices, and slack (excess capacities in the constraints). Only cereal and leguminous crops grown in the selected local government area were considered, as these are the main crops cultivated during the rainy season (May-

September). For further analysis, see Appendix 2 for the definition and naming of variables.

The model for determining the optimal solution quantities is formulated as follows:

$$\text{Max. } Z = y_1X_1 + y_2X_2 + y_3X_3 + y_4X_4 + \ldots\ldots\ldots + y_nX_n$$

Subject to :

$$a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + \ldots + a_nx_n \leq A(\text{ resource A constraint})$$

$$b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \ldots + b_nx_n \leq B(\text{ resource B constraint})$$

$$c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + \ldots + c_nx_n \leq C(\text{ resource C constraint})$$

$$d_1x_1 + d_2x_2 + d_3x_3 + d_4x_4 + \ldots + d_nx_n \leq D(\text{ resource D constraint})$$

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$$z_1x_1 + z_2x_2 + z_3x_3 + z_4x_4 + \ldots + z_nx_n \leq Z(\text{ resource Z constraint})$$

$$x_1, x_2, x_3, x_4, \ldots\ldots\ldots, x_n \geq 0 \text{ (no negativity constraint)}$$

Where :

Z = maximum profit,

y_1 to y_n = gross profit margin per crop,

x_1 to x_n = units of crops that will be produced

a_1 to a_n = proportion of resource type A to be used in crop x_1 to x_n respectively

b_1 to b_n = proportion of resource type B to be used in crop x_1 to x_n respectively

c_1 to c_n = proportion of resource type C to be used in crop x_1 to x_n respectively

d_1 to d_n = proportion of resource type D to be used in crop x_1 to x_n respectively

z_1 to z_n = proportion of resource type Z to be used in crop x_1 to x_n respectively

Where; Maize=X_1, Beans= X_2, Soy beans=X_3, Groundnut =X_4, Wheat=X_5, Millet =X_6, Rice =X_7, Benny Seed=X_8, Barley=X_9, Bambara nut=X_{10}, Guinea corn=X_{11}. Additionally, the optimal solution quantities for the crop production plan were utilized to determine the optimal land-use ratio and capital rationing ratio within the respective constraint inequalities. The optimal crop production plan was then compared with the results from the existing practices in the studied cases. Following this, hypotheses were tested using the parametric inferential statistic of the paired samples t-test to assess the difference between means, as outlined by Chambers and Crawshaw (1990). These statistical analyses were conducted using Excel Solver and SPSS (version 22).

Research Hypothesis

HO: There is no significant difference between operating at optimum solution quantity X_i and operating at existing practice quantity X_i

The independent t-test for testing the difference between means (See Chambers and Crawshaw (1990:481) as cited in Wirnkar (2020) and stated below:

$$/Z/ = \frac{(x_1 - x_2) - (\mu_1 - \mu_2)}{\frac{\sqrt{\delta_1^2}}{n_1} + \frac{\sqrt{\delta_2^2}}{n_2}}$$

$Where / Z / =$ magnitude of mean difference between :

(1) Optimum product mix quantity X_i *and existing practicequantity* X_i

$X_1 = mean\ or\ average of$:

(2) $Optimum\ product - mix\ quantity\ X_i$

$X_2 = mean\ or\ average of$:

(3) $Existing\ practicequantity\ X_i$

$\mu_1 = \mu_2 = mean\ of\ population (number\ of\ farmers)$

$\partial_1^{\ 2} = Variance of$:

(1) $Optimumproduct - mix\ quantity\ X_i$

$\partial_2^{\ 2} = Variance of$:

(2) $Existing\ practicequantity\ X_i$

$n_1 = numerical\ number\ of$;

(1) $Optimum\ product - mix\ quantity\ X_i$

$n_2 = numerical\ practice\ quantity$

(2) $Existing\ practicequantity\ X_i$

Table 1: Results

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Existing Solution - Optimum Solution	3.63636	3.00908	0.90727	1.61484	5.65789	4.008	10	0.002

Decision rule: The null hypothesis is accepted if the absolute value of Z or t falls within the range of -1.96 to +1.96 (i.e., |Z| or |t| < 1.96) at the 5% significance level. Otherwise, the alternative hypothesis is accepted. Alternatively, the null hypothesis

is rejected if the p-value is less than 5%. A two-tailed test was employed for this analysis.

The optimal solution indicates that a total of 315 mudus of beans and 81 mudus of guinea corn should be produced, reflecting a ratio of 8:2 (refer to Appendix 2). This suggests that a farmer in Balanga Local Government Area should allocate their land or capital in the same 8:2 ratio to focus on the commercial production of beans and guinea corn, while reserving a smaller portion of their resources for other crops.

Change in profit

Profit from optimum solution: N2800 (315) +N2244 (81) =N 1067004

Profit from existing solution: N 1875(156) = N293018

Percentage change in profit ((N1067004- N293018)/ N293018)*100 = 264%

(See, appendix 1 and 2)

Findings and Discussion of Findings

The initial findings reveal that a significant proportion of farmers (53%) fall within the age range of 31-50 years. Additionally, 73% of the farmers are male, 71% are married, and 50% have completed secondary education. Notably, 38% of the farmers have over six years of farming experience, while 69% report an annual farm income exceeding N400,000. Furthermore, maize production is the primary focus for 60% of the farmers, with a remarkable 88% funding their farming activities through personal savings. However, 68% also receive assistance in the form of fertilizers.

Hypothesis testing indicates that these farmers are not achieving optimal production, as there is a statistically significant difference in the means between the current production levels and the optimal solutions determined through paired samples t-test analysis. The optimal solution identified beans and guinea corn in an 8:2 ratio, suggesting that farmers could boost their profits by 264% (as detailed in previous calculations) by adjusting their production to this ratio. These noteworthy results align with the findings of Ibrahim, Oformata, Jirgi, and Adewumi (2019), Oladokun and Johnson (2012), and Igwe et al. (2013).

Recommendations

The study recommends that government entities at the federal, state, and local levels, along with other stakeholders, increase their visibility and support for farmers by providing financial assistance and enhancing farm infrastructure. It is particularly crucial for farmers in Balanga local government area to focus on cultivating beans and guinea corn in an 8:2 ratio for commercial purposes, while minimizing the production of other crops primarily for personal consumption.

Future Research Gap

Further studies should be carried out in each local government area of Gombe State. Such research will facilitate the optimal use of agricultural resources and enhance farm productivity and income levels.

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