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GRAECO-LATIN SQUARE DESIGN ON THE OPTIMIZATION OF CROP NUTRIENT BY APPLICATION OF FERTILIZER TO THE SOIL

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Abstract
This study investigates the optimization of crop nutrient application using the Graeco-Latin Square Design (GLSD), with a focus on four different varieties of guinea corn cultivated on Phanadam Farm in Bwari, Abuja, over four harvest seasons (2020–2023). The research assessed the effects of crop variety, soil type, cropping system, and fertilizer type on crop yield. Employing a GLSD of order 4, the design efficiently controlled for three sources of variability, allowing for a robust analysis of the four treatment factors. Data were obtained from secondary sources and analyzed using Analysis of Variance (ANOVA). Results indicated that there were no statistically significant differences in yield attributable to crop variety, soil type, cropping system, or fertilizer type, as the F-calculated values were consistently lower than the F-tabulated value of 9.28. These findings suggest that although these factors may intuitively affect yield, uniform application of fertilizers can standardize yield across different conditions. The study recommends the consistent use of fertilizers in guinea corn production, regardless of variety or environmental factors, to enhance agricultural productivity.

INTRODUCTION

Crop nutrients are *chemical elements* and *compounds* necessary for plant growth and reproduction, plant metabolism, and external supply. In its absence, the plant is unable to complete a normal life cycle, or that the element is part of some essential plant constituent or metabolite. This is in accordance with *Justus von Liebig's Law of the minimum* (Emanuel 2002). The total essential plant nutrients include 17 different elements: carbon, oxygen, and hydrogen, which are absorbed from the air, whereas other nutrients, including nitrogen, are typically obtained from the soil (exceptions include some parasitic or carnivorous plants).

Graeco-Latin square or Euler square or pair of orthogonal Latin squares of order n over two sets S and T, each consisting of n symbols, is an n×n arrangement of cells, each cell containing an ordered pair (s,t), where s is in

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S and t is in T, such that every row and every column contains each element of S and each element of T exactly once, and that no two cells contain the same ordered pair. The arrangement of the s-coordinates by themselves (which may be thought of as Latin characters) and of the t-coordinates (the Greek characters) each forms a Latin square. A Graeco-Latin square can therefore be decomposed into two "orthogonal" Latin squares. Orthogonality here means that every pair (s, t) from the Cartesian product S×T occurs exactly once Graeco-Latin squares are used in the design of experiments, tournament scheduling, and construction of magic squares. French writer Georges Perec structured his 1978 novel Life: A User's Manual around a 10×10 Graeco-Latin square.

Yates and Mather (2022) provided Graeco-Latin tables for orders 3 to 12 (excluding the order of six). A comprehensive description of GLSDs was also provided by Dénes and Keedwell (2014). Dodge and Shah (2017) addressed the estimation of missing data in Latin squares and Graeco-Latin squares. Preece (20060 discussed non-orthogonal GLSDs. Street (2021) used the theory of cyclotomy to construct certain balanced incomplete block designs (BIBDs) and partially balanced incomplete block designs (PBIBDs), which gave some GLSDs as well as some nested row and column designs. Seberry (2009) highlighted orthogonal GLSDs.

Neutrosophic logic is claimed by Smarandache (2010) to be more efficient than fuzzy logic. Smarandache (2014) introduced the concept of neutrosophic statistics (NS), which is an extension of classical statistics. Aslam (2019) explained the differences between fuzzy statistics, NS, and classical statistics. Neutrosophic ANOVA was highlighted by Aslam (2019). In a more recent article, AlAita and Aslam (2022) discussed the application of neutrosophic analysis of covariance to neutrosophic completely random, randomized complete block, and split-plot designs. Aslam and Albassam (2020) suggested post hoc multiple comparison tests for NS. Neutrosophic correlation and simple linear regression were discussed by Salama and Khaled (2014).

Latin squares are sometimes discussed in connection with magic squares. A (normal) magic square with k rows and k columns contains just one occurrence of each of the integers from 1 to k^2 in such a way that the numbers in each row, each column, and each diagonal add up to the same total (which simple mathematics shows must be $k(k^2 + 1)/2$). For example, a magic square with four rows and four columns would contain just one occurrence of each of the integers from 1 to 16, and the numbers in each row, column, and main diagonal would all add up to $[4 \times (16 + 1)]/2$ or 34. (Non-normal magic squares can be constructed using more complex arithmetic progressions than 1, 2, and . . . , k^2.) Latin squares and normal magic squares are conceptually different structures, but they are related in that Latin squares can be used to construct magic squares of the same dimensions (Emanouilidis, 2005).

Objectives of the Study

i. To determine the differences between the yields of the four varieties.
ii. To identify the effects of different between the various soil on the yield.
iii. To determine the difference between the systems of cropping on the yield.
iv. To identify the effects of different fertilizers on yield in each block.

RESEARCH METHODOLOGY

Research Design

Graeco-latin squares are also called orthogonal latin squares. The Graeco-latin square design can be used to systematically control three sources of extraneous variability; that is, to block in three directions. The design allows investigation of four factors (rows, columns, latin letters and greek letters), each at P levels in only P^2 runs.

Population, Sample and Sampling Techniques

Population

The research covered the harvest of Guinea corn on the Phanadam farm during four different harvest seasons.

Samples and Sampling Techniques

This research is to study the analytical study of crop nutrient optimization using Greco–latin Design.

Method of Data Collection

The data used in this research are distinct data and secondary data collected from the records of the storekeeper of Phanadam Farm, Bwari Abuja.

Graeco-Latin Square Design of order 4

0123	1230	2301	3012
0123	1302	2031	3210
0123	1032	2310	3201
0123	1032	2301	3210

Data Analysis and Model Specification Techniques

Data Analysis Technique

Graeco-Latin Square Design Layout

Latin Letters

A	B	C	D
B	C	D	A
C	D	A	B
D	A	B	C

Greek Letters

α	β	θ	φ
β	θ	φ	α
θ	φ	α	β
φ	α	β	θ

Model Specification

The experimental design of this research was the Graeco-Latin Square design. The design model is as follows:

$Y_{ijGL} = \mu + r_i + c_j + y_L + \delta_G + e_{ijLG}$

Here, Y_{ijGL} = the yield (observation) in the ith row and the column is receiving the and Gth greek treatments.

μ = the Overall mean of the experiment's

r_i = effect of the with row

c_j = effect of the with column

y_L = effect of the latin letter (Lth) treatment

δ_G = effect of the Greek letters (Gth) treatment's

e_{ijLG} = error term.

COMPUTATION OF SUM OF SQUARE

Correction factor = $\frac{Y^2....}{N}$

$SS_{T\,=}$

$$\sum_{i=1}^{p}\sum_{j=1}^{p}\sum_{G=1}^{p}\sum_{L=1}^{p} Y_{ijGL}^2 - C.F$$

$$SSr = \sum_{i=1}^{p} \frac{Y^2 i}{p} - C.F.$$

$$SSc = \sum_{j=1}^{p} \frac{Y^2 j}{p} - C.F.$$

$$SSL = \sum_{L=1}^{p} \frac{Y^2 L}{p} - C.F.$$

$$SSG = \sum_{G=1}^{p} \frac{Y^2 G}{p} - C.F.$$

SSE= SST-SSR-SSC-SSL-SSG

ANOVA Table

Source of Variations	Degree of Freedom	Sum of squares	Mean Square	F-Ratio
Rows	P-1	SS_r	SS_r/P-1	$M_{Sr/}$ M_{SE}
Columns	P-1	SS_C	SS_C/P-1	$M_{SC/}$ M_{SE}
Treatment 1 (Latin)	P-1	SS_L	SS_L/P-1	$M_{SL/}$ M_{SE}
Treatment 1 (Greek)	P-1	SS_G	SS_G/P-1	$M_{SG/}$ M_{SE}
Error	(P-3)(P-1)	SS_E	SS_E/(P-3) (P-1)	
Total	P^2-1	SS_T		

Where P: the number of rows or columns.

Trt: treatment

Decision rule:

If $F_{-tab} > F_{-cal}$

Accept H_o; otherwise, reject H_o

If $F_{-tab} > F_{-cal}$

Accept H_1, otherwise Reject H_1

DATA PRESENTATION AND ANALYSIS

Data Presentation

In Graeco-Latin Square Design, there is always a problem of one-way analysis of variance, which can be considered as the case of a farmer monitoring the effect of an N.P.K 15:15:15, N.P.K 5:10:5, organic fertilizer, and liquid fertilizer on four different low land crops. This research was conducted by selecting independent random samples from the farms.

A null hypothesis of equal mean yield could be tested clearly; the strategy of the experiment is that of the Graeco-Latin Square Design, which difference in the yield of four varieties of guinea corn using four different fertilizers on four plots of land for four cultivation seasons (2020-2023), using fertilizer as the Latin letters a, b, c, and d while varieties of guinea corn by the Greek letters α, β, θ and φ.

Data Analysis and Results

The data below represent the yields (bags) of four varieties of guinea corn arranged in rows and columns.

44	46	39	52
51	37	43	40
42	39	46	34
45	52	36	42

Arrangement of Graeco-Latin Square Design

The possible arrangement of graeco-Latin square design is as follows:

Cβ	Bφ	Dθ	Aα	Cβ44	Bφ46	Dθ39	Aα52
Bα	Cθ	Aφ	Dβ	Bα51	Cθ37	Aφ43	Dβ40
Aθ	Dα	Bβ	Cφ	Aθ42	Dα39	Bβ46	Cφ34

Dφ Aβ Cα Bθ Dφ45 Aβ52 Cα36 Bθ42

Hypothesis Testing

Ho: There are no significant differences between the yields of the varieties.

Ho: There are no significant differences in yields among the various soils.

Ho: There is no significant differences between cropping systems on yield.

Ho: There is no significant different between the effects of the fertilizers on yield.

Table I (Graeco-latin square)

	1	2	3	4	$Y_{i...}$
1	Cβ44	Bφ46	Dθ39	Aα52	181
2	Bα51	Cθ37	Aφ43	Dβ40	171
3	Aθ42	Dα39	Bβ46	Cφ34	161
4	Dφ45	Aβ52	Cα36	Bθ42	175
$Y_{j...}$	**182**	**174**	**164**	**168**	**Y…= 688**

Table II (Latin Letters Treatment Total)

A	52	43	42	52	**189**
B	46	51	46	42	**185**
C	44	37	34	36	**151**
D	39	40	39	45	**163**

Table III (GreekLetters Treatment Total)

Α	52	51	39	36	**178**
Β	44	40	46	52	**182**
Θ	39	37	42	42	**160**
Φ	46	43	34	45	**168**

Correction factor = $\frac{Y^2....}{N}$

C.F = $\frac{688^2}{16} = \frac{463344}{16}$ = 29584

$SS_T = \Sigma_{i=1}^{P}\Sigma_{j=1}^{p}\Sigma_{G}^{p}\Sigma_{L}^{P}Y_{ijGL}^{2}$ – C.F

$SS_T = 44^2 + 46^2 + 39^2 + 52^2 + 51^2 + 37^2 + 43^2 + 40^2 + 42^2 + 39^2 + 46^2 + 34^2 + 45^2 + 52^2 + 36^2 + 42^2 - 29584$

SS_T = 30042–29,584

SS_T= 458

$$SSr = \sum_{i=1}^{p} \frac{Y^2 i}{p} - C.F.$$

$$SSr = \frac{181^2 + 171^2 + 161^2 + 175^2}{4} 29584$$

SSr = 29637–29584

SSr = 53

$$SSc = \sum_{j=1}^{p} \frac{Y^2 j}{p} - C.F.$$

$SSc = \frac{181^2 + 174^2 + 164^2 + 168^2 29584}{4}$

SSc = 29630–29584

SSc = 46

$$SSL = \sum_{L=1}^{p} \frac{Y^2 L}{p} - C.F.$$

$SS_L = \frac{189^2 + 185^2 + 151^2 + 163^2 29584}{4}$

SS_L = 29829–29,584

SS_L = 245

$$SSG = \sum_{G=1}^{p} \frac{Y^2 G}{p} - C.F.$$

$SS_G = \frac{178^2 + 182^2 + 160^2 + 168^2 - 29584}{4}$

SS_G = 29658–29,544

SS_G = 74

$SS_E= SS_T-SS_R-SS_C-SS_L-SS_G$

$SS_{E =}$ 458–53–46–245–74

SS_E= 40

Table IV (Objective One: There is no significant difference between the yields of the varieties).

ANOVA TABLE

Source of Variations	**Degree of Freedom**	**Sum of squares**	**Mean Square**	**F-Ratio**
Rows (varieties)	3	53	17.67	1.33
Columns	3	46	15.33	1.115
Trt 1 (Latin)	3	245	81.67	6.13
Trt 1 (Greek)	3	74	24.67	1.85
Residual (Error)	3	40	13.33	
Total	15	458		

Decision Rule

If $F_{-tab} > F_{-cal}$

Accept H_0; otherwise, reject H_0

If f-tab < f –cal, then

Accept H_I; otherwise, reject H_I

Here, $F_{-tab}$is 9.28

Since the $F_{-tab} > F_{-cal}$ therefore (H_I) is rejected and (H_0) is accepted: There is no significant difference between the effects of the fertilizers on yields.

Table V (Objective Two: There is no significant difference between the various soils on the yields).

ANOVA Table

Source of Variations	**Degree of Freedom**	**Sum of squares**	**Mean Square**	**F-Ratio**
Rows	3	53	17.67	1.33
Columns (soil)	3	46	15.33	1.115
Trt 1 (Latin)	3	245	81.67	6.13

Trt 1 (Greek)	3	74	24.67	1.85
Residual (Error)	3	40	13.33	
Total	15	458		

Decision Rule

If $F_{-tab} > F_{-cal}$

Accept H_0; otherwise, reject H_0

If f-tab < f –cal, then

Accept H_I; otherwise, reject H_I

Here, $F_{-tab}$is 9.28

Because the $F_{-tab} > F_{-cal}$ therefore (H_I) is rejected and (H_0) is accepted: There are no significant differences between the yields produced from the four varieties.

Table VI (Objective Three: There is no significant difference between the systems of cropping on the yields).

ANOVA Table

Source of Variations	**Degree of Freedom**	**Sum of squares**	**Mean Square**	**F-Ratio**
Rows	3	53	17.67	1.33
Columns	3	46	15.33	1.115
Trt 1 (Latin) (systems of cropping)	3	245	81.67	6.13
Trt 1 (Greek)	3	74	24.67	1.85
Residual (Error)	3	40	13.33	
Total	15	458		

Decision Rule

If $F_{-tab} > F_{-cal}$

Accept H_0; otherwise, reject H_0

If f-tab < f –cal, then

Accept H_I; otherwise, reject H_I

Here, $F_{-tab}$is 9.28

Since $F_{-tab} > F_{-cal}$ therefore (H_I) is rejected and (H_0) is accepted: There is no significant difference between the various soil types on yield.

Table VII (Objective four: There is no significant different between the effect of the fertilizers on the yield).

ANOVA Table

Source of Variations	**Degree of Freedom**	**Sum of squares**	**Mean Square**	**F-Ratio**
Rows	3	53	17.67	1.33
Columns	3	46	15.33	1.115
Trt 1 (Latin)	3	245	81.67	6.13
Trt 1 (Greek) (fertilizer)	3	74	24.67	1.85
Residual (Error)	3	40	13.33	
Total	15	458		

Decision Rule

If $F_{-tab} > F_{-cal}$

Accept H_0; otherwise, reject H_0

If f-tab < f –cal, then

Accept H_I; otherwise, reject H_I

Here, F_{-tab} is 9.28

Because $F_{-tab} > F_{-cal}$ therefore (H_I) is rejected and (H_0) is accepted: that there is no difference between cropping systems on yield.

Discussions of Findings

Since the value of 9.28 is greater than the F-ratio, we accept H_0 that there is no significant difference between the yields of the varieties, the various soils on the yields, the systems of cropping on the yields, and the effect of the fertilizers on the yield.

Based on the above analysis and findings carried out on the data collected in this research work, it was therefore observed that whether the guinea corn is of different varieties, the soil is of different types, or the cropping systems are different, the yield of the guinea corn will be the same if the fertilizer is applied to the soil on which the crop (guinea corn) is planted and there will be a greater improvement in the yield.

In this regard, we can therefore suggest that fertilizer should be applied to guinea corn irrespective of its kind or the type of soil it is being planted on for the best yield, not just to the guinea corn alone but to other crops as well where fertilizer can be applied for the availability of more foods in the country at large.

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