Vol. 6 No. 1, June, 2026

FUAM Journal of Pure and Applied Science

Available online at
www.fuamjpas.org.ng

An official Publication of
College of Science
Joseph Sarwuan Tarka University,
Makurdi.

FUAM Journal of Pure and Applied Science

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Vol.6 No. 1 June, 2026

A Study on the Effect of Different Fertilizer Application on Yield of Some Selected Crops: Hierarchical Three-Stage Nested Design Approach

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Received: 29/07/2025 **Accepted**: 27/09/2025 **Published online**: 28/09/2025

Abstract

Due to the growing human population, there is a high demand for food and other agricultural products. As a result of this demand, soil nutrients are depleted after every planting season, hence the need for fertilizer, which plays a crucial role in providing crops with the necessary nutrients to replenish the soil. Analysis of variance (ANOVA) technique of hierarchical three-stage nested design was applied to data collated on the yield of some selected crops from three different farms with two different fertilizer applications and the third farm without fertilizer application to determine the fertilizer type that gives the best yield. The study was carried out at the research farm of the Agronomy department of Joseph Sarwuan Tarka University, Makurdi, from May 2018 to August, during the 2018 farming season. Analysis of variance showed that there is a significant effect of blocks on crop yield and there are significant differences between the mean yield of varieties from the same crops of different varieties from the various farm areas. Thus, organic based fertilizer should be encouraged as it is a natural fertilizer that is beneficial to crop production, containing organic matter that improve soil structure and preserve essential nutrients that crops need in order to grow, as well as restore soil fertility and balancing the P_H (potential of hydrogen) value of the soil. The software for analysis was Mini-tab

Keywords: Fertilizer**,** Nested designs, Hierarchical design, Experimental design, Design and Analysis of variance

Introduction

Fertilizer type plays a significant role in influencing plant growth, which can be measured in terms of height or biomass. There are primarily four common types of fertilizers: organic, synthetic, slow-release, and liquid fertilizers, each with its distinct impact on plant growth. Organic fertilizers, derived from natural materials like compost, animal manure, or plant residues, contribute to plant growth by improving soil structure and nutrient content. They release nutrients slowly, promoting long-term growth, and enhance microbial activity in the soil [1].

Synthetic fertilizers are chemically manufactured and provide nutrients to crops. They can lead to rapid growth in height and biomass due to their immediate nutrient supply. Overreliance on synthetic fertilizers may lead to soil degradation and environmental issues [2]. Slow-release fertilizers release nutrients gradually over time, ensuring a steady supply for crops. This type of fertilizer contributes to sustained crop growth and minimizes the risk of nutrient leaching. Liquid fertilizers, which are dissolved in water and applied through irrigation systems, offer a quick nutrient uptake by plants and enhance height and biomass, when applied in a well-timed manner [3].

[5] Crop growth estimated in height or biomass, is a crucial indicator of agricultural productivity and environmental health. In developed economies like the United States, there has been a noticeable trend of increasing plant biomass over the past decade. [4], the average biomass of crops in the USA increased by 12% from 2010 to 2020, basically due to advancements in agricultural technology, such as improved crop varieties and precision farming techniques. This trend signifies the ability of developed economies to enhance agricultural efficiency and meet the rising demands for food and bioenergy while minimizing environmental impacts [5].

[6] reported an average increase of 7% in tree height across Japanese forests over the past decade. This increase in biomass is related to afforestation efforts, reforestation policies, and sustainable forestry practices. Developed economies like Japan are increasingly recognizing the importance of maintaining and enhancing forest ecosystems for carbon sequestration, biodiversity conservation, and overall environmental sustainability. In developing economies, the trends in plant growth can vary significantly depending on local factors.

[7] Kenya have witnessed substantial growth in crop biomass due to improved irrigation methods and better crop management approach. However, this region also faces challenges such as land degradation and climate change, which can hinder plant growth in some areas. [8] reported a gradual increase in crop biomass in India over

the past decade, mainly attributed to the adoption of modern farming methods, increased use of fertilizers, and expansion of irrigated land.

[9] revealed the decline in biomass in certain regions of Nigeria due to unsustainable logging practices and agricultural expansion. However, there have been initiatives to combat deforestation and promote sustainable land management to reverse these negative trends. [10] showed positive trends in crop biomass, especially for maize and wheat, owing to the implementation of improved farming practices, better access to inputs, and the expansion of irrigation systems. In the Democratic Republic of Congo (DRC), for instance, deforestation due to logging and agricultural expansion has led to the loss of forest biomass. [11] revealed the need for sustainable land management practices to address this issue and mitigate the negative impact on plant growth and forest ecosystems in the DRC.

[12] highlighted the positive trend in plant biomass in newly established woodlands in the UK over the last decade. These efforts are in line with the country's commitment to increase forest cover and mitigate climate change impacts through carbon sequestration in trees. Germany, a developed economy with a strong emphasis on sustainable practices, has witnessed an increase in plant biomass in agricultural fields. [13] reported that improved soil management and organic farming practices have contributed to higher plant biomass in German farmlands. These trends signify the importance of environmentally friendly agriculture in developed nations.

[14] afforestation and reforestation programs have increased forest biomass in certain regions, intensive agriculture and urbanization have led to the loss of vegetation cover in others. The balance between these factors has significant implications for China's ecosystem health and carbon sequestration capacity. Brazil, as one of the largest developing economies, faces complex plant growth dynamics.

[15] revealed the impact of deforestation and land-use change on plant biomass in the Amazon rainforest. The findings underscore the importance of sustainable land management practices and conservation efforts in balancing economic development with environmental preservation in developing nations.

[16] showed an increase in plant growth in selected regions of Kenya, highlighting the potential for agricultural development in certain parts of the continent. On the other hand, Niger, a landlocked country in Sub-Saharan Africa, has faced challenges related to land degradation and desertification, impacting plant growth. [17] emphasized the importance of sustainable land management practices to address these issues and enhance plant growth in arid regions.

Nested design is a class of experimental design in which every level of a given factor appears with only a single level of any other factor. The levels of one factor (say, Factor B) are hierarchically subsumed under (or nested within) levels of another factor (say, Factor A). As a result, assessing the complete combination of A and B levels is not a nested design. Every level of a given factor appears with only a single level of any other factor. Factors which are not nested are said to be crossed. If every level of one appears with every level of the others, the factors are said to be completely crossed [18]. The aim of this study is to examine the effect of different fertilizer application on yield of some selected crops using hierarchical three-stage nested design.

Methods

[19] the model for the general three-stage nested design is given as:

$$Y_{ijkl} = \mu + \tau_i + \beta_{j(i)} + \gamma_{\kappa(ij)} + \varepsilon_{(ijk)} \quad (1)$$

where i= 1,2, 3, … a, j = 1,2, 3…, b, k=1,2, 3…, c

Where, $\boldsymbol{\tau_i}$ is the effect of the i^{th}fertilizer farm formations, $\boldsymbol{\beta_{j(i)}}$ is the effect of the j^{th}block section nested within the i^{th} fertilizer farm formations, $\boldsymbol{\gamma_{k(ij)}}$ is the effect of the k^{th} variety of crops nested within j^{th}block section and $\boldsymbol{i^{th}}$fertilizer farm formation and the $\varepsilon_{(ijk)}$is the usual NID $(0, \delta^2)$ error term. The total sums of squares are decomposed as follows

$$SS_{TOTAL} = SS_A + SS_{B(A)} + SS_{C[B(A)]} + SS_E \quad (2)$$

$$Sum\ of\ Square\ due\ to\ Factor\ A(SS_A) = bcn\sum_{i=1}^{a}(\bar{Y}_{i....} - \bar{Y}_{....})^2 \quad (3)$$

$$\text{Sum of square B Nested under A } (SS_{B(A)}) = cn\sum_{i=1}^{a}\sum_{j=1}^{b}(\bar{Y}_{ij..} - \bar{Y}_{i...})^2 \quad (4)$$

$$\text{Sum of square C Nested under B } (SS_{C[B(A)]}) = n\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{l=1}^{c}(\bar{Y}_{ijk.} - \bar{Y}_{ij..})^2 \quad (5)$$

$$\text{Sum of square Error } (SS_E) = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}\sum_{l=1}^{n}(Y_{ijkl} - \bar{Y}_{ijk.})^2 \quad (6)$$

$$Sum\ of\ Square\ Total\ (SS_T) = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}\sum_{l=1}^{n}(Y_{ijkl} - \bar{Y}_{....})^2 \quad (7)$$

The corresponding F-test statistics when all the factor levels of A, B and C are fixed is given below and as shown in the ANOVA table

$$F_A = \frac{MS_A}{MS_E} \sim F_A = F_{\alpha,(a-1)(abc(n-1)} \quad (8)$$

$$F_{B(A)} = \frac{MS_{B(A)}}{MS_E} \sim F_{B(A)} = F_{\alpha,a(b-1)(abc(n-1)} \quad (9)$$

$$F_{C(AB)} = \frac{MS_{C(AB)}}{MS_E} \sim F_{C(AB)} = F_{\alpha,ab(c-1)(abc(n-1)} \quad (10)$$

Table 1: ANOVA Table for the Three - Stage Nested Design

SV	SS	DF	MS	Fcal
Factor A	SS_A	a – 1	$\frac{SS_A}{a-1}$	$\frac{MS_A}{MS_E}$
Factor B within A	$SS_{B(A)}$	$a(b-1)$	$\frac{SS_{B(A)}}{a(b-1)}$	$\frac{MS_{B(A)}}{MS_E}$
Factor C within B	$SS_{C(BA)}$	$ab(c-1)$	$\frac{SS_{B(C)}}{ab(c-1)}$	$\frac{MS_{B(C)}}{MS_E}$
Error	SS_E	$abc(n-1)$	$\frac{SS_E}{abc(n-1)}$	
Total	SS_T	$abcn-1$	$\frac{SS_T}{abcn-1}$	

Table 2: Method of Data Collection/Classification of Data

Class	Levels	Values
Fertilizer	3	1,2.3
Block	3	1,2,3
Seeds Types	4	1,2,3,4
Varieties of seeds	4	1,2,3,4

Where: a =1, 2,3, b = 1, 2, 3, c = 1, 2, 3, 4, n = 1, 2, 3, 4, (a = 3, b = 3, c = 4, n = 4)
N = $a \times b \times c \times n$, N= 144

Tukey Lsd/Hsd Post Anova Test

[19] described the Tukey LSD as a test of all pairwise mean comparisons of a rejected null hypothesis of equal mean treatment. Since there was a rejection of the null hypothesis for this experiment, we have that:

$H_0: \mu_i = \mu_j$ and $H_1: \mu_i \neq \mu_j$, for all i ≠ j, where μ is the mean of all the testable variable in the experiment (block and varieties). For block: i, j=1,2,3, For varieties: i, j=1,2,3,4.

The simultaneous confidence interval level on the differences in all pairs of means for the intervals is 100(1-α) percent for all the sample sizes. The Tukey procedure makes use of the distribution of the studentized range statistics:

$$q = \frac{\bar{y}_{max} - \bar{y}_{min}}{\sqrt{MS_E/n}} \qquad (11)$$

Where $\bar{y}_{max}$ and $\bar{y}_{min}$ are the largest and smallest sample means of all the group of dependent variables that is significant in the experiment, out of a group of *p* samples, the value of $q_\alpha(a, f)$ can be found from the statistical table, using the studentized range statistics table, the upper α percentage points of *q*, the studentized range distribution, where *f* is the number of degrees of freedom associated with the MSE. Tukey test declares two means significantly different if the absolute value of their mean difference exceeds;

$$T_\alpha = q_\alpha(a, f)\sqrt{\frac{MS_E}{n}} \qquad (12)$$

The 100(1- α) percent confidence intervals for all pairs of mean are given as follows:

$$\bar{y}_{i.} - \bar{y}_{j.} - q_\alpha(a, f)\sqrt{\frac{MS_E}{n}} \leq \mu_i - \mu_j \leq \bar{y}_{i.} - \bar{y}_{j.} + q_\alpha(a, f)\sqrt{\frac{MS_E}{n}}, \ i \neq j.$$

Data: Secondary data on crop yield were collected from the research farm of Joseph Sarwuan Tarka University, Makurdi, from May 2018 to August 2018 (4 Months) to assess the impact of different fertilizer applications on the yield of Maize and groundnut seeds, both in single plantings and in combination. Observations on the responses of each seedling of the same crop and the yields were recorded from both the mono-cropping and intercropping farming methods under the different farm areas, blocks and the different fertilizer applications in addition to the control experiments to determine the fertilizer with best yield. We have three different farm areas, the controlled farm without the application of fertilizer, the farm with the application of chemical-based fertilizer and the farm with the application of organic based fertilizer. The organic-based fertilizer used is the compost plus organic fertilizer, and the chemical-based fertilizer used is NPK in 20:10:10 in equal proportion.

Results

The P value for the first hypothesis H_0^I is $.510 > 0.05$, we do not reject the null hypothesis that there is no significant effect of fertilizer on crop yields in each farm, because each of the farm is equal in size and dimension but differs in the fertilizer application. The second hypothesis H_0^{II} $.021 < 0.05$ and the third hypothesis H_0^{III} $.00 < 0.05$,

Table 3: Analysis of Variance for the Experimental Condition, All Factor

Source	DF	SS	MS	F	P
Farm (Fertilizer)	2	66563.85	33281.92	100.20	0.56
Block (Seeds-crop)	6	264934.13	44155.69	132.99	0.02
Seeds Varieties	27	465504.75	17240.92	51.928	0.00
Error	108	35857.50	332.01		
Total	143	832860.22			

DF = Degree of Freedom, SS = Sum of Squares, MS = Mean Square, P = Probability value

we reject the null hypothesis and conclude that there is a significant effect of blocks on crop yield and there are significant differences between the mean yield of varieties from the same crops of different varieties from the various farm areas (Table 3). The post ANOVA results of the homogeneous mean and multiple comparison test in table 4-8 shows that there are no significant differences in all the block 1 from the various farm. Block 2 from the organic based fertilizer farm.

Table 4: Post Hoc Tests for the Block Differences: Homogenous Subsets

Farms	N	1	2
Block 1			
Farm 3	16	671.81	
Farm 2	16	709.19	
Farm 1	16	723.81	
Sig.		0.244	
Block 2			
Farm 3	16	668.00	
Farm 2	16		699.50
Farm 1	16		716.88
Sig.		1.00	0.32
Block 3			
Farm 3	16	761.63	
Farm 2	16	787.00	787.00
Farm 1	16		817.69
Sig.		0.23	0.12

Tukey Least Significance Difference (LSD[a])- Means for groups in homogeneous subsets are displayed, Harmonic Mean Sample Size (N) = 16 and Subset for alpha = 0.05

is significant to block 2 from the control-experiment farm with a mean difference of 48.88but not significant to the chemical-based fertilizer farm. Block 3 from the organic based fertilizer farm is significant to the block 3 of the controlled experiment with a mean difference of 56.10 (Table 4). For the varieties of seeds planted, white maize from farm 1 is significant to the white maize of farm 3 with a mean difference of 105.75, and white maize of farm 2 is significant to farm 3 with a mean difference of 85.75.

Table 5a: Post Hoc Tests for the Varieties of Maize: Homogeneous Subsets

Farms	N	1	2	3
White Maize				
Farm 3	4	746.00		
Farm 2	4		831.75	
Farm 1	4		851.75	
Sig.			1.00	0.16
Yellow Maize				
Farm 3	4	728.00		
Farm 2	4	765.75	765.75	
Farm 1	4		776.25	
Sig.			0.09	0.78
Hybrid Maize				
Farm 3	4	619.50		
Farm 2	4	637.75		
Farm 1	4	659.75		
Sig.				0.06
Pop Maize				
Farm 3	4	593.75		
Farm 2	4	601.50		
Farm 1	4	607.50		
Sig.		1.00	1.00	1.00

Tukey Least Significance Difference (LSD[a])**-** Means for groups in homogeneous subsets are displayed, Harmonic Mean Sample Size (N) = 4 and Subset for alpha = 0.05

Yellow maize of farm 1 is significant to yellow maize of farm 3 with a mean difference of 48.25000, there is no mean difference for the hybrid maize. Pop maize from farm 1 is significant from pop maize of farm 2 and 3 with mean differences of 6.00 and 13.75 (Table 5a). For the groundnuts, Sam-nut 9 has no significant mean difference, Sam-nut 10 from farm 1 is significant to Sam-nut of farm 3 with a mean difference of 98.00. Sam-nut of farm 2 is significant from farm Sam-nut of farm 3 with a mean difference of 70.50.

Table 5b: Post Hoc Tests for the Varieties of Groundnut: Homogeneous Subsets

Farms	N	1	2
	Sam-nut 9		
Farm 3	4	701.75	
Farm 2	4	717.00	
Farm 1	4	734.00	
Sig.		0.09	
	Sam-nut 10		
Farm 3	4	594.50	
Farm 2	4		665.00
Farm 1	4		692.50
Sig.		1.00	0.21
	Sam-nut 11		
Farm 3	4	693.50	
Farm 2	4	709.25	709.25
Farm 1	4		719.75
Sig.		0.054	0.214
	Sam-nut 14		
Farm 3	4	682.25	
Farm 2	4	706.75	706.75
Farm 1	4		721.25
Sig.		0.165	0.488

Tukey Least Significance Difference (LSD[a])- Means for groups in homogeneous subsets are displayed, Harmonic Mean Sample Size (N) = 4 and Subset for alpha = 0.05

Sam-nut 11 from farm1 is significant to Sam-nut 11 from farm 3 with a mean difference of 26.25. Sam-nut 14 from farm 1 is significant to Sam-nut of farm 3 with a mean difference of 39.00. For the mixed crops, there is no significant mean between Sam-nut 9 and white maize from all the farms (Table 5b). Sam-nut 10 and yellow maize of farm 1 is significant to Sam-nut 10 and yellow maize of farm 3 with a mean difference of 98.00 and Sam-nut 10 and yellow maize of farm 2 is significant to Sam-nut 10 and yellow maize of farm 3 with a mean difference of 70.50. Sam-nut 11 and hybrid maize from farm 1 is significant to Sam-nut 11 and hybrid maize from farm 3 with a mean difference of 25.00.

Table 6: Mixed Crops Types: Homogeneous Subsets

Farms	N	1	2
Sam-nut 9 and White Maize			
Farm 3	4	701.75	
Farm 2	4	717.00	
Farm 1	4	734.00	
Sig.		0.088	
Sam-nut 10 and Yellow Maize			
Farm 3	4	594.50	
Farm 2	4		665.00
Farm 1	4		692.50
Sig.		1.00	0.211
Sam-nut 11 and Hybrid Maize			
Farm 3	4	693.50	
Farm 2	4	709.25	709.25
Farm 1	4		719.75
Sig.		0.054	0.214
Sam-nut 14 and Pop Maize			
Farm 3	4	682.25	
Farm 2	4	706.75	706.75
Farm 1	4		721.25
Sig.		0.165	0.488

Tukey Least Significance Difference (LSD[a])- Means for groups in homogeneous subsets are displayed, Harmonic Mean Sample Size (N) = 4 and Subset for alpha = 0.05

Sam-nut 14 and Pop maize from farm 1 is significant to Sam-nut 14 and Pop maize from farm 3 with a mean difference of 39.00000. The homogenous subsets mean results of all the results show that the homogenous mean of the blocks and the varieties of all the experiments from Farm 1 have the highest mean respectively. The experimental analysis result agrees with that of Edelman (1974) and Obinna *et al.* (2020) on statistically significant results (Table 6).

Conclusion

Although the results of the analysis show that there is no difference in the farm areas of the different fertilizer applications because the farm areas are of the same sizes, there is differences in the blocks and varieties of seeds planted in the various farms. The post ANOVA test used has established the differences as follows, that the differences in block 1 across all the farms are not statistically significant, Block 2 of farm 1and Block 2 of farm 2 are both statistically significant to Block 2 of farm 3, Block 3 of farm 1 is statistically significant to block 3 of farm 1 which means that the fertilizers performed better in Block 2 and Block 3 where the various groundnut seeds and the mixed crops were planted across the farms. For the varieties of seeds planted, white maize of farm 1 and white maize of farm 2 are both significant to white maize of farm 3, but the farm 1 is higher which means that organic based fertilizer gave the white maize more yield than the other fertilizer. Yellow maize of farm 1 is also significant to yellow maize of farm 3, There is no statistically significant mean between the hybrid maize across all farms, Pop maize of farm 1 is significant to both farm 2 and farm 3, which means that the organic based fertilizer also gave the Pop maize more yield than the rest of the fertilizer. For the Groundnut, there is no statistically significant mean between Sam-nut 9 across the farms, Sam-nut 10 of farm 1 and farm 2 are both significant to farm 3, Sam-nut 11 of farm 1 is significant to Sam-nut 11 of farm 3, Sam-nut 14 of farm 1 is significant to farm 3. For the mixed crops there is no statistically significant mean between the yield of Sam-nut 9 and white maize, Sam-nut 10 and yellow maize of farm 1 and farm 2 is significant to farm 3, Sam-nut 11 and hybrid maize of farm 1 is significant to farm 3, Sam-nut 14 and pop maize of farm 1 is significant to farm 3. Therefore, organic-based fertilizer farm has the best yield from the other farms as 3 out of the 4 seeds planted across the farms shows statistically significant mean under the organic based fertilizer application.

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Cite this article

Chogudo M.O., & Nwosu S.C. (2026). A Study on the Effect of Different Fertilizer Application on Yield of Some Selected Crops: Hierarchical Three-Stage Nested Design Approach. FUAM Journal of Pure and Applied Science, **6(1)**:20-27