Investigating the Effect of Nitrogen and Phosphorus on the Height, Weight and fruits Yield of Tomatoes in Nigeria: Using MANOVA

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Abstract

Fertilization in crops acts as an insurance against possible nutrient deficiencies that may be created by the repeated use of single land for plantation. Many farmers in Nigeria apply different combination of chemical fertilizers like Nitrogen, Phosphorus and Potassium known as NPK fertilizers to enhance the height, weight and yield of tomatoes fruits. However, excessive use of fertilizers has hazard effect on soil, plants, and human health. Despite these adverse effects associated with excessive use of fertilizers, farmers in Nigeria use inadequate fertilizer inputs, inappropriate quality and inefficient combinations of fertilizers, which in the end prove to be very costly. Therefore, this research employed Multivariate Analysis of Variance (MANOVA) to investigate if nitrogen and phosphorus application contribute to the height, weight, and yield of tomato fruit; identify specific level of nitrogen and phosphorus requirement for the optimal yield of tomato; and estimate the optimal yield of tomato fruit at the recommended levels. Series of data analysis carried out show that Nitrogen and Phosphorus contribute significantly to the height, weight and fruits yield of tomato. Further test carried out revealed that Nitrogen at 95kg/ha and Phosphorus at 22kg/ha are required to obtain perfect height, weight and optimal fruits yield of tomatoes. Hence, the derived Multivariate regression model was obtain for the height, weight and the fruits yield of tomatoes respectively as: $Y_{height} = -1314.615 + 1.9474(95) + 1.4197(22) + 8.6620(43)$;$Y_{weight} = 15.056 + 0.331(95) + 0.2204(23) + 0.3761(43)$ and $yield = 442.665 + 0.331(95) + 0.2204(22) + 0.3761(43)$.

Thus, the optimal of height of 38.42cm, the optimal weight of 0.556kg and the optimal fruit yield of 182 ton/ha.

Keywords: *Multivariate Analysis of Variance (MANOVA), Analysis of Variance (ANOVA), Wilks' Lambda, and Tomatoes Fruit Yield.*

1.0 Introduction

Tomato (*Lycopersicon lycopersicum*) belongs to the Solanaceae family. It originated in Peru and Mexico, in the Central and South America from where it spread to other parts of the world [1]. Tomato reached Europe from Mexico in the 16th century and was initially used as ornamental plant. Its cultivation for edible fruits started at the end of the 18th century. Tomato was introduced to West Africa and Nigeria in particular, at the end of the 19th century [2]. It is currently considered to be one of the main vegetable crops in the world and constitutes an economic force that influences the income of many growers in the world [3]. In Nigeria, tomato also finds its way into almost every kitchen. Tomato crop is very important in terms of diet and economy both during the rainy season (rain-fed) and dry season using irrigation facilities. It is used as a condiment in stews and soup or eaten raw in salads. Industrially, the crop is made into puree, sauce, paste and powder [4]. In the recent decades, the consumption of tomatoes has been associated with prevention of several diseases [5, 6] mainly due to the content of antioxidants including carotenes, (Lycopene as well as β-carotene), ascorbic acid, and phenolic compounds [7]. The world production of tomato figure in 2012 was 145.8 metric tons with China leading with 41.9 metric tons. In Africa, Egypt is the leading producer with the production of 39.5 metric tons and Nigeria is the fourth in Africa and leads in West Africa sub-region with an estimated output of 1.10 metric tons and average yield of 10 tons ha^{-1} [8]. Tomato productivity at a given location depends on the potential of the genotype used and timely availability of resources. Low and declining soil fertility is a major concern in many African small holder farms and has been exacerbated by continuous cultivation without adequate soil fertility enhancement measures [9, 10]. African soil nutrient balances are often negative due to a low level of fertilizer inputs, and soil nutrient depletion is a major reason for decreasing or stagnation of agricultural productivity. Sanchez [11], Mbah [12] asserts that soil fertility is a major overriding constraint that affects all aspects of crop production. As is the case in other regions in Africa, local farmers use inadequate nutrient inputs, inappropriate quality and inefficient combinations of fertilizers, which in the end prove to be very costly [13]. A consequence of this trend is a deeply unbalanced soil nutrient composition that ultimately leads to a reduction in crop yield potential [14]. Nutrients, when in adequate quantity, increases fruit quality, fruit size, color, and fruit taste of tomato [15]. It also helps in increasing desirable acidic flavor. Tomato production cuts across Nigeria's geo-political zones and generates income to the farmers, but the production system is on a low scale in southern guinea savannah, due to improper fertilizer usage which leads to increases in soil acidity [16]. In vegetable production, organic fertilizer combined with inorganic has proved to be effective in combating nematodes [17]. The high cost of tomato in the Nigerian market justifies that the production is far lower than the demand. If proper nutrient management is adapted by the tomato producer, the production will certainly goes up to meet the demand. This research work therefore, employed Multivariate Analysis of Variance (MANOVA) to investigate if nitrogen and phosphorus application contribute to the height, weight and yield of tomato fruit; identify specific level of nitrogen and phosphorus require for the optimal yield of tomato; and determine the optimal yield of tomato fruit at recommended levels.

2.0 Methodology

The Analysis of Variance ANOVA examines how that single variable is altered in different conditions. In contrast, the Multivariate Analysis of Variance, also known as MANOVA, tests the effect of a between-groups factor on two or more dependent measures on two or more independents variables simultaneously [17]. Those multiple Dependent Variables are not compared to each other (as they would be in within-subjects ANOVA); instead, they are compared in parallel as they change across between subjects groups. Multivariate ANOVA is the perfect test when you have several Qualitatively Different Dependent Variables (QDDVs) that are all distinct indicators of the same underlying construct. Multivariate ANOVA can be more powerful than running several univariate ANOVAs. First, for rhetorical purposes, it can be more convincing to show your effect in a single statistical test rather than as a piecemeal series of tests that is essentially testing the same conceptual hypothesis. Second, in some cases, multivariate ANOVA is statistically more powerful than any univariate ANOVA on its own. This is especially the case when the QDDVs are negatively correlated with each other. Depending on the data, it is possible to find a statistically significant group difference using MANOVA when none of the individual variables shows a difference in an ANOVA [18]. In some ways, the MANOVA approach is similar to latent variable approaches such as structural equation modeling. Both techniques assume that the measured variables each relate to an unobserved (or latent) construct that is the target of the group-based manipulation, and both techniques capitalize on the increased power of using several different measures as indicators of that latent construct. One key difference is that MANOVA is intended to be used for categorical independent measures, whereas structural equation modeling is based on a regression model and is more appropriate for continuous independent measures [19].

2.1 Research variables

The study involves effect of 2 types of fertilizers namely Nitrogen and Phosphorus at different levels (dependent variables) on 3 different (independent) variables namely: Plant Height, Fruit dry weight, and yield of fresh fruit. All measured in ton/ha hence the use of Multivariate Analysis if Variance MANOVA.

3.0 Data Analysis and Interpretation

The fitted model for the experiment is two-way MANOVA which is given as:

$$\boldsymbol{Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}}$$

Where:

Y_{ijk}= vectors of observation response or dependent variables,

μ= vetor of overall mean

τ_i= vector of i^{th} of Nitrogen effect,

β_j = vector of j^{th} of Phosphorus effect, and

$(\tau\beta)_{ij}$= vector interaction between Nitrogen and Phosphorus effect, and ε_{ijk}= vector error term normally and independent distributed i.e NID(0, δ^2).

Table 3.1 Summary of Data: **Between-Subjects Factors**

Between-Subjects Factors			
		Value Label	N
Nitrogen (kg/ha)	1	0	6
	2	30	6
	3	60	6
	4	90	6
	5	120	6
Phosphorus(kg/ha)	1	0	10
	2	13	10

	3	26	10

Table 3.2. Multivariate Analysis of data

Multivariate Tests[a]						
Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.997	1293.473[b]	3.000	13.000	.000
	Wilks' Lambda	.003	1293.473[b]	3.000	13.000	.000
	Hotelling's Trace	298.494	1293.473[b]	3.000	13.000	.000
	Roy's Largest Root	298.494	1293.473[b]	3.000	13.000	.000
nitrogen	Pillai's Trace	.835	1.446	12.000	45.000	.181
	Wilks' Lambda	.267	1.869	12.000	34.686	.048
	Hotelling's Trace	2.358	2.293	12.000	35.000	.028
	Roy's Largest Root	2.183	8.188[c]	4.000	15.000	.001
phosphorus	Pillai's Trace	.710	2.567	6.000	28.000	.042
	Wilks' Lambda	.313	3.413[b]	6.000	26.000	.013
	Hotelling's Trace	2.123	4.246	6.000	24.000	.005
	Roy's Largest Root	2.088	9.745[c]	3.000	14.000	.001
nitrogen * phosphorus	Pillai's Trace	.813	.697	24.000	45.000	.828
	Wilks' Lambda	.319	.770	24.000	38.305	.748
	Hotelling's Trace	1.734	.843	24.000	35.000	.665
	Roy's Largest Root	1.480	2.775[c]	8.000	15.000	.042
a. Design: Intercept + nitrogen + phosphorus + nitrogen * phosphorus						
b. Exact statistic						
c. The statistic is an upper bound on F that yields a lower bound on the significance level.						

3.1 Test of significance for Nitrogen effect

Hypothesis test: Nitrogen effect

H_0: $\tau 1 = \tau 2 = \tau 3 = \tau 4 = \tau 5$: that is the vector of means of the dependent variables (Plant Height, Fruit Dry Weight, Yield of fresh fruit) are equal across the group after Nitrogen effect.

H_1: $\tau 1 \neq \tau 2$ for at least one of the Nitrogen levels, that is the vector means of the dependent variables are not equal across the group.

At $\alpha = 0.05$

The test statistic is given as:

$\Lambda = (|E|) / (|H+E|)$

Where: $|E|$= the determinant of error sspm

$|H|$ = the determinant of treatment sspm

Effect	Value	F	Hypothesis df	Error df	Sig.
Wilks' Lambda	.267	1.869	12.000	34.686	.048

Decision rule:

Reject H_O if p-value is less than 0.05 otherwise, do not reject H_O

Decision:

Since p-value (0.048) is less than α (0.05), we reject $H_0$and conclude that the vector of means is significantly different across the group. This implies that the Fertilizer Nitrogen has some significant effect on some or all of the dependent variables under study.

3.2 Test of significance for phosphorus effect

H_0:β1= β2 = β3: that is the vector of means of the dependent variables (Plant Height, Fruit Dry Weight, Yield of fresh fruit) are equal across the group after Phosphorus effect

H_1: H_0 is not true that is the vector means of the dependent variables are not equal across the group.

At $\alpha = 0.05$

The test statistic is given as:

$\Lambda = (|E|) / (|H+E|)$

Where: $|E|$= the determinant of error sspm

$|H|$ = the determinant of treatment sspm

Effect	Value	F	Hypothesis df	Error df	Sig.
Wilks' Lambda	.313	3.413b	6.000	26.000	.013

Decision rule:

Reject H_0 if p-value is less than 0.05 otherwise, do not reject H_O

Decision:

Since p-value (0.013) is less than α (0.05), we reject H_0 and conclude that the vector of means is significantly different across the group. This implies that the fertilizer Phosphorus has some significant effect on some or all of the dependent variables under study.

3.3 Test of significance for interaction effect

H_0: $(\tau\beta)_{ij} = 0$: that is the vector of means of the dependent variables (Plant Height, Fruit Dry Weight, Yield of fresh fruit) are equal across the group after interaction effect.

H_1 :$(\tau\beta)_{I\ j} \neq 0$:$H_0$ Is not true that is the vector means of the dependent variables are not equal across the group.

At α= 0.05

The test statistic is given as:

$\Lambda = (|E|) / (|H+E|)$

Where: |E|= the determinant of error sspm

|H| = the determinant of treatment sspm

Effect	Value	F	Hypothesis df	Error df	Sig.
Wilks' Lambda	.319	.770	24.000	38.305	.748

Decision rule:

Reject H_0 if p-value is less than 0.05 otherwise, do not reject H_0.

Decision:

Since p-value (0.748) is greater than α (0.05), we accept $H_{0,}$ and conclude that the vector of means is significantly different across the group.

3.4 **Test of factor effect on individual dependent variable**

Having obtained some significant effect, it becomes important to carry out the test of factor effect which is used to identify the significant variable from the group of variables under study with respect to the significant effect.

Table 3.3 **Test of factor effect on individual dependent variable**

Tests of Between-Subjects Effects						
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Plant Height (cm)	426.475[a]	14	30.463	2.323	.058
	Fruit Dry Weight(kg)	.144[b]	14	.010	.116	1.000
	Yield of Fresh Fruit(ton/ha)	57216.045[c]	14	4086.860	3.399	.012
Intercept	Plant Height (cm)	23349.510	1	23349.510	1780.740	.000
	Fruit Dry Weight(kg)	1.624	1	1.624	18.418	.001
	Yield of Fresh Fruit(ton/ha)	135663.425	1	135663.425	112.824	.000
nitrogen	Plant Height (cm)	301.885	4	75.471	5.756	.005
	Fruit Dry Weight(kg)	.045	4	.011	.127	.970
	Yield of Fresh Fruit(ton/ha)	21204.951	4	5301.238	4.409	.015
phosphorus	Plant Height (cm)	94.529	2	47.264	4.605	.053
	Fruit Dry Weight(kg)	.035	2	.018	.200	.821
	Yield of Fresh Fruit(ton/ha)	28446.705	2	14223.352	11.829	.001
nitrogen * phosphorus	Plant Height (cm)	30.062	8	3.758	.287	.960
	Fruit Dry Weight(kg)	.063	8	.008	.090	.999
	Yield of Fresh Fruit(ton/ha)	7564.389	8	945.549	.786	.622
Error	Plant Height (cm)	196.684	15	13.112		
	Fruit Dry Weight(kg)	1.323	15	.088		
	Yield of Fresh Fruit(ton/ha)	18036.590	15	1202.439		
Total	Plant Height (cm)	23972.669	30			
	Fruit Dry Weight(kg)	3.090	30			
	Yield of Fresh Fruit(ton/ha)	210916.060	30			
Corrected Total	Plant Height (cm)	623.159	29			
	Fruit Dry Weight(kg)	1.466	29			
	Yield of Fresh Fruit(ton/ha)	75252.635	29			
a. R Squared = .684 (Adjusted R Squared = .390)						

b. R Squared = .098 (Adjusted R Squared = -.744)
c. R Squared = .760 (Adjusted R Squared = .537)

Estimation of optimal yield of tomatoes height, weight and fruits at recommended levels of nitrogen and phosphorus

To compute the optimal yield, the study employed the use of a two way MANOVA model:

$$\boldsymbol{Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}}$$

Tomato plant height

For the optimal plant height of tomato nitrogen at 95kg/ha and phosphorus at 22kg/ha are required.

Thus, the derived multivariate model:

Y_{height} = -1314.615 + 1.9474(95) + 1.4197(22) + 8.6620(43) = 38.42cm

Tomato fruit dry weight

For the optimal growth of tomato fruit dry weight, nitrogen at 105kg/ha and phosphorus at 20kg/ha are required.

Thus, the derived multivariate model:

Y_{weight}= 15.056 + 0.331(105) + 0.2204(20) + 0.3761(66.5) = 0.556kg.

Yield of tomato fruit

For the optimal yield of fresh tomato fruit, it can be observed that nitrogen at 120kg/ha and phosphorus at 26kg/ha are required for optimal yield of fresh tomato fruit

Thus, the derived multivariate model:

Y_{fruit} = 442.665 + 0.331(120) + 0.2204(26) + 0.3761(73) =182ton/ha

Conclusion:

From the series of data analysis carried out, it shows Nitrogen and phosphorus are statistically significant, that is the two factors contribute greatly to the yield of tomato considering the Plant Height (measured in centimeter), Fruit Dry Weight (measured in kg) and Yield of fresh fruit (measured in ton/ha). This implies that the interaction between the Nitrogen and Phosphorus fertilizer have significant effect on the yield of tomato. Further tests were carried out to identify at what level each of the dependent variables namely Plant Height, Fruit Dry Weight, Yield of fresh fruit is actually significant. The results show that the Nitrogen Fertilizer has a significant effect on the plant height of tomato at 5.756, fruit dry weight at 0.127, and fresh fruit at 4.409 for the Nitrogen effect; that the Phosphorus fertilizer has a significant effect on the plant height of tomato at plant height is 4.605, fruit dry weight is 0.200, and yield of fresh fruit at 11.829. Also, it can be observed that Nitrogen at 95kg/ha and phosphorus at 22kg/ha are optimal for perfect plant height, Nitrogen at 105kg/ha and phosphorus at 20kg/ha are optimal for perfect tomato fruit dry weight, and Nitrogen at 120kg/ha and phosphorus at 26kg/ha are optimal for perfect Yield of Fresh Tomato FruitThus, the optimal of height of 38.42cm, the optimal weight of 0.556kg and the optimal fruit yield of 182 ton/ha is achievable if nitrogen and phosphorous are applied to tomato at the recommended levels.

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