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Investigating the Appropriate levels of NPK Fertilizers for Optimum Yield of Soybeans in South West Nigeria

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ABSTRACT

In Nigeria, farmers applied different combination of Nitrogen, Phosphorus and Potassium known as NPK fertilizers to improve the yield which may not be adequately applied at an appropriate levels and this may cause harmful effect on the soil, plants and human. Also, excessive application of chemical fertilizers at times depresses nodule formation and nitrogen fixation in soybeans which retard the growth of the crops and hence, reduce the yield. Therefore, this research seeks to investigate if NPK fertilizers contribute to the yield of soybeans; examine which of the three elements contribute most to the yield; investigates the appropriate levels each of the trio of NPK are to be applied for optimum yield; and estimate the optimal yield of soybeans when applied at an appropriate level. A 3 by 3 factorial design was used to determine if the trio of nitrogen, phosphorus and potassium contribute to the yield of soya-beans, post-hoc analysis were carried out to investigate at what proportion those elements are to be applied, multiple regression model were derived for the optimization of the yield and surface methodology was used to obtain the optimal yield. The result shows that only Nitrogen and Phosphorus contribute significantly to the yield of soya-beans and thus the derived model: Yield = 23.56047 – 12.49669N + 11.45511P - 9.128539K + 8.412062NP + 8.600928NK + 6.808789PK – 6.330242NPK were obtained. Hence, the optimal yield of 76.27tonne/hectare of soya-beans could be obtained if Nitrogen is applied at 90kg, Phosphorus at 90 kg and 0kg of Potassium.

1. Introduction

Soybean (Glycine max L.) belongs to the family of Leguminosae, originated in East Asia, but now it is widely cultivated in tropical, subtropical, and temperate climatic regions with an optimum mean temperature of 20–30°C. Soybean is rich in nutrients, and it is regarded as a nutrient storage. Soybean is not only seen as an oil plant but also used for various purposes (Arslan, et.al., 1993). Among grain legumes, soybean is an economically important crop that is grown in diverse environments throughout the world. Soybean is an important crop for human food and feed for livestock. World soybean production is increasing especially in North, South America, and Africa especially Nigeria. Its adaptation to tropical and subtropical regions is still involving extensive breeding work (ITC, 1990). In Nigeria, farmers applied different combination of Nitrogen, Phosphorus and Potassium known as NPK fertilizers to improve the yield which may not be adequately applied at an appropriate levels and this may cause harmful effect on the soil, plants and human. Also, excessive application of chemical fertilizers at times depresses nodule formation and nitrogen fixation in soybeans which retard the growth of the crops and hence, reduce the yield. Therefore, this research seeks to investigate if NPK fertilizers contribute to the yield of soybeans; examine which of the three elements contribute most to the yield; investigates the appropriate levels each of the trio of NPK are to be applied for optimum yield; and estimate the optimal yield of soybeans when applied at an appropriate levels.

2. Literature Review

When land is used continuously for crop cultivation, incorporating organic and inorganic fertilizers to soil would provide multiple benefits for improving the chemical and physical status of the soil which results in improved crop yield (Basso and Ritchie, 2005). Organic fertilizers include compost, farm yard manure (FYM), slurry, worm-castings, urine, peat, green-manure, dried blood, bone-meal, fishmeal, and feather-meal (Haynes and Naidu, 1998). Inorganic fertilizers include sodium nitrate, rock phosphate, limestone, ammonium nitrate, potassium nitrate, NPK fertilizers, muriate of potash (MOP), and supper phosphates (Taylor, 1997). Both organic and inorganic fertilizers are sources of mineral elements, which plants require for effective growth and development. Essential mineral elements are required in optimum amounts and are classified into micro and macro. Nitrogen, phosphorus, and potassium have great effects in plant growth and development. Their deficiencies or excesses result in marked effects on the growth and yield of crops. Nitrogen is a chlorophyll component, and it promotes vegetative growth and green coloration of foliage (Jones, 1983). Phosphorus plays a major role in photosynthesis, respiration, energy storage, cell division, and maturation. Potassium is important in plant metabolism, protein synthesis, and chlorophyll development (Remison, 2005). The most important crop nutrients in agricultural systems are nitrogen (N), phosphorus (P), and potassium (K) (Chude et.al. 2004). Most compound fertilizers will contain three elements essential for plant growth: NPK which stands for nitrogen (promotes leaf growth), phosphorus (root, flower, and fruit), and potassium (stem and root growth and protein analysis). Soybean seeds contain a high percentage of protein about 35–40%, and may require a large amount of nitrogen, phosphorus and potassium compared with other crops. Soybean plants make root nodules with rhizobia, and rhizobia can fix atmospheric Nitrogen and give the fixed Nitrogen to the host soybean plants. Also, soybean can absorb nitrogen usually nitrate from soil or fertilizers. The amount of total assimilated nitrogen in shoot is proportional to the soybean seed yield either from nitrogen fixation or from nitrogen absorption, and the nitrogen availability is very important for soybean cultivation. Maintenance of a high and long-term nitrogen fixation activity is very important for a high production of soybean. However, application of chemical nitrogen fertilizers usually depresses nodule formation and nitrogen fixation. Nitrate in direct contact with a nodulated part of roots causes severe inhibition of nodule growth and nitrogen fixation, although a distant part of nodules from nitrate application gives no or little effect. Soybean nitrogen (N) requirements are met in a complex manner, as this crop is capable of utilizing both soil N (mostly in the form of nitrate) and atmospheric Nitrogen (through symbiotic nitrogen fixation) (Vera, et al., 2002). The use of fertilizer is considered to be one of the most important factors to increase crop yield. Phosphorous has been shown to be an essential element, and its application has been shown to be important for growth, development, and yield of soybean (Kakar, et al., 2002). Phosphorus deficiency is probably one of the greatest constraints for agriculture. Potassium often limits production and needs to be included in a soil fertility program; potassium should be included as corrective nutrient. Increases in soybean yield were obtained in response to Potassium fertilization. Farhad, et al., (2010) in their research, reported that potassium showed significant effect on yield and yield attributes of soybeans when applied at 40 kg ha in Sudan. The increased growth of soybean may be due to optimum nutrient supply and better soil condition for growth of root and shoot of soybean crop in the country. In Nigeria, farmers applied different levels of NPK fertilizers to improve the yield of soybeans which sometimes may not be adequately applied at an appropriate and require levels and this may cause harmful effect on the soil, plants and human. Also, excessive application of chemical fertilizers depresses nodule formation and nitrogen fixation in soybeans which retard the growth of the crops and hence, reduce the yield. The objective of this study is to investigate if NPK fertilizers have effect on the yield of soybeans; examine which of the three elements of NPK contribute most to the yield of soybeans; investigating the appropriate levels each of the trio of NPK are to be applied for optimum yield; and estimate the optimal yield of soybeans when applied at the required levels.

3. Methodology

Factorial experimentation is adopted in this investigation because it permits the experimenter to evaluate effect of two or more factors as well as interactions effect between factors. The model for factorial experiment depends on the number of factors to be investigated, in this experiment, there are three factors Nitrogen, Phosphorus and potassium each at three different levels namely: N_{30}, N_{60}, N_{90}; P_{30},P_{60}, P_{90} and K_{30}, K_{60}, K_{90} are to be investigated on soya-beans, then the model for the 3 by 3 factorial design is:

$$y_{ijkl} = \mu + \tau_i + \beta_j + (\tau\beta)ij + \gamma_k + (\tau\gamma)ik + (\beta\gamma)jk + (\tau\beta\gamma)ijk + \varepsilon_{ijkl} \qquad (2.1)$$

As $i = 0,1,2$, $j = 0,1,2$, $k = 0,1,2$, and $l = 0,1$

y_{ijkl} Is the yield recorded for the i^{th} level of factor N, the j^{th} level of factor P and K^{th} level of factor K.

μ is the overall mean effect; τ_i is the effect of the i^{th}level of factor N.

β_j Is the effect of the j^{th} level of factor P; $(\tau\beta)ij$ is the interaction effect between levels of the factors N and P.

Ɣ_k Is the effect of U^{th} level of factor K; $(\tau\text{Ɣ})ik$ is the interaction effect between levels of factors N and K; $(\beta\text{Ɣ})jk$ is the interaction between levels of factors P and K, and $(\tau\beta\text{Ɣ})ijk$ is the interaction effect between levels of factors N, P, and K; ε_{ijkl} is the random error while n represents the number of replicate.

3.1 The use of ANOVA

Analysis of Variance (ANOVA) helps one to determine whether there are significant differences among the means of various groups or conditions. Hence, ANOVA helps to establish if there is contribution of the trio of Nitrogen, Phosphorus and Potassium on the yield of Soybean.

3.2 Post-Hoc Means Comparisons

Post-hoc comparisons (also known as *a posteriori*) are used when you want to conduct a whole set of comparisons, exploring the differences between each of the groups or conditions in one study. Hence, post-hoc comparisons are designed to guard against the possibility of an increased Type 1 error due to the large number of different comparisons being made. In-order to examine which of the three elements contribute most to the yield of soybeans, the study employed various means comparisons techniques such as: LSD, Tukey, Scheffe and Bonferroni. The test were carried out to know which level of the factors differ from the rest at N_{30}, N_{60}, N_{90}; P_{30},P_{60}, P_{90} and K_{30}, K_{60}, K_{90}.

3.3 Optimization of the application of NPK: Using Multiply Regression

To obtain the optimal application of Nitrogen, Phosphorous and Potassium the study employed the application of multiple regressions to determine the appropriate levels for those elements that contribute most to the yield.
General Multiple Regression Model:

$$Y = \beta_0 + \beta_1 Ni + \beta_2 P_i + \beta_3 K_i + e_i \qquad (2.2)$$

Where Y is dependent variable, $Y =$ Soybeans yield

N_i, P_i and K_i are independent variables; β_1, β_2, β_3 and β_4 are partially regression coefficients

β_o is the intercept (mean effect of variable excluded from the model) and e_i is the stochastic disturbance term.

3.4 Estimation of the optimal yield: The use of Response Surface Methodology

In experiments where one or more quantitative factors are tested at multiple levels, it is often convenient to summarize the data by fitting a suitable model depicting the factor-response relationship. The quantitative factors are the various NPK fertilizers levels used. A typical model may be

$$g_u = f(x_{1u}, x_{2u}, \ldots, x_{ku}; b) + e_u \qquad (2.3)$$

Where u = 1, …, t represents the N observations with x_{iu} representing the level of the ith factor (i = 1, 2, …, k) in the in the uth observation. The residual e_u measures the experimental error of the uth observation. The function f is called the response surface. Hence, the estimation of the optimal yield is obtained.

4. Results and Discussion

Table 3.1: ANOVA Results of the Soya-beans Growth

Source	Sum of Squares	df	Mean Square	F_{cal}	Sig.	Remark
Corrected Model	25766.184[a]	17	1515.658	378.880	.000	Sig.
Intercept	48823.278	1	48823.278	12204.721	.000	Sig.
N	51.751	2	25.876	6.468	.041	Sig.
P	22934.729	2	11467.364	2866.583	.000	Sig.
K	8.035	1	8.035	2.009	.216	Not Sig.
N * P	50.003	4	12.501	3.125	.122	Not Sig.
N * K	12.092	2	6.046	1.511	.307	Not Sig.
P * K	414.270	2	207.135	51.779	.000	Sig.

N * P * K	16.514	4	4.128	1.032	.473	Not Sig.
Error	20.002	5	4.000			
Total	82275.665	23				
Corrected Total	25786.186	22				

a. R Squared = .999 (Adjusted R Squared = .997)

4.1 Post Hoc Analysis of Soya-Beans

Since the Nitrogen, Phosphorus and Phosphorus*Potassium were significant at 5%, we therefore carry out a Post Hoc Analysis; the Duncan, LSD, Tukey, Scheffe and Bonferroni. The test were carried out to know which level of the factors differ from the rest for Nitrogen at N_{30}, N_{60}, N_{90} be the levels and Phosphorus at P_{30}, P_{60} and P_{90} levels.

Table 3.2: Post-Hoc Analysis of Nitrogen on the Yield of Soya-Beans

	(I) N	(J) N	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1.00	2.00	-.3083	1.08017	.956	-3.8231	3.2065
		3.00	2.2239	1.05414	.182	-1.2062	5.6540
	2.00	1.00	.3083	1.08017	.956	-3.2065	3.8231
		3.00	2.5322	.97187	.103	-.6302	5.6946
	3.00	1.00	-2.2239	1.05414	.182	-5.6540	1.2062
		2.00	-2.5322	.97187	.103	-5.6946	.6302
Scheffe	1.00	2.00	-.3083	1.08017	.960	-3.9829	3.3662
		3.00	2.2239	1.05414	.204	-1.3621	5.8099
	2.00	1.00	.3083	1.08017	.960	-3.3662	3.9829
		3.00	2.5322	.97187	.117	-.7739	5.8383
	3.00	1.00	-2.2239	1.05414	.204	-5.8099	1.3621
		2.00	-2.5322	.97187	.117	-5.8383	.7739
LSD	1.00	2.00	-.3083	1.08017	.787	-3.0850	2.4683
		3.00	2.2239	1.05414	.089	-.4859	4.9336
	2.00	1.00	.3083	1.08017	.787	-2.4683	3.0850
		3.00	2.5322*	.97187	.048	.0340	5.0305
	3.00	1.00	-2.2239	1.05414	.089	-4.9336	.4859
		2.00	-2.5322*	.97187	.048	-5.0305	-.0340
Bonferroni	1.00	2.00	-.3083	1.08017	1.000	-4.1258	3.5091
		3.00	2.2239	1.05414	.266	-1.5016	5.9493
	2.00	1.00	.3083	1.08017	1.000	-3.5091	4.1258
		3.00	2.5322	.97187	.144	-.9025	5.9669
	3.00	1.00	-2.2239	1.05414	.266	-5.9493	1.5016
		2.00	-2.5322	.97187	.144	-5.9669	.9025

Table 3.3: Post-Hoc Analysis of Phosphorus on the Yield of Soya-Beans

	(I) P	(J) P	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1.00	2.00	42.8170*	1.03514	.000	39.4487	46.1852
		3.00	-39.2400*	1.00004	.000	-42.4941	-35.9859
	2.00	1.00	-42.8170*	1.03514	.000	-46.1852	-39.4487
		3.00	-82.0570*	1.03514	.000	-85.4252	-78.6887
	3.00	1.00	39.2400*	1.00004	.000	35.9859	42.4941
		2.00	82.0570*	1.03514	.000	78.6887	85.4252
Scheffe	1.00	2.00	42.8170*	1.03514	.000	39.2956	46.3383
		3.00	-39.2400*	1.00004	.000	-42.6420	-35.8380
	2.00	1.00	-42.8170*	1.03514	.000	-46.3383	-39.2956
		3.00	-82.0570*	1.03514	.000	-85.5783	-78.5356
	3.00	1.00	39.2400*	1.00004	.000	35.8380	42.6420
		2.00	82.0570*	1.03514	.000	78.5356	85.5783
LSD	1.00	2.00	42.8170*	1.03514	.000	40.1560	45.4779
		3.00	-39.2400*	1.00004	.000	-41.8107	-36.6693
	2.00	1.00	-42.8170*	1.03514	.000	-45.4779	-40.1560
		3.00	-82.0570*	1.03514	.000	-84.7179	-79.3960
	3.00	1.00	39.2400*	1.00004	.000	36.6693	41.8107
		2.00	82.0570*	1.03514	.000	79.3960	84.7179
Bonferroni	1.00	2.00	42.8170*	1.03514	.000	39.1586	46.4753
		3.00	-39.2400*	1.00004	.000	-42.7743	-35.7057
	2.00	1.00	-42.8170*	1.03514	.000	-46.4753	-39.1586
		3.00	-82.0570*	1.03514	.000	-85.7153	-78.3986
	3.00	1.00	39.2400*	1.00004	.000	35.7057	42.7743
		2.00	82.0570*	1.03514	.000	78.3986	85.7153

4.2 Response Surface Method

Response surface methodology deals with the optimization of responses that is influenced by various factors of the levels of the three fertilizers; Nitrogen, Phosphorus and Potassium (NPK) on the growth of the soya-beans. The analysis was done using coded units through Estimated Regression Coefficients for the soya-beans yield.

Table 3.4: **Response Surface Regression of the Soya-Beans**
Response Surface Regression: Soya-beans Yield versus N, P, K
Model: Yield = C(1)+C(2)*N+ C(3)*P+ C(4)*K+ C(5)*N*P+ C(6)*N*K+ C(7)*P*K+C(8)* N*P*K

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	23.56047	180.8519	0.130275	0.8981
C(2)	-12.49669	82.36799	-0.151718	0.8814
C(3)	11.45511	82.92662	0.138135	0.8920
C(4)	-9.128539	113.5851	-0.080367	0.9370
C(5)	8.412062	36.88439	0.228066	0.8227
C(6)	8.600928	50.60355	0.169967	0.8673
C(7)	6.808789	52.41687	0.129897	0.8984
C(8)	-6.330242	23.30424	-0.271635	0.7896
R-squared	0.256132	Mean dependent var		49.55870
Adjusted R-squared	-0.091006	S.D. dependent var		34.23594
S.E. of regression	35.75986	Akaike info criterion		10.25974
Sum squared resid	19181.51	Schwarz criterion		10.65469
Log likelihood	-109.9870	Hannan-Quinn criter.		10.35907
F-statistic	0.737839	Durbin-Watson stat		1.745779
Prob(F-statistic)	0.644347			

The goodness of fit was determined by the R-squared value of 26% with the F-statistic of white soya-beans at 5% level of significance.

4.3 Estimation of Soya-beans Maximum Yield Levels

Overall Model: Yield = 23.56047 – 12.49669N + 11.45511P - 9.128539K + 8.412062NP + 8.600928NK + 6.808789PK – 6.330242NPK, this model will be the appropriate method to know the maximum yield in order to confirm the real levels of the fertilizers (N, P and K) to give the significant maximum yield of soya-beans.

Table 4.5: Estimation of Maximum Yield Overall Model for Soya-beans

N	P	K	Rep1	Rep2	Rep3	Yield	Max Yield
1	1	1	14.2	23.8	9.6	47.6	30.88189
1	1	2	17.75	29.75	12	59.5	30.83282
1	2	1	4.33	4.76	3.35	12.44	51.22761
1	2	2	0.3	0.43	0.32	1.05	51.65709
1	3	1	28.16	32.06	32.9	93.12	71.57333
1	3	2	24.79	28.3	35.13	88.22	72.48136

2	1	1	10.2	18.8	9.4	38.4	29.06795
2	1	2	12.75	23.53	11.75	48.03	31.28957
2	2	1	4.4	4.67	4.6	13.67	51.49549
2	2	2	0.3	0.34	0.29	0.93	47.86541
2	3	1	27.65	31.1	29.78	88.53	73.92302
2	3	2	27.81	26.7	31.23	85.74	64.44126
3	1	1	13.2	18	12.8	44	27.254
3	1	2	16.5	22.5	16	55	31.74631
3	2	1	4.41	4.38	4.13	12.92	51.76336
3	2	2	0.28	0.36	0.29	0.93	44.07373
3	**3**	**1**	27	30.38	28.21	85.59	**76.27272**
3	3	2	23.36	34.84	31.78	89.98	56.40116
3	2	2	0.3	0.34	0.29	0.93	44.07373
2	3	1	27.65	31.1	29.78	88.53	73.92302
2	3	2	27.81	26.7	31.23	85.74	64.44126
2	1	1	13.2	18	12.8	44	29.06795
3	1	2	16.5	22.5	16	55	31.74631

5. Conclusion

From the ANOVA table 3., the results indicated that the fittest model is the factorial design since the corrected model is significant with the value of 0.000 that is lesser than the level of significance 0.05. It can be affirmed that Nitrogen, Phosphorus and Phosphorus*Potassium have significant effect on the yield or growth of soya-beans at 5% level of significance. The goodness of fit of the model affirmed 99.9% of the Factorial Analysis. The Post-Hoc Analysis of table 3.2 shows that Nitrogen at N_{60} and N_{90} using the Fisher's Least Significant Difference (LSD). Hence, soya-beans need between 60kg and 90kg of Nitrogen. Also, post-hoc analysis for phosphorus implies that there is significant difference in the means of all combinations of all the levels of phosphorus fertilizer; that is level 1, level 2 and level 3, but phosphorus at 90kg is better than other levels used. Hence, the regression equation for the linear and interaction between the factors using the coded unit from table 3.4 is given thus; Yield = 23.56047 – 12.49669N + 11.45511P - 9.128539K + 8.412062NP + 8.600928NK + 6.808789PK – 6.330242NPK. Hence, from table 3.5, it shows that the optimal yield of 76.27tonne/hectare of soya-beans could be obtained if Nitrogen is applied at 90kg, Phosphorus at 90 kg and 0kg of Potassium,

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