

**APPLICATION OF LINEAR PROGRAMMING AND SENSITIVITY ANALYSIS FOR OPTIMAL CROP PRODUCTION: A STUDY OF SELECTED LOCAL GOVERNMENT AREAS OF GOMBE STATE**

**Habib Abdulkarim, PhD**

Department of Accounting,

Gombe State University, Gombe State.

Email: [habib.abdulkarim@gsu.edu.ng](mailto:habib.abdulkarim@gsu.edu.ng), Tel. No. +2348034727360

**Alphonsius D. Wirnkar, PhD**

Department of Accounting,

Gombe State University, Gombe.

Email: [wadphorse26@gmail.com](mailto:wadphorse26@gmail.com).

**Murtala Sirajo, PhD**

Department of Accounting,

Gombe State University, Gombe State.

**Ahmed Sabo**

Department of Accounting,

Gombe State University, Gombe State.

**Oteikwu A. Michael**

Department of Economics,

Gombe State University, Gombe State.

**Abstract**

*Statistics show that despite the continuous growth in the population of Nigeria and the percentage of the population that engage in agriculture, the contribution of agriculture to the Gross Domestic Product (GDP) has declined continuously. The survey and exploratory research designs were used. Descriptive and inferential statistics were the techniques of data analysis. Application software employed were the excel-solver and SPSS. For the Akko LGA, the results showed the optimal crop mix of benny seed and bambara nut in a 6:4 ratio (153 to 109 mudus) and that adopting this strategy could boost a farmer's profit by 16.4%. The study recommended that a farmer in Akko LGA of Gombe State should focus on cultivating benny seed and bambara nut for commercial purposes while growing other crops minimally for personal use. For the Balanga LGA, the optimal crop mix identified was an 8:2 ratio of beans to guinea corn (315 mudus of beans to 81 mudus of guinea corn), which could increase the farmer's profit by 264%. The study thus recommended that a farmer in Balanga LGA focus on growing beans and guinea corn in the recommended ratio for commercial purposes, while limiting the cultivation of other crops for personal use. The study also emphasized the need for increased support from government and other stakeholders to provide financial aid and resources to these farmers.*

**Keywords:** Optimality, Farm yields, Gombe, Akko, Balanga, Local Government Areas

**1. Introduction**

Agriculture plays a crucial role in sustaining human life and driving national economies. Beyond providing food and raw materials, it serves as a major source of employment, directly or indirectly supporting a vast percentage of the global population. According to the World Bank (2020), agriculture is instrumental in reducing poverty, raising incomes, and enhancing

food security for 80% of the world's poor, who primarily reside in rural areas and engage in farming. However, a 2020 report by the World Bank highlighted that approximately 690 million people—8.9% of the global population—suffer from hunger, marking an increase of 60 million in just five years.

In Nigeria, agriculture remains a vital sector, second only to oil in economic significance (Varrella, 2020). While oil revenue benefits a limited portion of the population, agriculture provides livelihoods for millions. The Food and Agriculture Organization (FAO, 2021) reported that between January and March 2021, agriculture contributed 22.35% to Nigeria's Gross Domestic Product (GDP). This represents a decline from the 40% reported by the Nigerian Board of Statistics (NBS, 2012), as cited by Ibrahim et al. (2019). Despite this drop, agricultural participation has increased, with FAO (2021) estimating that 70% of Nigerians were engaged in farming during the same period, up from 60% in 2012 (NBS, 2012; Ibrahim et al., 2019).

Despite its contributions, Nigeria's agricultural sector faces numerous challenges, including inefficient land tenure systems, low irrigation levels, climate change, land degradation, inadequate input distribution, limited financing, high post-harvest losses, and poor market access (FAO, 2021). The sector's declining GDP contribution and increasing food imports indicate decreasing food self-sufficiency (FAO, 2019). Between 2016 and 2019, Nigeria's agricultural imports totaled N3.35 trillion, quadrupling its agricultural exports of N803 billion in the same period. Additionally, Varrella (2020) reported that between 2017 and 2019, approximately 9% of Nigerians experienced entire days without food due to financial constraints, while consumer prices continued to rise.

To address these challenges, the Nigerian government has implemented several agricultural initiatives (FAO, 2019), including the Agriculture Promotion Policy (APP), the Nigeria-Africa Trade and Investment Promotion Programme, the Presidential Economic Diversification Initiative, and the Zero Reject Initiative. Other programs, such as Reducing Emission from Deforestation and Forest Degradation (REDD+), the Nigeria Erosion and Watershed Management Project (NEWMAP), and the Action Against Desertification (AAD) Programme, aim to promote sustainable resource management. A notable policy intervention was the 2019 ban on rice imports, designed to encourage local production.

With Nigeria's population projected to reach 400 million by 2050, enhancing agricultural productivity through modern techniques and innovations is crucial to ensuring food security (FAO, 2019). Effective collaboration among government bodies, private sector stakeholders, and international organizations is necessary to achieve this goal.

Operations research, particularly linear programming (LP), provides valuable quantitative methods for addressing agricultural management challenges (Vico & Bodirola, 2017). LP is widely applied in agriculture at farm, regional, and national levels to optimize decision-making in farm planning, resource allocation, and production efficiency. Bhatia & Bhat (2019) emphasized that LP helps farmers determine optimal cropping patterns, manage scarce resources, and maximize returns. It is particularly beneficial for small-scale farmers practicing mixed cropping, which integrates both crop cultivation and livestock rearing.

Mellaku et al. (2018) advocate for LP-based cropland allocation as a means to enhance smallholder farmers' profitability, meet household food needs, and ensure sustainable land use. In Gombe State, where rice and groundnut are the primary crops (Nairaland, 2018),

many farmers face financial constraints, high input costs, pest infestations, and labor-intensive farming practices (Bakoji, 2014). Research has shown that LP models can effectively address these challenges by optimizing resource allocation and improving productivity (Ibrahim et al., 2019).

Yusuf et al. (2017) found that the majority of Gombe State residents engage in arable farming (58%), followed by trading (18%) and civil service (15%), with the remaining 9% involved in various other livelihoods. Despite agriculture's significance, farmers continue to face barriers such as limited access to credit, high production costs, and manual farming methods. Bakoji (2014) recommended expanding credit access, reducing input costs, adopting labor-saving technologies, and implementing effective pest control measures to enhance agricultural productivity.

Given these challenges, the application of LP to optimize resource allocation in Gombe State is both timely and essential. This study aims to maximize farmers' returns by employing LP techniques to determine the most efficient use of available resources across selected local government areas. The findings will provide valuable insights for policymakers and stakeholders in improving agricultural productivity and sustainability in Nigeria.

## **2. Literature Review**

### **2.1 Conceptual Review**

A number of people have defined Linear Programming (LP) in a number of ways and among them are: Bhatia & Bhat (2019), Sankheerth, et al (2010), Soumendra (2005), and Wiley (2002). Bhatia & Bhat (2019) defined LP as an optimization technique which is widely used to allocate resources optimally in order to increase the production. Soumendra (2005) defined LP as a minimization problem where we are asked to minimize a given linear function subject to one or more linear inequality constraints and that the linear function is also called the objective function. Sankheerth, et al (2010) defined LP as a mathematical modeling technique useful for the allocation of scarce or limited resources such as labour, material, time, warehouse space, et cetera, to several competing activities such as product, service, job, new equipment, projects, etc...on the basis of a given criteria of optimality. Wiley (2002) defined LP as a model that seeks to maximize or minimize a linear function, which is subject to a set of linear constraints; a model consisting of the following components: a set of decision variables, an objective function and a set of constraints. All of these definitions convey that LP is a linear function with decision variables to optimize, which are subject to a set of constraints such that by optimizing these decision variables, the objective to be attained could be maximized or minimized as the case may be.

Among the most dominant objectives in agricultural domain, Vico & Bodioga (2017) listed the followings: Maximize total production; Maximize revenue/income; Minimize cost; Minimize labour force use; Minimize fertilizer usage; Minimize water usage; and Minimize total travelling distance of truck. Moreover, a sample of maximization constraints according to Vico & Bodioga (2017) include the followings: Available arable agricultural land; Agro technical constraints (e.g. crop – rotation); Available labour force; Available agricultural mechanization resource; Limitation of the barn/ stable capacity; Available capital and Market constraints. According to Vico & Bodioga (2017), linear programming is a very frequently used technique in solving the types of problems in the crop production and livestock production.

### **2.2 Empirical Review**

Gbedevi et al. (2024) applied Mixed Integer Programming (MILP) model to study “The effect of planning horizon length and green manure on net income in crop rotation problems

and the results showed that farmer's income improve when a longer planning period was considered.

Siagian et al. (2023) studied "Optimization model of maize production in various land use in Banten province", Jakarta, Indonesia. Using ratio analysis and linear programming, among other findings, the study found improved productivity of maize using the optimization technique for the upland area.

Ibrahim et al. (2019) examined "Optimum Production Plan for Maize Based Crop Farmers in Niger State, Nigeria." The researchers adopted a survey research design and descriptive statistics to carry out the study. Among the software used, is the Excel Solver for the optimum solution quantities and sensitivity analysis report. Among other findings, the results show that: the mean age of the respondents (farmers) was 37 years; the mean household size was 5; an average farming experience of 20 years; majority of farmers 99.25% were male and 0.75% were female; 90.98% of the farmers were married while 8.27% were single; the majority of those involved in farming were educated; the mean farm size in the area was found to be 1.88 hectares; the average annual off-farm income of the farmers was estimated to be 13,684.21; 21.80% cultivated maize as a sole crop while the remaining 79.20% of the respondents cultivated maize as mixtures with other crops; the crops cultivated as mixtures in the study area comprised cereal and legumes which include maize/rice, maize/sorghum, maize/millet, maize/soybeans, maize/groundnut, maize/bambaranut and maize/cowpea respectively; maize/sorghum (27.82%) and maize/groundnut (17.29%) were the most cultivated while maize/bambaranut was the least cultivated; the optimum cropping pattern prescribed 1.1988 ha for maize/soybeans and 0.0468 ha for maize/cowpea; for shadow prices, maize/rice N73,955.35, maize N67,927.62, maize/bambaranut N25,319.16; the binding constraints were labour and capital with shadow prices of N1,076.90 and N2.75 respectively; the surplus resources were land, seed, fertilizer and agrochemical; the gross margin in the existing plan was N120,122.73 while in the optimum plan it was N211,555.70, that is, a 76.12% increase in the optimum solution plan as compared to the existing solution plan.

Mellaku et al. (2018) examined "Role of Linear Programming Based Cropland Allocation to Enhance Performance of Smallholder Crop Production : A Pilot Study on Abaro Kebele, Shashemene Zuria District, West Arsi Zone, Oromiya Regional State, Ethiopia". The survey research method was adopted and among other findings were that: in the current conventional cropland allocation, households were not able to meet their household consumption; the average profitability of farms under current practice was found to be significantly below the estimated optimal level of profit that could have been realized using linear programming; in addition, it was uncovered that low performance of crop production (in terms of meeting household consumption demand and profitability) was the primary cause that limited the effort of households to participate in environmental and natural resource management.

Bakoja (2014) examined "Economic Analysis of Maize/Cowpea Intercrops in Akko Local Government Area of Gombe State in Nigeria". Using survey research design, descriptive and inferential statistics of regression analysis found that: 77.8% of maize/cowpea farmers were male, while 22.2% were female; 71.4% of the sampled farmers fall within the age group of 31-50 years; 87.3% were married; 54% had formal education, 36% had Quranic education with only a small percentage of 3.17% that have never been to school; 71.4% had more than 10 years of farming experience; 65% obtained capital based on personal savings, while 35% from family and friends, agricultural banks, cooperatives and local money lenders respectively; majority of sampled maize-cowpea farmers had less than or equal to 5 hectares of farmland; 55.56% of maize/cowpea farmers had family size of between 1-10 person per household while 39.68% and 4.76% had 11-20 and 21-30 persons per household respectively; cost of fertilizer had the highest proportion with 47.63% of the total variable cost while

transportation had the lowest proportion of 0.20%; the total cost-per hectare (TC) was found to be N22,135.85 and the total returns per hectare (TR) was N42,743.93; the net return per hectare was estimated to be N20605.09; the return per naira was N0.93 for every N1 invested; the gross margin was 0.51; the  $R^2$  for the regression model was 53%; age, seeds, and fertilizer were significant at 5%; farm size, household size, hired labour, herbicide, repair tools and transportation were not significant but had appositve coefficients; educational level, family labor, and use of insecticides had an inverse or negative relationship between the revenue and production components; problems associated with maize/cowpea farmer in decreasing order of importance are: over reliance on household resources, lack of capital to purchase production inputs and hired labour with lack of capital first at 65%, high cost of input second at 50%, poor marketing outlet at 33.3%, storage facilities at 31.7% and pest and diseases at 26.9% respectively.

Oladokun & Johnson (2012) applied mathematical optimization techniques to the feed formulation problem of the typical Nigerian poultry farm using locally available feed ingredients and found that the weekly cost of producing layers feed is N47974 using the existing practice of the farm compared with the N43798 if feed formulation were based on the proposed mathematical model and that this is a substantial savings of about 9%.

Igwe et al. (2013) applied linear programming approach to combination of crops, Monogastric Farm Animal and Fish Enterprises in Ohafia Agricultural Zone, Abia State, Nigeria and prescribed 0.29 hectares for yam, 0.02 hectares for cassava and 0.13 hectares for cassava/maize/cocoyam for crop enterprises while 0.14 for 500 birds (70 birds) broiler II done August –December, 0.22 of 1000 fish (220 fish) of fish I done January – June and 0.41 of 500 birds (205) of Layer for the livestock enterprises in the study area to maximize gross margin. The results indicate that optimum plans resulted in an increase in gross margin over the existing plan by 72.90%. This implies that farm resources were not optimally allocated in the existing plan.

Khan et al (2011) used linear programming and sensitivity analysis to determine the optimal production planning for Ici Pakistan and found the followings; that the company can generate a profit of R.s 3273786300, an amount R.s 30,300 greater than the presently operating profit. That the cost of goods sold, quantity sold of polyester, paints and chemicals were binding constraints and they were consumed fully whereas all the other constraints were non-binding and were available for the future production runs. That among the four different products manufactured at the company taken into consideration, the analysis predicted that the production of Soda Ash is contributing more than other products to the objective function. Also determined were the lower and upper limits of the variables in which the solution is optimal.

According to Agarana et al (2014), an effective way of evaluating bank's credit policies for bad debt is through the linear programming approach. Moreover, Agarana et al (2014) applied linear programming technique to find an optimal way of managing the loan portfolio of banks in order to maximize profit and found that in order to reduce the risk of bad debt incidence to the barest minimum, the banks should reduce the percentage of the unsecured loans since that will not significantly affect the achievement of their aims and objectives.

Okoli et al (2012) applied linear programming technique in production planning and scheduling of five parts of two particular plastic products on three different machines and found the optimum profit of N4,898,182, the optimum production plan as follows; Ice cream

body 203,636 pieces, Paint bucket body 120,000 pieces, Paint bucket handle 120,000 pieces, Paint bucket cover 120,000 pieces, the Ice cream cover 203,636 pieces and that all parts that make up the Paint bucket should be produced only during the night shifts while those of Ice cream container should be produced only during the day.

Wirnkar (2020) applied linear programming to determine the optimum product mix of foams manufacturing companies in Gombe, Nigeria and among other findings, foams manufacturing companies in Gombe State do not use an optimization model in product mix planning; foams manufacturing companies in Gombe State are not operating optimally although the optimum solution quantities and the existing solution quantities showed a correlation of 0.741 and a t-value of -0.751 signifying no significant difference in the mean values of operating at optimum solution level and operating at the existing solution level; We also found an 817% increase in the weekly revenue for company A given an optimum solution while for company B, it was a 922% increase in the weekly revenue.

### **2.3 Theoretical Framework**

The theoretical foundation of this study is rooted in optimization theory and agricultural economics, where LP serves as a decision-support tool for improving farm productivity and economic returns. Given the increasing challenges faced by farmers in Gombe State, this study aims to apply LP and sensitivity analysis to optimize resource allocation, maximize crop production, and improve farmers' livelihoods. The findings will contribute to existing literature by demonstrating the practical application of LP in addressing real-world agricultural problems and providing empirical evidence for policy recommendations in Nigeria's agricultural sector.

### **3. Method**

The study employed both survey and exploratory research designs. Two senatorial zones (Gombe North and Gombe South) were selected in this study hoping to consider Gombe Centre in the future. According to the Gombe State Agricultural Development Programme (GSADP) (2023), Akko Local Government Area (LGA) holds the top position for cereal and leguminous crop production in Gombe State. For this reason, Akko LGA was chosen from the Gombe North senatorial zone. The GSADP (2023) also ranked Balanga LGA sixth in cereal and leguminous crop production in Gombe State and was first in the Southern Senatorial Zone. For this reason, the Balanga LGA was chosen from the Gombe South senatorial zone. The population of the study for each LGA was considered infinite, comprising all farmers within the LGA. A multi-stage random sampling technique was applied to determine the sample size. In the first stage, all villages in each LGA 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 for each LGA.

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 areas were considered,

as these are the main crops cultivated during the rainy season (May-September). The model for determining the optimal solution quantities is formulated as follows:

**Variables and their Measurements**

Where; Maize= $X_1$ =number of mudus of Maize, Beans= $X_2$ =number of mudus of Beans, Soy beans= $X_3$ =number of mudus of Soy beans, Groundnut = $X_4$ =number of mudus of Groundnut, Wheat= $X_5$  = number of mudus of Wheat, Millet = $X_6$ = number of mudus of Millet, Rice = $X_7$  = number of mudus of Rice, Benny Seed= $X_8$  =number of mudus of Benny Seed, Barley= $X_9$  =number of mudus of Barley, Bambara nut= $X_{10}$  = number of mudus of Bambara nut and Guinea corn= $X_{11}$ = number of mudus of Guinea corn.

**Model Specifications**

Max.  $Z = Y_1X_1 + Y_2X_2 + Y_3X_3 + Y_4X_4 + \dots + Y_nX_n$

Subject to:

$a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + \dots + a_nX_n \leq A$  ( Resource A Constraint)

$b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + \dots + b_nX_n \leq B$  ( Resource B Constraint)

$c_1X_1 + c_2X_2 + c_3X_3 + c_4X_4 + \dots + c_nX_n \leq C$  ( Resource C Constraint)

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$z_1X_1 + z_2X_2 + z_3X_3 + z_4X_4 + \dots + z_nX_n \leq Z$  ( Resource Z Constraint)

$X_1, X_2, X_3, \dots, X_n \geq 0$  ( non negativity Constraint)

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 study cases. Following this, hypotheses were tested using the parametric inferential statistics of the paired samples t-test to assess the difference between means, as outlined in Chambers & Crawshaw (1990). These statistical analyses were conducted using Excel Solver and SPSS (version 22).

**Research Hypotheses**

H0: 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 (Chambers & Crawshaw, 1990, p.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 practice quantity  $X_i$

$X_1$  = mean or average of :

(2) Optimum product – mix quantity  $X_i$

$X_2$  = mean or average of :

(3) Existing practice quantity  $X_i$

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

$\partial_1^2$  = Variance of :

(1) Optimum product – mix quantity  $X_i$

$\partial_2^2$  = Variance of :

(2) Existing practice quantity  $X_i$

$n_1$  = numerical number of ;

(1) Optimum product – mix quantity  $X_i$

$n_2$  = numerical practice quantity

(2) Existing practice quantity  $X_i$

**4. Results**

**Table 1: Results for Akko LGA**

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	3.54545	3.41654	1.03012	1.25019	5.84072	3.442	10	.006

Source: Researchers computation

The result is positive and significant and suggests producing 153 mudus of benny seed and 109 mudus of bambaranut, resulting in a ratio of 6 to 4. This means that a farmer in Akko Local Government Area should allocate their land or capital in a 6 to 4 ratio for the production of benny seed and bambaranut for commercial purposes while designating limited resources to other crops.

**Change in profit for Akko LGA**

Profit from optimum solution: N1426 (153.3) +N1204 (109.9) =N350497.6

Profit from existing solution: N882.4\*341.7 = N301527.5

Percentage change in profit ((N350497.6- N301527.5)/ N301527.5)\*100 = 16.4% increase

**Results and Discussion of Findings for Akko LGA**

The preliminary findings indicate that a significant portion of farmers (52%) fall within the age group of under 30 years, with 81% being male and 80% married. Additionally, 49% have completed secondary education, while 37% have been engaged in farming for six years or less. Furthermore, 30% report an annual farm income ranging from N1 to N100, 000. A large majority (89%) is involved in maize production, and 84% of farmers finance their agricultural activities through personal savings, although 51% also receive assistance from some individuals in the form of fertilizers. Results from our hypothesis testing reveal that these farmers are not operating at optimal production levels, as there is a significant difference between the means of existing solution values and optimal solution values, determined using paired samples t-test statistics. The two crops identified in the optimal solution are benny seed and bambaranut, with a recommended production ratio of 6 to 4. By adhering to this ratio, farmers could potentially increase their profits by 98% (as demonstrated in previous calculations). These significant findings align with the results of studies conducted by Ibrahim et al. (2019), Oladokun & Johnson (2012), and Igwe et al. (2013).

**Conclusion and Recommendations for Akko LGA**

The research concludes that a farmer in Akko local government area would maximize farm income by producing the combination of the crops in the optimum solution and dividing his/her capital and land in the prescribed ratio. The study recommends that government entities at the federal, state, and local levels, along with other stakeholders, enhance their support for farmers by providing improved access to financing and agricultural resources. Specifically, farmers in Akko local government area are encouraged to prioritize the production of benny seed and bambaranut in a 6 to 4 ratio for commercial purposes, while cultivating other crops primarily for personal consumption.

**Table 2: Results for Balanga LGA**

Paired Samples Test	
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		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	.90727	1.61484	5.65789	4.008	10	.002

Source: Researchers computation

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. 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 for Balanga LGA**

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

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

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

**Results and Discussion of Findings for Balanga LGA**

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 et al. (2019), Oladokun & Johnson (2012), and Igwe et al. (2013).

**Conclusion for Balanga LGA**

The research concludes that a farmer in Balanga local government area would maximize farm income by producing the combination of the crops in the optimum solution and dividing his/her capital and land in the prescribed ratio. Specifically, farmers in Balanga local government area are advised to prioritize the production of beans and guinea corn in the 8:2 ratios, for commercial purposes as this would boost profit, while cultivating other crops primarily for personal consumption.

**Future Research Gap**

Further studies may 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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