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Statistical Analysis of Optimum Phosphorous Fertilizer Requirement for Improved Yield Performance of Cowpea in Nigeria

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Abstract

This paper investigates optimum required amount of Phosphorous fertilizer (P_2O_5) and optimal duration of maturity for cowpea. The study was conducted on a cowpea variety using randomized complete block design (RCBD) replicated three times. Appropriate Analysis of variance technique for the design type was used in collecting datasets on growth variables of the plant, using fixed effects, in an experiment conducted by the teaching and research farm of University of Ilorin, Ilorin, Nigeria in year 2010. Five quantitative and equally spaced levels of 0Kg/Ha, 30Kg/Ha, 60Kg/Ha, 90Kg/Ha and 120Kg/Ha respectively, of the fertilizer type were considered in the experiment. Measurements were taken on a number of variables namely, plant height (cm), number of branches, number of leaves, number of flowers and number of pods of cowpea. The datasets were inspected for homogeneity of variances using Bartlett's and Fligner-Killeen's tests respectively in the language R. The tests revealed that ANOVA assumption of homoscedasticity was not violated in the datasets except for cowpea height. Logarithmic transformation was performed on the dataset for cowpea height to correct for violation of homoscedasticity assumption. Shapiro-Wilk's test of normality was conducted on the residuals of the ANOVA models for the various response variables. The results of the test revealed that ANOVA assumption of normally distributed residuals was not violated in the datasets. We also investigated presence of potential outliers in the datasets using standardized residuals. The results were adequately supported by residuals plot and normal quantile plot respectively. It was observed that minimum and maximum standardized residuals lie within ± 2 as expected. Phosphorous fertilizer level of 60Kg/Ha was found to be the most economically efficient and optimum for growing cowpea with the corresponding optimum yield from the 8th through the 11th week after planting.

Keywords: RCBD, Phosphorous, fixed Effects, Shapiro-Wilk's test, Fligner-Killeen's test, Bartlett's test, ANOVA, and R

1. Introduction

Cowpea (Vigna unguiculata [L.] Walp) is an important grain legume in drier regions and marginal areas of the tropics and subtropics. It is particularly important in West Africa with over 9.3 million metric tons of annual production (Ortiz, R., 1998). Fatukun reported in 2002 that Cowpea grain is a good source of human protein, while the haulms are valuable source of livestock protein (Owolade et al 2006). In the light of this, research efforts channeled towards determination of economically efficient fertilizer level required for increased Cowpea production is important for making necessary decisions.

Phosphorus (P) is important for cowpea production in many tropical African soils with inherent low P fertility. Adetunji, 1995 and Mokwunye *et al.,* 1986 have reported deficiency of the fertilizer type in many tropical soils with the former stating that the deficiency can be so acute in some soils of the savanna zone of western Africa that plant growth ceases as soon as the P stored in the seed is exhausted. Sellschop 1962; Rachie and Roberts, 1974 recommended application of P for cowpea production on soils low in P. Phosphorus, although required in small quantities, is critical to cowpea yield because of its multiple effects on nutrition (see: Muleba and Ezumah 1985; Owolade et al., 2006; Luse et al. 1975; Kang and Nangju 1983 and references therein). We will therefore present in this write-up, the economically optimal level of P required for best yield performance and maturity of Cowpea in this ecological zone.

The remaining part of this work comprises discussion of research objectives in section 1.1, materials and methodology of the study in section 2.0, Section 3.0 discusses results of data analysis and conclusion is presented in section 4.0.

1.1 Objectives of the Study

The main objectives of this work are presented in what follows:

1. To investigate whether or not Phosphorous application has meaningful impact on yield performance of Cowpea.
2. To determine the economically optimum Phosphorous fertilizer requirement for improved yield performance of Cowpea in the South Guinea Savannah zone of Nigeria.
3. To determine the minimum duration required for growing Cowpea with Phosphorous fertilizer in the South Guinea Savannah zone of Nigeria.

2. **Materials and Methodology**

2.1 **Site Description**

The field experiment was conducted during 2010 cropping season at the University of Ilorin Teaching and Research Farm, a location in the Southern Guinea ecology zone of Nigeria. The topography of the area had a gentle slope which has little or no effect on erosion of the area.

2.3 Analysis of Variance (ANOVA)

The main statistical technique of data analysis adopted in this study is ANOVA using randomized complete block design model with Phosphorous fertilizer levels representing the four treatments in the study and number of weeks after planting at which observations were taken representing blocks. The ANOVA model used for collecting the measurements is as presented in what follows.

$$\left.\begin{array}{c} \boldsymbol{y_{ij} = \mu + \alpha_j + \beta_i + \varepsilon_{ij}} \cdots\cdots\cdots (\mathbf{1}) \\ \boldsymbol{For\ i = 1, \cdots, 4\ and\ j = 1, \cdots\cdots\cdots, 4} \\ \boldsymbol{with\ restriction \sum_{i=1}^{4} \alpha_i = \sum_{j=1}^{4} \beta_j = 0} \end{array}\right\} \boldsymbol{fixed\ effect\ model}$$

Where

$\boldsymbol{y_{ij} = Observation\ under\ ith\ Phosphorous\ level\ arrising\ from\ jth\ week\ after\ planting}$

$\boldsymbol{\alpha_j = Effect\ of\ jth\ Phosphorous\ level\ on\ Cowpea}$

$\boldsymbol{\beta_i = Effect\ of\ Phosphorous\ fertilizer\ on\ Cowpea\ after\ ith\ week\ of\ planting}$

$\boldsymbol{\varepsilon_{ij} = ijth\ normally, identical\ and\ independently\ distributed\ random\ error\ with\ mean\ zero}$ $\boldsymbol{and\ constant\ but\ unknown\ variance\ \sigma^2\ i.e\ \varepsilon_{ij} \sim NID(0, \sigma^2)}$

2.3.1 Test of Significance about Effects of Phosphorous Fertilizer Levels on Cowpea

Null hypothesis (H_o): Effects of Phosphorous levels on Cowpea are the same

Alternative Hypothesis (H_1): Not H_o

Test Statistic: $\boldsymbol{F_{ratio} = \frac{MS_{Phosphorous\ levels}}{MS_{Error}}}$

Decision Rule: Reject H_o in favour of H_1 at $\alpha = 0.05$ level of significance if $P - Value < 0.05$, otherwise do not reject $\boldsymbol{H_o}$

2.3.2 Test of Significance about Duration of Maturity for Cowpea

Null hypothesis (H_o): Cowpea yield is the same across the weeks

Alternative Hypothesis (H_1): Not H_o

Test Statistic: $F_{ratio} = \frac{MS_{Weeks\ after\ planting}}{MS_{Error}}$

Decision Rule: Reject H_o in favour of H_1at $\alpha = 0.05$ level of significance if $P - Value < 0.05$, otherwise do not reject H_o

3.0 Data Analysis

3.1 Tests of Homogeneity of Variances for Cowpea Yield Variables

One of the basic assumptions for validity of results of analysis of variance is equality of sample variances. The decomposition of the variability in the observations through an analysis of variance is just an algebraic relationship. To use the method to test formally for no differences in means of the various treatments therefore requires that certain assumptions be satisfied (Olorede et al., 2013; Olorede and Alabi, 2013). Specifically, these assumptions are that the residuals are normally and independently distributed with mean zero and constant but unknown variance (Montgomery, 2001). We therefore test the hypothesis that all samples came from populations with identical variances (Zar, 1999). Datasets on plant height (cm), number of branches, number of leaves, number of flowers and number of pods were inspected for homogeneity of error variances using *Bartlett's* and *Fligner-killeen's* tests (Conover et al, 1981) in the language R (R Core team 2013). These two tests are employed to achieve the same purpose due to nature and type of the sample data under each Cowpea yield variable and the underlying assumptions of tests. Results of *Fligner-Killeen's* test presented in table 1 reveal that homoscedasticity assumption is not violated on sample datasets for number of branches, number of pods, number of flowers and number of leaves of Cowpea since we failed to reject the null hypothesis of equal variances due to the corresponding p-values. Furthermore, result of Bartlett's test of equal variances on Cowpea height initially revealed that the variances were unequal with small p-value of 0.0418 < 0.05 for number of weeks after planting but after logarithmic transformation of the sample data, we obtained the result presented in table 1 showing that variances are the same. Similar results for other variables are not presented. By implication, it means that we may proceed to conduct analysis of variance on the datasets.

Table 1: Homogeneity of Variances for Cowpea Yield Variables

Fligner-Killeen's Test				
	Number of Cowpea Branches			
Dataset	DF	Chi-squared	P-value	Decision
Phosphorous Levels	4	0.6156	**0.9613**	Variances are the same
WAP	3	0.532	**0.9118**	Variances are the same
	Number of Cowpea Pods			
Dataset	DF	Chi-squared	P-value	Decision
Phosphorous Levels	5	2.1976	**0.6995**	Variances are the same
WAP	5	1.8045	**0.8755**	Variances are the same
⋮ ⋮	⋮ ⋮			⋮ ⋮
Bartlett's Test				
	Cowpea Height (cm)			
Dataset	DF	K-squared	P-value	Decision
Phosphorous Levels	4	2.7117	**0.6072**	Variances are the same
WAP	3	5.1024	**0.1645**	Variances are the same

3.2 Checking Model Adequacy

3.2.1 Normality Assumption

For our ANOVA model in 1 above to be sufficient for the sample datasets, assumption of normally distributed residuals must be satisfied (Montgomery, 2001). We will obtain residuals of the models and test hypotheses that the residuals follow a normal distribution for sample datasets resulting from the growth variables of cowpea using Shapiro-Wilk test of normality (Shapiro and Wilks, 1965). Normal quantiles plots of the residuals and Plots of residuals against fitted values of the models are obtained in each case to further check normality of the residuals and homoscedasticity. If the residual plot appears structureless by having about the same extension of scatter of the residuals around zero for each Phosphorous level (Kutner, 2005; Olorede et al., 2013; Olorede and Alabi, 2013), it is an indication of homogeneous variances. If the dots in the normal quantile plots, particularly those in the middle, are close to the line, it is reasonable to infer that the data follow a normal distribution. We will also check possible effects of outliers in sample data by using the standardized residual criterion suggested Barnett and Lewis, 1994, John and Prescott, 1975, and Stefansky, 1972. We will obtain minimum and maximum residuals of the models and standardize them by dividing each by the root mean square error of the corresponding model. It is expected that the minimum standardized residual should fall within ± 1 and the largest standardized residual should fall within ± 2, otherwise we have a potential outlier.

3.3 Analysis of Variance on Number of Cowpea Branches

In this section, we present ANOVA results for effects of quantitative levels of Phosphorous fertilizer on Cowpea number of branches, blocked by number of weeks (period) to maturity. These results presented in table 2 reveal that we reject the null hypothesis of equality of effects of the levels of the fertilizer type on number of branches of Cowpea and that branches of Cowpea varies over maturity periods with p-values of 1.39e-06 and 1.22e-08 respectively. The implication of this is that application of the fertilizer type has positive impact on Cowpea branch production. It is also important to determine the optimum amount of Phosphorous fertilizer for increasing number of branches of Cowpea and the maximum duration expected for it to grow to maturity due to application of the fertilizer type.

Table 2: ANOVA Table for Cowpea Number of Branches

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-value	P-value
Phosphorous Levels	**4**	**20.30**	**5.075**	**35.82**	**1.39e-06**
WAP	**3**	**40.55**	**13.517**	**95.41**	**1.22e-08**
Residuals	**12**	**1.70**	**0.142**		

WAP: Number of weeks after planting

Therefore, we conduct Tukey's Honestly Significant Difference (TukeyHSD) test (Tukey, J.W. 1949b) on the results. Results of the test presented in table 3 reveal that only pairs of Phosphorous levels (120Kg/ha vs. 0Kg/ha), (90Kg/ha vs. 120Kg/ha) and (90Kg/ha vs. 30Kg/ha) produce the same effects on number of branches of Cowpea. The simple interpretation of this result is that effect of 120Kg/Ha level of Phosphorous fertilizer on Cowpea branches is as good as applying 0Kg/Ha of it and that 30 and 90Kg/Ha levels of P impact cowpea branches equally. All other pairs of the fertilizer levels are significantly different. Table 4 also reveals that Cowpea branches actually vary from the fifth week through the eleventh week of cultivation. Results of the post-hoc tests are further summarized using box plots presented in figures 1 and 2.

Because it is of interest to determine the economically optimum Phosphorous level for improving Cowpea number of branches, we estimated effects of the fertilizer levels on number of branches and the average number of branches due to each of them. We also estimated the number of weeks after which effects of the levels were optimum and the corresponding Cowpea number of branches in that week. These results are presented in table 5. It can be inferred from the results that 60Kg/Ha of Phosphorous is the most efficient and economically optimum for improving number of branches of Cowpea because its influence is more noticeable on branch production by the plant. It is also evident from table 5 that the week in which influence of this fertilizer level is optimum on Cowpea branches is 11WAP because the optimum yield was recorded therein. The results are strongly supported by figures 1 and 2.

Table 3: TukeyHSD for Effects of Phosphorous Levels on Cowpea Number of Branches

Pairs of P Levels	Difference	Lower Bound	Upper Bound	Adjusted P-value	Decision
120Kg/Ha Vs. 0Kg/Ha	0.75	-0.0983	1.5983	0.0929	Pairs are the same
30Kg/Ha Vs. 0Kg/Ha	1.75	0.9017	2.5983	0.0002	Pairs are not the same
60Kg/Ha Vs.0Kg/Ha	3.00	2.1517	3.8483	0.0000	Pairs are not the same
90Kg/Ha Vs. 0Kg/Ha	1.25	0.4017	2.0983	0.0038	Pairs are not the same
30Kg/Ha Vs. 120Kg/Ha	1.00	0.1517	1.8483	0.0188	Pairs are not the same
60Kg/Ha V.s 120Kg/Ha	2.25	1.4017	3.0983	0.0000	Pairs are not the same
90Kg/Ha Vs. 120Kg/Ha	0.50	-0.3483	1.3483	0.3776	Pairs are the same
60Kg/Ha Vs. 30Kg/Ha	1.25	0.4017	2.0983	0.0038	Pairs are not the same
90Kg/Ha Vs. 30Kg/Ha	-0.50	-1.3483	0.3483	0.3776	Pairs are the same
90Kg/Ha Vs. 60Kg/Ha	-1.75	-2.5983	-0.9017	0.0002	Pairs are not the same

P: Phosphorous

Table 4: TukeyHSD for Cowpea Number of Branches across Weeks of Cultivation

Pairs of P Levels	Difference	Lower Bound	Upper Bound	Adjusted P-value	Decision
5WAP Vs.11WAP	-3.6	-4.3067	-2.8933	0.0000	Pairs are not the same
7WAP Vs.11WAP	-2.8	-3.5067	-2.0933	0.0000	Pairs are not the same
9WAP Vs.11WAP	-1.0	-1.7067	-0.2933	0.0058	Pairs are not the same
7WAP Vs.5WAP	0.8	0.0933	1.5067	0.0253	Pairs are not the same
9WAP Vs.5WAP	2.6	1.8933	3.3067	0.0000	Pairs are not the same
9WAP Vs.7WAP	1.8	1.0933	2.5067	0.0000	Pairs are not the same

WAP: Number of weeks after planting

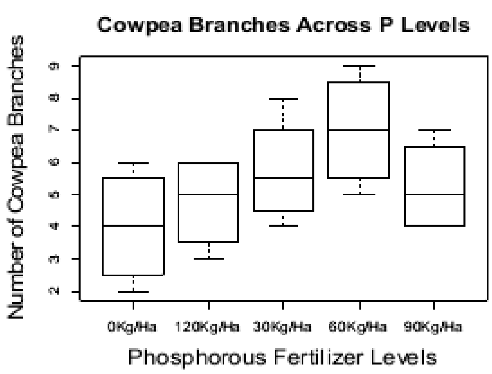

Figure 1: Box Plot for Number of Cowpea Branches per Phosphorous Level

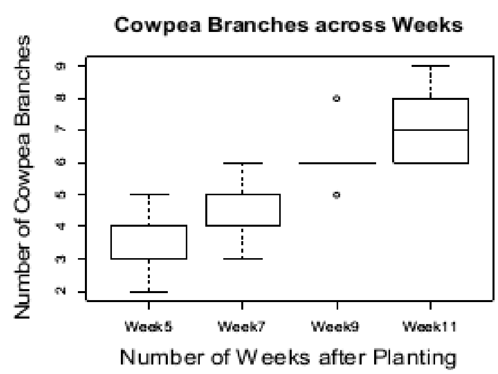

Figure 2: Box Plot for Number of Cowpea Branches from Week 5 through Week 11

Table 5: Estimates of Effects of Phosphorous Fertilizer Levels on Number of Branches of Cowpea

	Phosphorous Fertilizer Levels				
Estimates	0Kg/Ha	30Kg/Ha	60Kg/Ha	90Kg/Ha	120Kg/Ha
Effects	-1.35	0.40	**1.65***	-0.10	-0.60
Average Yield	4.00	5.75	**7.00***	5.25	4.75
	Weeks after Planting				
Estimates	5WAP	7 WAP	9 WAP	11 WAP	
Effects	-1.75	-0.95	0.85	**1.85***	
Average Yield	3.6	4.4	6.2	**7.2***	

***: Highest effect of Phosphorous and highest average yield of Cowpea**

3.3.1 Checking Normality Assumption of ANOVA Model for Dataset on Cowpea Branches

Now that we have conducted ANOVA and corresponding post-hoc test, we will proceed to check whether residuals arising from the ANOVA model are normally distributed using Shapiro-Wilk test of normality. The test reveals that the sample data on Cowpea branches come from normal distribution by failing to reject the null hypothesis of normally distributed residuals with a p-value of 0.4072 as displayed in table 6. Standardized residuals for the outliers observed in the dataset are also presented in table 6. The results do not portray any serious effect of outliers on result of the ANOVA as they fall within± 1 and ± 2. Figures 3 and 4 present residuals plot and the normal quantile plot respectively. Since the residuals plot is patternless and the dots in the middle of the normal-quantiles plot are close to the line, it is reasonable to infer that the sample dataset on Cowpea branches has a normal distribution.

Table 6: Shapiro-Wilk Test of Normality and Standardized Residuals for Number of Branches

	Shapiro.test (residuals(CowpeaBranch.fit))			
Sample Data	**W-statistic**	**P-value**	**Min. Std. Residual**	**Max. Std. Residual**
Cowpea Branches	**0.9525**	**0.4072**	**-1.592235**	**1.326862**

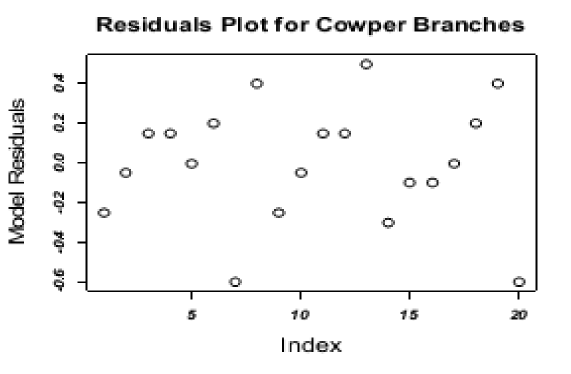

Figure 3: Plot of Residuals versus Fitted Values of Cowpea Number of Branches

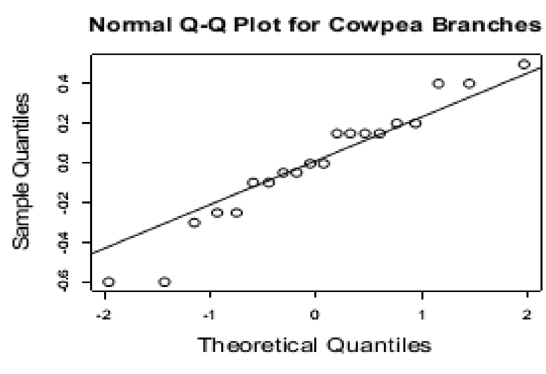

Figure 4: Normal Quantiles Plot for ANOVA on Cowpea Number of Branches

3.5 Analysis of Variance on Height (cm) of Cowpea

In this section, we present ANOVA results for effects of levels of Phosphorous fertilizer on height of Cowpea across periods of maturity. The results presented in table 7 reveal that effects of the levels of the fertilizer type on Cowpea height are not the same and that height of Cowpea varies over maturity periods with p-values of 0.000108 and 4.16e-06 respectively. The implication of this is that application of the fertilizer type has positive impact on Cowpea height. We also determined the optimum amount of Phosphorous fertilizer for increasing Cowpea height and the maximum duration expected for it to grow to maturity.

Table 7: ANOVA Table for Cowpea Height (cm)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-value	P-value
Phosphorous Levels	**4**	**0.2397**	**0.0599**	**15.53**	**0.0001**
WAP	**3**	**0.3870**	**0.1290**	**33.44**	**4.16e-06**
Residuals	**12**	**0.0463**	**0.0039**		

WAP: Number of weeks after planting

Results of Tukey's Honestly Significant Difference test are presented in table 8. The results reveal that only pairs of Phosphorous levels (30Kg/ha vs. 0Kg/ha), (60Kg/ha vs. 0Kg/ha), (60Kg/ha vs. 120Kg/ha) and (90Kg/Ha Vs. 60Kg/Ha) produce significantly different effects on height of Cowpea. The simple interpretation of this result is that these pairs of Phosphorous levels impact Cowpea height significantly differently while all other pairs have equal impact. Table 9 also reveals that Cowpea height actually vary in all pairs of weeks except in (9WAP & 11wap). Results of the post-hoc tests are further summarized in the box plots presented in figures 5 and 6.

Because of interest in determining the economically optimum Phosphorous level for increasing Cowpea height, we estimated effects of the fertilizer levels on Cowpea height and the average Cowpea height due to each of them. We also estimated the number of weeks after which effects of the levels was optimum and the corresponding Cowpea height in that week. These results are presented in table 10. It can be inferred from the results that 60Kg/Ha of Phosphorous is the most efficient and economically optimum for improving Cowpea height because its influence is more noticeable therein. It is also evident from table 10 that the week in which influence of this fertilizer level is optimum on Cowpea height is 11WAP because the optimum yield was recorded therein. The results are strongly supported by figures 7 and 8.

Table 8: TukeyHSD for Effects of Phosphorous Levels on Cowpea Height (cm)

Pairs of P Levels	Difference	Lower Bound	Upper Bound	Adjusted P-value	Decision
120Kg/Ha Vs. 0Kg/Ha	0.0711	-0.0689	0.2111	0.5143	Pairs are the same
30Kg/Ha Vs. 0Kg/Ha	0.1868	0.0468	0.3268	0.0081	Pairs are not the same
60Kg/Ha Vs.0Kg/Ha	0.3223	0.1823	0.4623	0.0001	Pairs are not the same
90Kg/Ha Vs. 0Kg/Ha	0.1275	-0.0125	0.2675	0.0807	Pairs are the same
30Kg/Ha Vs. 120Kg/Ha	0.1158	-0.0242	0.2558	0.1248	Pairs are the same
60Kg/Ha V.s 120Kg/Ha	0.2513	0.1113	0.3913	0.0007	Pairs are not the same
90Kg/Ha Vs. 120Kg/Ha	0.0564	-0.0836	0.1964	0.7048	Pairs are the same
60Kg/Ha Vs. 30Kg/Ha	0.1355	-0.0045	0.2755	0.0595	Pairs are the same
90Kg/Ha Vs. 30Kg/Ha	-0.0594	-0.1994	0.0806	0.6670	Pairs are the same
90Kg/Ha Vs. 60Kg/Ha	-0.1948	-0.3348	-0.0548	0.0059	Pairs are not the same

P: Phosphorous

Table 9: TukeyHSD for Cowpea Height (cm) across Weeks of Cultivation

Pairs of P Levels	Difference	Lower Bound	Upper Bound	Adjusted P-value	Decision
5WAP Vs.11WAP	-0.34656	-0.4632	-0.2299	0.0000	Pairs are not the same
7WAP Vs.11WAP	-0.2087	-0.3253	-0.0921	0.0009	Pairs are not the same
9WAP Vs.11WAP	-0.0367	-0.1533	0.0800	0.7880	Pairs are the same
7WAP Vs.5WAP	0.1379	0.0212	0.2545	0.0195	Pairs are not the same
9WAP Vs.5WAP	0.3099	0.1933	0.4265	0.0000	Pairs are not the same
9WAP Vs.7WAP	0.1720	0.0554	0.2887	0.0043	Pairs are not the same

WAP: Number of weeks after planting

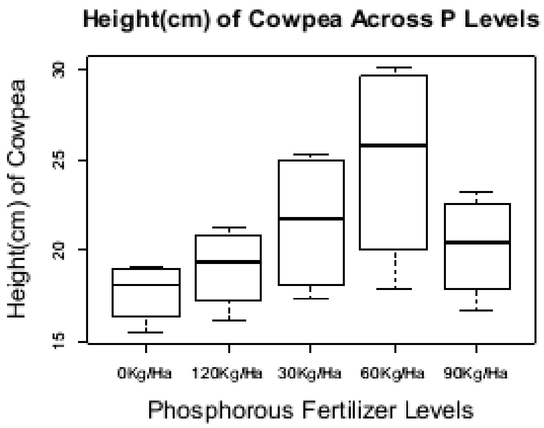

Figure 5: Box Plot for Number of Cowpea Height per Phosphorous Level

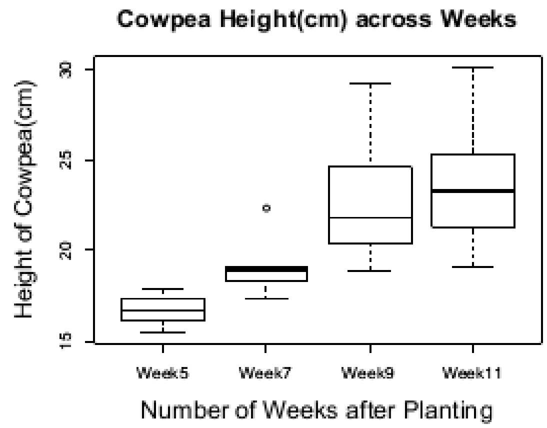

Figure 6: Box Plot for Number of Cowpea Height from Week 5 through Week 11

Table 10: Estimates of Effects of Phosphorous Fertilizer Levels on Height (cm) of Cowpea

	Phosphorous Fertilizer Levels				
Estimates	0Kg/Ha	30Kg/Ha	60Kg/Ha	90Kg/Ha	120Kg/Ha
Effects	-0.1415	0.0453	**0.1808***	-0.0141	-0.0705
Average Yield	2.87	3.06	**3.19***	3.00	2.94
	Weeks after Planting				
Estimates	5WAP	7 WAP	9 WAP	11 WAP	
Effects	-0.1986	-0.0607	0.1113	**0.1480***	
Average Yield	2.813	2.951	3.123	**3.160***	

***: Highest effect of Phosphorous and highest average yield of Cowpea**

3.5.1 Checking Normality Assumption of ANOVA Model for Dataset on Cowpea Height (cm)

In this section, we checked whether residuals arising from ANOVA model on height of Cowpea are normally distributed using Shapiro-Wilk test of normality. The test revealed that the sample data on Cowpea height come from normal distribution by failing to reject the null hypothesis of normally distributed residuals with a p-value of 0.6427 as displayed in table 11. Standardized residuals for the outliers observed in the dataset do not portray any serious effect of outliers on result of the ANOVA as they fall within ± 1 and ± 2. Figures 7 and 8 present residuals plot and the normal-quantiles plot respectively. Since the residuals plot is patternless and the dots in the middle of the normal-quantiles plot are close to the line, it is reasonable to infer that the sample dataset on leave area has a normal distribution.

Table 11: Shapiro-Wilk Test of Normality and Standardized Residuals for Height of Cowpea

	Shapiro.test (residuals(CowpeaHeight.fit))			
Sample Data	**W-statistic**	**P-value**	**Min. Std. Residual**	**Max. Std. Residual**
Cowpea Branches	**0.9648**	**0.6427**	**-1.8167**	**1.1517**

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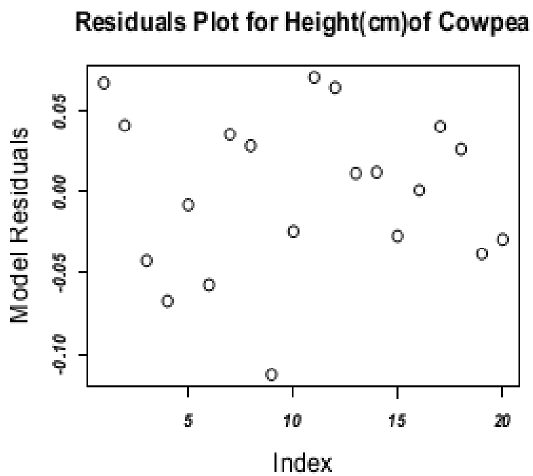

Figure 7: Plot of Residuals versus Fitted Values of ANOVA on Cowpea Height

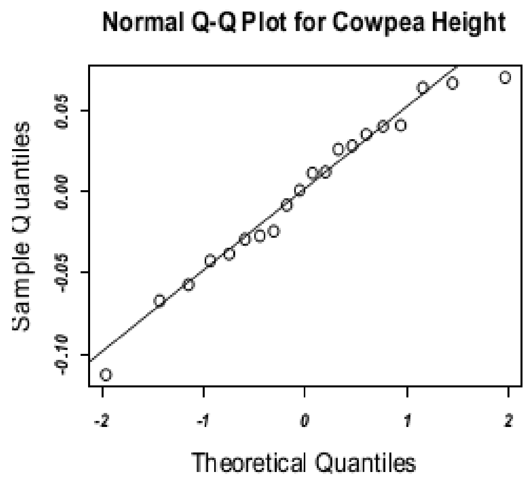

Figure 8: Normal Quantiles Plot for ANOVA on Cowpea Height

3.6 Analysis of Variance on Cowpea Pods

Here, we present ANOVA results of effects of Phosphorous fertilizer levels on number of Cowpea pods, across weeks of cultivation. The results presented in table 12 reveal that effects of the levels of the fertilizer type on Cowpea pods are different and that number of Cowpea pods varies over maturity periods with p-values of 1.45e-05 and 9.08e-10 respectively. This also implies that application of the fertilizer type has positive impact on Cowpea pods. We also determined the optimum amount of Phosphorous fertilizer for improving Cowpea pod production and the maximum duration expected for Cowpea to grow to maturity due to application of the fertilizer type.

Table 12: ANOVA Table for Cowpea Pod Production

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-value	P-value
Phosphorous Levels	4	156.0	39.00	13.83	1.45e-05
WAP	5	567.6	113.52	40.26	9.08e-10
Residuals	20	56.4	2.82		7

WAP: Number of weeks after planting

Tukey's Honestly Significant Difference test was conducted for the results in table 12. Results of the test presented in table 13 reveals that only pairs of Phosphorous levels (120Kg/ha vs. 0Kg/ha), (30Kg/ha vs. 120Kg/ha), (90Kg/ha vs. 120Kg/ha) and (90Kg/ha vs. 30Kg/ha) produced the same effects on number of pods of Cowpea. This means that effect of 120Kg/Ha level of Phosphorous fertilizer of Cowpea pods is as good as applying 0Kg/Ha of it and that 30, 60Kg/Ha and 90Kg/Ha levels of P impact cowpea pods more significantly differently than 0Kg/Ha and 120Kg/Ha . Table 14 also reveals that Cowpea pods actually vary across all pairs of weeks except (9WAP vs. 10WAP) and (7WAP vs. 11WAP) respectively. Results of the post-hoc tests are further summarized in the box plots presented in figures 9 and 10.

We determined the economically optimum Phosphorous level for increasing Cowpea pods and the average number of pods due to each of them. We also estimated number of weeks after which effects of the levels was optimum and the corresponding average number of Cowpea pods in that week. These results are presented in table 15. It can be inferred from the results that 60Kg/Ha of Phosphorous is economically optimum for improving Cowpea pods production because its influence is more noticeable on pods production by the plant. It is also evident from table 15 that the week in which influence of this fertilizer level is optimum on Cowpea pods is 8WAP because the optimum average yield was recorded therein. The results are strongly supported by figures 9 and 10.

Table 13: TukeyHSD for Effects of Phosphorous Levels on Cowpea Pods

Pairs of P Levels	Difference	Lower Bound	Upper Bound	Adjusted P-value	Decision
120Kg/Ha Vs. 0Kg/Ha	2.1667	-0.7345	5.0679	0.2077	Pairs are the same
30Kg/Ha Vs. 0Kg/Ha	3.6667	0.7655	6.5679	0.0092	Pairs are not the same
60Kg/Ha Vs.0Kg/Ha	7.0000	4.0988	9.9012	0.0000	Pairs are not the same
90Kg/Ha Vs. 0Kg/Ha	3.0000	0.0988	5.9012	0.0405	Pairs are not the same
30Kg/Ha Vs. 120Kg/Ha	1.5000	-1.4012	4.4012	0.5458	Pairs are the same
60Kg/Ha V.s 120Kg/Ha	4.8333	1.9321	7.7345	0.0006	Pairs are not the same
90Kg/Ha Vs. 120Kg/Ha	0.8333	-2.0679	3.7345	0.9082	Pairs are the same
60Kg/Ha Vs. 30Kg/Ha	3.3333	0.4321	6.2345	0.0195	Pairs are not the same
90Kg/Ha Vs. 30Kg/Ha	-0.6667	-3.5679	2.2345	0.9569	Pairs are the same
90Kg/Ha Vs. 60Kg/Ha	-4.0000	-6.9012	-1.0988	0.0042	Pairs are not the same

P: Phosphorous

Table 14: TukeyHSD for Cowpea Pods across Weeks of Cultivation

Pairs of P Levels	**Difference**	**Lower Bound**	**Upper Bound**	**Adjusted P-value**	**Decision**
11WAP Vs. 10WAP	-6.0000	-9.3384	-2.6616	0.0002	Pairs are not the same
6WAP Vs.10WAP	-9.6000	-12.9384	-6.2616	0.0000	Pairs are not the same
7WAP Vs.10WAP	-3.6000	-6.9384	-0.2616	0.0299	Pairs are not the same
8WAP Vs. 10WAP	3.6000	0.2616	6.9384	0.0299	Pairs are not the same
9WAP Vs. 10WAP	0.0000	-3.3384	3.3384	1.0000	Pairs are the same
6WAP Vs. 11WAP	-3.6000	-6.9384	-0.2616	0.0299	Pairs are not the same
7WAP Vs. 11WAP	2.4000	-0.9384	5.7384	0.2556	Pairs are the same
8WAP Vs. 11WAP	9.6000	6.2616	12.9384	0.0000	Pairs are not the same
9WAP Vs. 11WAP	6.0000	2.6616	9.3384	0.0002	Pairs are not the same
7WAP Vs. 6WAP	6.0000	2.6616	9.3384	0.0002	Pairs are not the same
8WAP Vs. 6WAP	1.3200	9.8616	16.5384	0.0000	Pairs are not the same
9WAP Vs. 6WAP	9.6000	6.2616	12.9384	0.0000	Pairs are not the same
8WAP Vs. 7WAP	7.2000	3.8616	10.5384	0.0000	Pairs are not the same
9WAP Vs. 7WAP	3.6000	0.2616	6.9384	0.0299	Pairs are not the same
9WAP Vs. 8WAP	-3.6000	-6.9384	-0.2616	0.0299	Pairs are not the same

WAP: Number of weeks after planting

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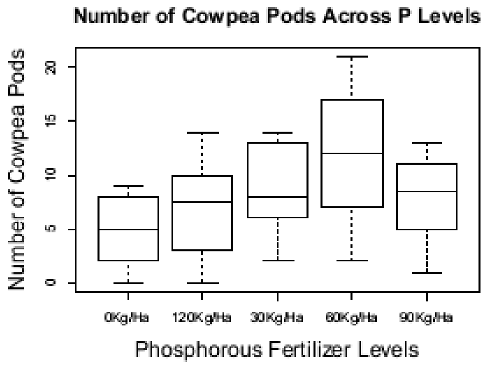

Figure 9: Box Plot for Number of Cowpea Pods per Phosphorous Level

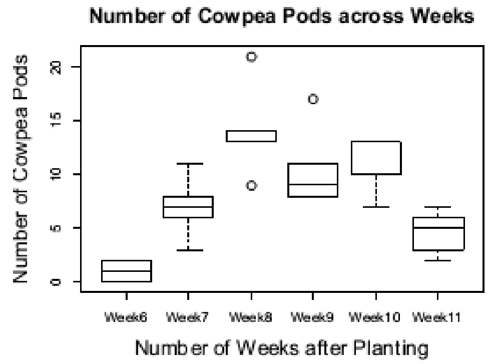

Figure 10: Box Plot for Number of Cowpea Pods across Weeks

Table 15: Estimates of Effects of Phosphorous Fertilizer Levels on Cowpea Pods

	Phosphorous Fertilizer Levels					
Estimates	0Kg/Ha	30Kg/Ha	60Kg/Ha	90Kg/Ha	120Kg/Ha	
Effects	-3.17	0.50	**3.83***	-0.17	-1.00	
Average Yield	4.83	8.50	**11.83***	7.83	7.00	
	Weeks after Planting					
Estimates	6 WAP	7 WAP	8 WAP	9 WAP	10 WAP	11 WAP
Effects	-7.0	-1.0	**6.2***	2.6	2.6	-3.4
Average Yield	1.0	7.0	**14.2***	10.6	10.6	4.6

***: Highest effect of Phosphorous and highest average yield of Cowpea**

3.6.1 Checking Normality Assumption of ANOVA Model for Dataset on Cowpea Pods

In this section, we checked whether residuals arising from ANOVA model on Cowpea pods are normally distributed using the test adopted in the previous sections. The test revealed that the sample data on Cowpea pods have normal distribution with a p-value of 0.4252 as displayed in table 16. Standardized residuals for the outliers observed in the dataset do not portray any serious effect of outliers on result of the ANOVA as they fall within± 1 and ± 2. Figures 11 and 12 present residuals plot and the normal quantiles plot respectively. Since the residuals plot is patternless and the dots in the middle of the normal-quantiles plot are close to the line, it is reasonable to infer that the sample dataset on Cowpea pods has a normal distribution.

Table 16: Shapiro-Wilk Test of Normality and Standardized Residuals for Cowpea Pods

	Shapiro.test (residuals(CowpeaPods.fit))			
Sample Data	**W-statistic**	**P-value**	**Min. Std. Residual**	**Max. Std. Residual**
Cowpea Pods	**0.9655**	**0.4252**	**-1.846023**	**1.766624**

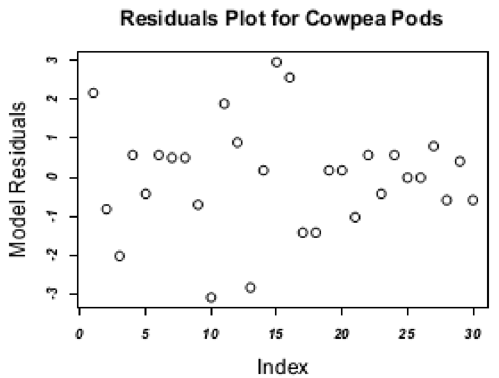

Figure 11: Residuals Plot for ANOVA on Cowpea Pods

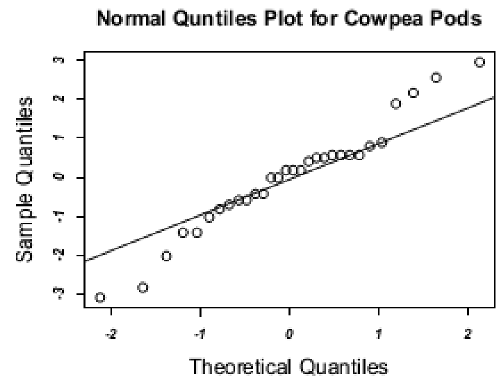

Figure 12: Normal-Quantiles Plot for ANOVA on Cowpea Pods

3.7 Analysis of Variance on Cowpea Flower Production

Here, we present ANOVA results of Phosphorous fertilizer levels on number of Cowpea flowers. The results presented in table 17 reveal that effects of levels of Phosphorous on Cowpea flowers are the same but Cowpea number of flowers varies over maturity periods with p-values of 0.5979 and 0.0002 respectively. The implication of this is that application of the fertilizer type has positive but negligible impact on Cowpea flower production.

Table 17: ANOVA Table for Cowpea Flower Production

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-value	P-value
Phosphorous Levels	4	6.56	1.640	0.708	0.597892
WAP	4	96.56	24.140	10.428	0.000237
Residuals	16				

WAP: Number of weeks after planting

Results of Tukey's HSD test in table 18 reveal that Cowpea number of flowers actually vary across all pairs of weeks except (9WAP vs. 10WAP) and (7WAP vs. 11WAP) respectively. Results of the post-hoc tests are further summarized in the box plots presented in figures 13 and 14. From table 19, It can be inferred from the results that 60Kg/Ha of Phosphorous is economically optimum for improving Cowpea flower production because its influence is more noticeable on flowers production by the plant. It is also evident from table 19 that the week in which influence of this fertilizer level is optimum on Cowpea flowers is 8WAP because the optimum average yield was recorded therein. The results are strongly supported by figures 13 and 14.

Table 18: TukeyHSD for Cowpea Flowers across Weeks of Cultivation

Pairs of P Levels	Difference	Lower Bound	Upper Bound	Adjusted P-value	Decision
11WAP Vs. 10WAP	-3.8	-6.7481	-0.8519	0.0087	Pairs are not the same
7WAP Vs. 10WAP	-3.0	-5.9481	-0.0519	0.0451	Pairs are not the same
8WAP Vs. 10WAP	1.6	-1.3481	4.5481	0.4821	Pairs are not the same
9WAP Vs. 10WAP	-1.0	-3.9481	1.9481	0.8336	Pairs are not the same
7WAP Vs. 11WAP	0.8	-2.1481	3.7481	0.9169	Pairs are the same
8WAP Vs. 11WAP	5.4	2.4519	8.3481	0.0003	Pairs are not the same
9WAP Vs. 11WAP	2.8	-0.1481	5.7481	0.0669	Pairs are the same
8WAP Vs. 7WAP	4.6	1.6519	7.5481	0.0017	Pairs are not the same
9WAP Vs. 7WAP	2.0	-0.9481	4.9481	0.2760	Pairs are the same
9WAP Vs. 8WAP	-2.6	-5.5481	0.3481	0.0979	Pairs are the same

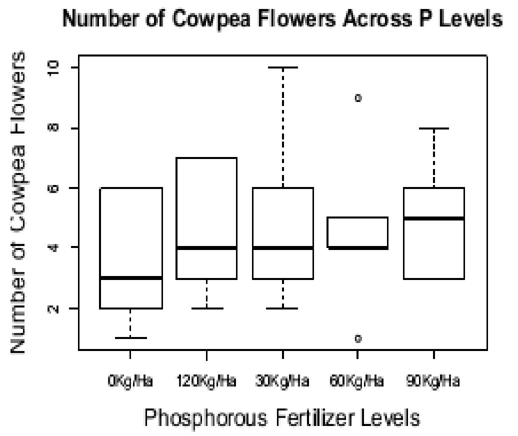

Figure 13: Box Plot for Number of Cowpea Flowers per Phosphorous Level

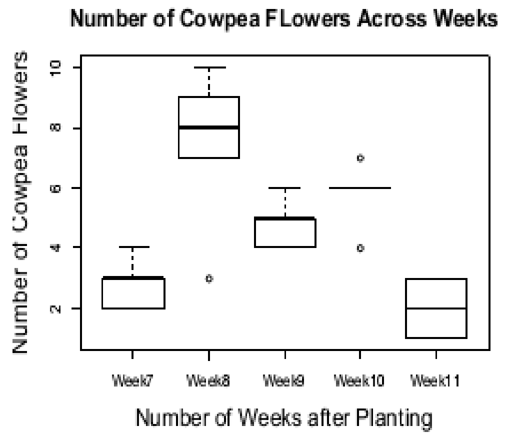

Figure 14: Box Plot for Number of Cowpea Flowers from across Weeks

Table 19: Estimates of Effects of Phosphorous Fertilizer Levels on Cowpea Flowers

	Phosphorous Fertilizer Levels				
Estimates	0Kg/Ha	30Kg/Ha	60Kg/Ha	90Kg/Ha	120Kg/Ha
Effects	-0.96	**0.44***	**0.04**	0.44	0.04
Average Yield	4.83	8.50	**11.83***	7.83	7.00
	Weeks after Planting				
Estimates	7 WAP	8 WAP	9 WAP	10 WAP	11 WAP
Effects	-1.76	**2.84***	0.24	1.24	-2.56
Average Yield	7.0	**14.2***	10.6	10.6	4.6

***: Highest effect of Phosphorous and highest number of Cowpea flowers**

3.7.1 Checking Normality Assumption of ANOVA Model for Dataset on Cowpea Flowers

With evidence from Shapiro-Wilk test results in table 20, residuals arising from ANOVA model on Cowpea flowers are normally distributed. Standardized residuals for the outliers observed in the dataset are also not potential ones. The results, therefore, do not portray any serious effect of outliers on result of the ANOVA because they fall within ± 1 and ± 2. Figures 15 and 16 also support these decisions.

Table 20: Shapiro-Wilk Test of Normality and Standardized Residuals for Cowpea Flowers

	Shapiro.test (residuals(Flowersfit))			
Sample Data	W-statistic	P-value	Min. Std. Residual	Max. Std. Residual
Cowpea Pods	0.9522	0.2816	-2.260908	1.41964

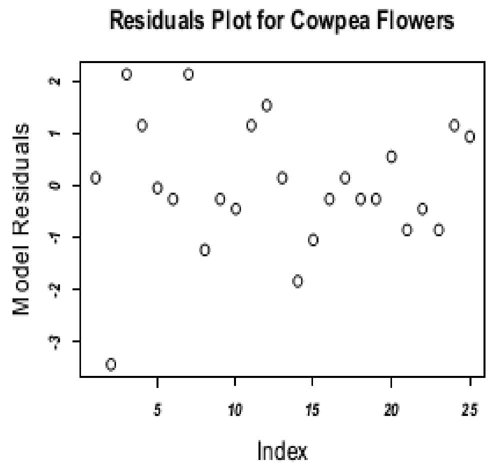

Figure 15: Plot of Residuals versus Fitted Values of ANOVA on Cowpea Flowers

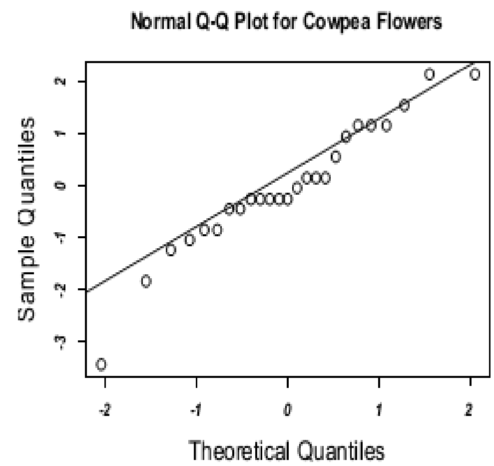

Figure 16: Normal Quintiles Plot for ANOVA on Cowpea Flowers

3.8 Analysis of Variance on Cowpea Leaves Production

Here, we present ANOVA results of effects of quantitative levels of Phosphorous fertilizer on number of Cowpea leaves. The results in table 21 reveal that effects of levels of Phosphorous on Cowpea leaves are not the same and that Cowpea number of leaves varies over maturity periods with p-values of 0.5979 and 0.0002 respectively. The implication of this is that application of the fertilizer type has positive impact on Cowpea flower production.

Table 21: ANOVA Table for Cowpea Leaf Production

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-value	P-value
Phosphorous Levels	4	257.3	64.33	14.76	0.000139
WAP	3	539.0	179.65	41.22	1.35e-06
Residuals	12				

WAP: Number of weeks after planting

Results of Tukey's HSD test (not presented) reveal that only pairs of Phosphorous levels (120Kg/ha vs. 0Kg/ha), (90Kg/ha vs. 120Kg/ha), (60Kg/ha vs. 30Kg/ha) and (90Kg/ha vs. 30Kg/ha) produce the same effects on number of leaves of Cowpea. The simple interpretation of this result is that effect of 120Kg/Ha level of Phosphorous fertilizer of Cowpea pods is as good as applying 0Kg/Ha of it, 30Kg/Ha and 90Kg/Ha levels of P impact cowpea leaves equally in that order. We also found that Cowpea leaves actually vary across all pairs of weeks except (5WAP vs. 11WAP) and (9WAP vs. 7WAP) respectively. Box plots are not produced for these results to conserve space.

Estimates of number of weeks after which effects of the levels was optimum and the corresponding average number of Cowpea leaves in that week were also obtained. These results are presented in table 22. It can be inferred from the results that 60Kg/Ha of Phosphorous is economically optimum for improving Cowpea pods production because its influence is more noticeable on leaves production by the plant. It is also evident from table 22 that the week in which influence of this fertilizer level is optimum on Cowpea pods is 9WAP because the optimum average yield was recorded therein.

Table 22: Estimates of Effects of Phosphorous Fertilizer Levels on Cowpea Leaves

	Phosphorous Fertilizer Levels				
Estimates	0Kg/Ha	30Kg/Ha	60Kg/Ha	90Kg/Ha	120Kg/Ha
Effects	-4.60	2.65	**5.15***	-0.10	-3.10

Average Yield	16.25	23.50	**26.00***	20.75	17.75

	Weeks after Planting			
Estimates	5 WAP	7 WAP	9 WAP	11 WAP
Effects	-3.05	2.95	**6.75***	-6.65
Average Yield	17.8	23.8	27.6	14.2

***: Highest effect of Phosphorous and highest number of Cowpea leaves**

3.4.1 Checking Normality Assumption of ANOVA Model for Dataset on Cowpea Leaves

With evidence from Shapiro-Wilk test results in table 23, residuals arising from ANOVA model on Cowpea flowers are normally distributed. Standardized residuals for the outliers observed in the dataset are also not potential ones. The results, therefore, do not portray any serious effect of outliers on result of the ANOVA as they fall within ± 1 and ± 2.

Table 23: Shapiro-Wilk Test of Normality and Standardized Residuals for Cowpea Leaves

	Shapiro.test (residuals(CowpeaLeaves.fit))			
Sample Data	W-statistic	P-value	Min. Std. Residual	Max. Std. Residual
Cowpea Pods	0.9909	0.999	-1.7241	1.7480

4. Conclusion

It is crystal clear from the results of this work that Phosphorous fertilizer placement has positive impacts on improved growth and yield performance of Cowpea. However, effects of quantitative levels of the fertilizer type on response variables of Cowpea were found to be different. Average growth of Cowpea due to Phosphorous placement increases across the weeks of cultivation from the 5th week after planting to the 8th week after planting for pod production, flower production and leaves production respectively but Cowpea height and number of branches increased through the 11th week after planting. Our statistical analysis in this work revealed that the most economically efficient and optimum Phosphorous level for growing Cowpea in the ecological zone is 60Kg/ha. The optimum Cowpea yield due to application of the fertilizer level is from the 8th to the 11th week after planting.

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