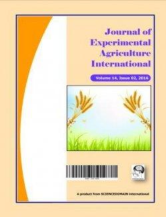

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Modelling the Dual Potential of Cowpea in the Lawra-Yagtuuri in the Upper West Region

Puoviel Yengbaar Evans[1], Jakperik Dioggban[1*] and Adjabui Michael Jackson[2]

[1]Department of Statistics, University for Development Studies, Tamale, Navrongo Campus, P.O.Box 24, Navrongo, Ghana.
[2]Department of Mathematics, University for Development Studies, Tamale, Navrongo Campus, P.O.Box 24, Navrongo, Ghana.

Authors' contributions

This work was carried out in collaboration between all authors. Author PYE designed the study, wrote the protocol and wrote the first draft of the manuscript. Author JD wrote the protocol and performed the statistical analysis. Author AMJ managed the analysis and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This research was conducted in pot of trials at the farm land of Lawra-Yagtuuri in the Upper West Region to determine the effect of Rhizobia inoculants, Boostxtra, and appropriate Phosphorus Fertilizer level required for cowpea growth and yield.

Study Design: The research design used in this study was experimental. Specifically, the experiment was run as a split-plot design.

Place and Duration of Study: Department of Statistics and Department of Mathematics, University for Development Studies, between November, 2015 and July, 2016.

Methodology: The experiment assessed the effects of rhizobia inoculants at two levels (2.5 g and 5.0 g) per kg, boostxtra and four levels of phosphorus fertilizer (0 kg P_2O_5 ha^{-1}, 25 kg P_2O_5 ha^{-1}, 50 kg P_2O_5 ha^{-1} and 75 kg P_2O_5 ha^{-1}) on the growth and yield of cowpea. It was run in a split-plot design. The analysis was done using Generalized Linear Model and Subset Regression.

**Corresponding author: E-mail: jdioggban@yahoo.com;*

Results: Phosphorus Fertilizer and Boostxtra significantly enhanced cowpea growth and yield; Pod weight plant (g), Nodule dry weight (g), Pod and Nodule numbers in all the weeks of measurement were significantly improved. However, the highest yield was observed at 50 kg P_2O_5 ha^{-1}. Cowpea response to rhizobia inoculation was not sufficient to raise cowpea yield. The model was significant ($P<0.05$) accounting for 77.70% of total variation in the yield. The subset regression analysis had C(p)=5.28 from six variables in the model with the Adjusted R Square = 0.9318.

Conclusion: The ability to optimize cowpea grain yield depends on the application of 50 kg P_2O_5/ha and Boostxtra and care should be taken to apply the right amount of Phosphorus Fertilizer.

Keywords: Cowpea; leguminous crop; subset regression; yield; generalized linear model.

1. INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp) is an important leguminous crop in the dry savannah of the tropics covering 12.5 million hectares with annual production of about 3 million tons [1]. Cowpea in Africa; in Ghana is popularly called ‘beans’ and ‘niebe’ in the Francophone Countries. The largest production is in the moist and dry Savannas of Sub Saharan Africa (SSA), where it is intensively grown as an intercrop with other cereal crops like millet, sorghum and maize [2]. Though it is grown in other parts of the world, Nigeria remains the largest producer and consumer of Cowpea in the world [3]. According to FAO data [3], Nigeria produces an average of 2.58 ± 0.31 million metric tons of cowpea per year.

Both grain and leaves are edible products of cowpea that are rich and cheap sources of high-quality protein. They supplement to the lower quality cereal or root and tuber protein commonly consumed in tropical Africa [4,5]. On average cowpea grains contain 23-25% protein and 50-67% starch in dry bases [6]. From a single planting, one may be able to have several products such as leaves, immature pods, immature and mature seeds. Careful and positive attention to cowpea would support 850 million people in the world with high incidence of undernourishment in sub-Saharan Africa as documented by FAO [3].

The area under cowpea cultivation in Ghana peaked in the year 2003 with 190,400ha, but cowpea production continues to be lower than its consumption rate in Ghana in 2010 [7]. This is evidenced by the import of 3,380 MT of cowpea grains which supplemented the country’s production of 219,300 MT in 2010 [7].

The inability of Ghana to produce enough cowpea to feed the citizenry is multi-faceted. Specific fertilizer recommendation and integration of biological materials to increase the yield of cowpea farmers may prove successful. The effectiveness of applied fertilizer, rhizobia inoculants and boostxtra are constrained by the use of the inappropriate rate and improper timing of sowing. Hence, the low yield of cowpea among smallholder farmers in the Country especially in the Lawra-Yagtuuri in the Upper West Region requires attention.

The main objective of the study is to model the yield of Cowpea production in the Lawra-Yangtuuri using Generalized Linear Model.

2. METHODOLOGY

The data was obtained in the experimental field at Yagtuuri in a split-plot design with inoculation rates (5.0 and 2.5 kg of rhizobia inoculants per ha), phosphorus rates (0, 25, 50, and 75 kg P_2O_5/ha) and boostxtra. The plant height, shoot dry weight, nodule dry weight and nodule number per plant were recorded at two weeks after planting (2 WAP), six weeks after planting (6 WAP), eight weeks after planting (8 WAP), ten weeks after planting (10 WAP), twelve weeks after planting (12 WAP) and fourteen weeks after planting (14 WAP). Plant height was taken from the ground level to the apex of the plant with a graduated pole and the average was calculated for each plot. Pods on these plants were removed and counted to obtain the pod number/plant.

Mainly two models were used in the analysis: The Subset Regression analysis and the Generalized Linear Model.

2.1 Generalized Linear Models

The generalized linear model is partitioned into three components made up of the Systematic component, the Link function component, and the Random component.

The Systematic component expresses explanatory variables in a linear predictor function. Given covariates X_i, the mean of Y_i can be expressed in terms of the following linear combination of predictors.

$$\eta_i = X_i^T \beta \tag{1}$$

It consists of a linear predictor

$$\eta_i = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_p x_{pi} \tag{2}$$

The Link function component is an invertible function that links the mean of the response to the systematic component. This link function associates the linear combination of predictors with the transformed mean response.

$$\eta_i = g(\mu_i) \tag{3}$$

$$\text{Where } \mu_i = E(Y_i \mid X_i) \tag{4}$$

Thus the link function typically describes how the mean, $E(Y_i) = \mu_i$ depends on the linear predictor

$$g(\mu_i) = \eta_i \tag{5}$$

The Random component identifies Y_i, the response and its probability distribution. Y_i is assumed to follow distribution that belongs to the exponential family.

$$Y_i \mid X_i \sim f(\theta_i, \phi) \tag{6}$$

Where ϕ is the dispersion parameter.

This essentially, is a variance function that describes how the variance, $\operatorname{var}(Y_i)$ depends on the mean

$$\operatorname{var}(Y_i) = \phi V(\mu) \tag{7}$$

Where the dispersion parameter ϕ is constant [8,9].

In the random component of Generalized Linear Model, Y_i is assumed to follow a probability distribution that belongs to the exponential family. The density functions of the exponential family of distributions have this general form:

$$f(y;\theta,\phi) = \exp\left\{ \frac{y\theta - b(\theta)}{a(\phi)} + c(y,\phi) \right\} \tag{8}$$

Where θ is called the canonical parameter and ϕ the scale (dispersion) parameter.

$a(\phi)$ and $b(\theta)$ are some specific functions that distinguish one member of the exponential family from another. If ϕ is known, this is an exponential family model with only canonical parameter of θ [8].

2.1.1 Assumptions of the generalized linear model

Four major assumptions underlie the Generalized Linear Model.

Linearity, the assumption of linearity implies that the relationship between the dependent variable and the recently freed independent variable is also linear.

Normality of the residuals, the normality assumption implies that the dependent variable is normally distributed within each group.

Equality of residual variances, the assumption of the equality of residual variances holds that all these variances will be the same.

Fixed independent variables measured without error, this assumption is required only when one wishes to have a point estimate of the population parameter [8,10].

2.2 Mallows C(p) Criterion

The Mallows C(p) Criterion compares predictive ability of the best subset models to that of full model. Generally, full model is best for prediction; but if multicollinearity is present, then parameter estimates are not useful. Subset of full model that does not have as much multicollinearity will be better as long as there is no substantial “bias” in predicted values relative to full model (that is, close to same predictive ability). C(p) considers ratio of Sum of Squares Error (SSE) for p – 1 variable model to Mean Square Error (MSE) for full model; then penalizes for the number of variables:

$$C(p) = \frac{SSEp}{MSE(full)} - (n - 2p) \quad (9)$$

A model is considered “good” if C(p) ≤ p. The smallest model for which this is true is chosen to reduce intercorrelation and to ensure parsimony. The benefit of C(p) is that, you can use it to select model size – getting a good model that contains as few variables as possible, and it is more about C(p) relative to p, and getting a smaller number of variables in the model while still having the same predictive ability.

3. RESULTS

The study revealed that fertilizer at level 2 showed the highest average performance of 3017.6658 kg/ha and 2837.5428 kg/ha at level 3 as compared to the control at level 0 (Table 1).

However, the control level average is higher than the fertilizer at level 1. This is followed by boostxtra with 2869.3811 kg/ha higher than the control mean value of 2575.4025 kg/ha. There is slight difference in the average performance of inoculation at 5.0 g and 2.5 g of rhizobia inoculants per kg with 2732.8327 kg/ha and 2711.9509 kg/ha respectively (Table 1).

The study showed (Table 2) that the parameter estimates of the model are statistically significant with significant difference in their performance over the controls (P<0.05).

Fertilizer at levels (2 and 3) performed better with 496.041 kg/ha and 315.918 kg/ha respectively over the control. No difference in the performance of Fertilizer at level 1 compared to the Control was recorded. Inoculation rates (0 and 1) indicated no difference in their performance. The Boostxtra showed that level 0 performed -293.979kg/ha over the control (Table 2).

The research again revealed that the performance of fertilizer level 2 and boostxtra are statistically significant over the controls (P<0.05). Fertilizer levels 2 vs. 1 group also showed significance in performance (Table 3).

Table 1. Estimates of the mean of the variables levels

Variable	Category	Mean	Std. error	95% Wald confidence interval	
				Lower	Upper
Innoculation	0	2732.8327	0.1415	2732.5553	2733.1101
	1	2711.9509	0.1476	2711.6616	2712.2401
Boostxtra	0	2575.4025	0.1479	2575.1127	2575.6922
	1	2869.3811	0.1418	2869.1033	2869.6590
Fertilizer	0	2521.6253	0.2045	2521.2245	2522.0260
	1	2512.7333	0.2041	2512.3333	2513.1334
	2	3017.6658	0.2043	3017.2654	3018.0662
	3	2837.5428	0.2050	2837.1410	2837.9446

Inoculation (0) = 5.0 g of inoculants per kg, Inoculation (1) = 2.5 g of inoculants per kg, Boostxtra(0) = No boostxtra, Boostra(1) = Boostxtra applied, fertilizer(3) = 75 kg P/ha, fertilizer(2) = 50 kg P/ha, fertilizer(1) = 25 kg P/ha, fertilizer(0) = 0 kg P/ha

Table 2. The test of parameter estimates

Parameter	B	Std. error	Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald Chi-square	Df	Sig.
Innoculation=0	2679.056	0.2437	2678.578	2679.533	120854966.524	1	0.00
Innoculation=1	2658.174	0.2503	2657.683	2658.664	112746228.409	1	0.00
Fertilizer=1	-8.892	0.2889	-9.458	-8.326	947.131	1	0.00
Fertilizer=3	315.918	0.2888	315.352	316.484	1196597.144	1	0.00
Fertilizer=2	496.041	0.2893	495.473	496.608	2939744.503	1	0.00
Fertilizer=0	0	-	-	-	-	-	-
Boostxtra=0	-293.979	0.2052	-294.381	-293.576	2052500.768	1	0.00
Boostxtra=1	0	-	-	-	-	-	-

Inoculation (0) = 5.0 g of inoculants per kg, Inoculation (1) = 2.5 g of inoculants per kg, Fertilizer (1) = 25 kg P/ha, Fertilizer (3) = 75 kg P/ha, Fertilizer (2) = 50 kg P/ha, Fertilizer (0) = 0 kg P/ha, Boostxtra (0) = No boostxtra, Boostxtra (1) = Boostxtra, DF=Degrees of Freedom, Sig=probability that the given variable is different from 0, (also called the P-Value), and B=parameter estimates

Table 3. The individual test results of the variable levels

Variable	Level	Contrast estimation	Std. error	Wald Chi-square	Df	Sig.
Innoculation	0 vs. 1	20.882	149.517	0.020	1	0.89
Boostxtra	0 vs.1	-293.979	150.040	3.839	1	0.84
	1 vs.0	-8.892	211.264	-.002	1	0.97
	2 vs.0	496.041	211.542	5.498	1	0.02
Fertilizer	3 vs.0	315.918	211.171	2.238	1	0.14
	3 vs.1	32.481	21.847	2.210	1	0.14
	2 vs.1	50.493	21.809	5.360	1	0.02
	2 vs.3	18.013	21.895	0.677	1	0.41

Inoculation (0) = 5.0 g of inoculants per kg, Inoculation (1) = 2.5 g of inoculants per kg, Fertilizer (1) = 25 kg P/ha, Fertilizer (3) = 75 kg P/ha, Fertilizer (2) = 50 kg P/ha, Fertilizer (0) = 0 kg P/ha, Boostxtra (0) = No boostxtra, Boostxtra (1) = Boostxtra, DF=Degrees of Freedom, Sig=probability that the given variable is different from 0, (also called the P-Value)

There had been 20.882 kg/ha difference in the performance of the inoculation rates. The boostxtra level 0 also showed -293.979 kg/ha significant difference in its performance over the control. There was also a noticeably 496.041 kg/ha significant difference in the performance of fertilizer at level 2 over the control (Table 3). Fertilizer at level 3 and level 1 respectively indicated 315.918 kg/ha and -8.892 kg/ha performance difference over the control. The fertilizer rates (2 vs. 1) indicated 50.493 kg/ha significant difference in performance.

From Table 4, the analysis of variance showed that there is linear relationship between dependent variable (grain yield kg/ha) and at least one of the explanatory variables with a p-value of 0.005. This indicated that the model is significant and good for predicting Grain yield. The relevant plots used for the validation of the assumptions are shown in appendix A1.

The estimated model becomes;

$\hat{Y}$ = 496.041*Fertilizer (2) - 293.979*Boostxtra (0)

Where $\hat{Y}$ = Grain yield kg/ha, Fertilizer (2) = 50kg P/ha and Boostxtra (0) = Presence of Boostxtra.

The R Squared Adjusted (.78) indicated that 78% of the variation in grain yield is explained by Inoculation, Fertilizer, and Boostxtra (Table 5). The Durbin Watson value of 1.57 indicated a positive autocorrelation in the data set.

Based on the above statistics, a subset regression was conducted to identify a best subset that optimizes grain yield using the Mallows C(p) approach; Pod number, Pod weight per plant (g), Nodule number, and Nodule dry weight (g) for all the weeks of measurement constituted the best subset of variables that optimized grain yield. The subset had a C(p)=5.28 from six variables in the model with Adjusted R Squared = 0.9318.

4. DISCUSSION

The study indicated that Rhizobia inoculation rates could not significantly increase nodules formation and grain yield. This agrees with the studies [11-12] which reported no significant increase in nodulation and seed following rhizobia inoculation. However, [13-14] reported a significant increase in nodule number due to rhizobia inoculation.

Phosphorus Fertilizer rates and Boostxtra significantly increased grain yield ($P<0.05$). This is in line with the findings of [15]. Although they used potassium in their studies, the maximum growth and grain yield were attained at 45 kg/ha. The Phosphorus Fertilizer applications at 50kg P_2O_5/ha significantly optimized grain yield over the Control (0kg P_2O_5/ha). Fertilizer rate 50kg P_2O_5 ha^{-1} gave the highest average grain yield of 3017.6658 kg/ha followed by 75 kg P_2O_5 ha^{-1} with 2837.5428 kg/ha over the control (0 kg P_2O_5/ha). This was in contrast to [16-17] that Phosphorus applications at 22.5 P_2O_5/ha and 45 kg P_2O_5/ha induced significantly similar responses with respect to grain yield and seed size but both were significantly higher than that of the control (0 kg P_2O_5/ha). This is contrary to the reports of other researchers that 30 – 0 – 30 kg N-P_2O_5- K_2O ha^{-1} gives the highest grain yield of 1.85 and 1.80 tons ha^{-1} for the 2 years [18]. This could be attributed to the levels of P (16.98 $mgkg^{-1}$) available in the soil before treatments were applied [18].

Table 4. Analysis of variance

Source	DF	SS	MS	F	P
Regression	16	18901835	1181365	2.41	0.01
Residual error	79	38778175	490863		
Total	95	57680010			

DF=Degrees of Freedom, SS=Sum of Squares, MS=Means Squares, F=Fisher's ratio (which defines the significance of the regression model), and P=Probability that the F-value is significantly different from 0

Table 5. Selection for model summary

Model	R	R-squared	Adj. R-squared	Std. error of the estimate	Statistic		Durbin watson
					F	Sig	
	0.885	0.784	0.777	134.0667	112.284	0.00	1.565

R=Correlation coefficient, F=Fisher's ratio (which defines the significance of the regression model), Sig=probability that the given variable is different from 0, (also called the P-Value)

The increase in P fertilizer rate from 25 kg P_2O_5 to 50 kg P_2O_5 resulted in an increase in grain yield and declined as the rate increased to 75 kg P_2O_5. This response to P_2O_5 is similar to the observation of [19] that increased P fertilization led to increased grain yield up to 30 kg P_2O_5 ha^{-1} treatment beyond which yield decline was observed.

The generalized linear model is significantly high and explains about 77.70% of the total variation in cowpea farming in the study area. Boostxtra and fertilizer were the two most influential variables that defined yield in the study area. This result is a clear indication of the presence of multicollinearity. A further subsets regression analysis was performed and the results indicated that Pod number, Pod weight per plant (g), Nodule number, and Nodule dry weight (g) for all the weeks of measurement constituted the best subset of variables that optimized grain yield with C(p) = 5.28 and Adjusted R^2 = 0.9318. This is not different from [16] that the application of Phosphorus fertilizer of 22.5 and 45 kg P_2O_5 ha^{-1} significantly increase pod number, nodule number, plant height, biomass and shoot dry weight over the control treatment (0 kg P_2O_5 ha^{-1}) for all the weeks of measurements. Also, [20] observed that the application of phosphorus fertilizer rates 40 and 60 kg/ha significantly enhanced both number and dry weight of nodules of cowpea varieties.

5. CONCLUSION

The study revealed that the most influential variables that optimize cowpea yield in Lawra-Yagtuuri are the application of phosphorus fertilizer at 50 kg P_2O_5/ha and boostxtra. The application of phosphorus fertilizer at 50 kg P_2O_5/ha increased cowpea growth and grain yield and care should be taken to apply the P in the right amount.

Additionally, for optimum grain yield of cowpea, farmers should use 50 kg P_2O_5/ha. In the event that the soil fertility is not sufficient enough, farmers can adopt 75 kg P_2O_5/ha for yield optimization. Farmers are also advised to save the cost of buying artificial inoculants.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A1

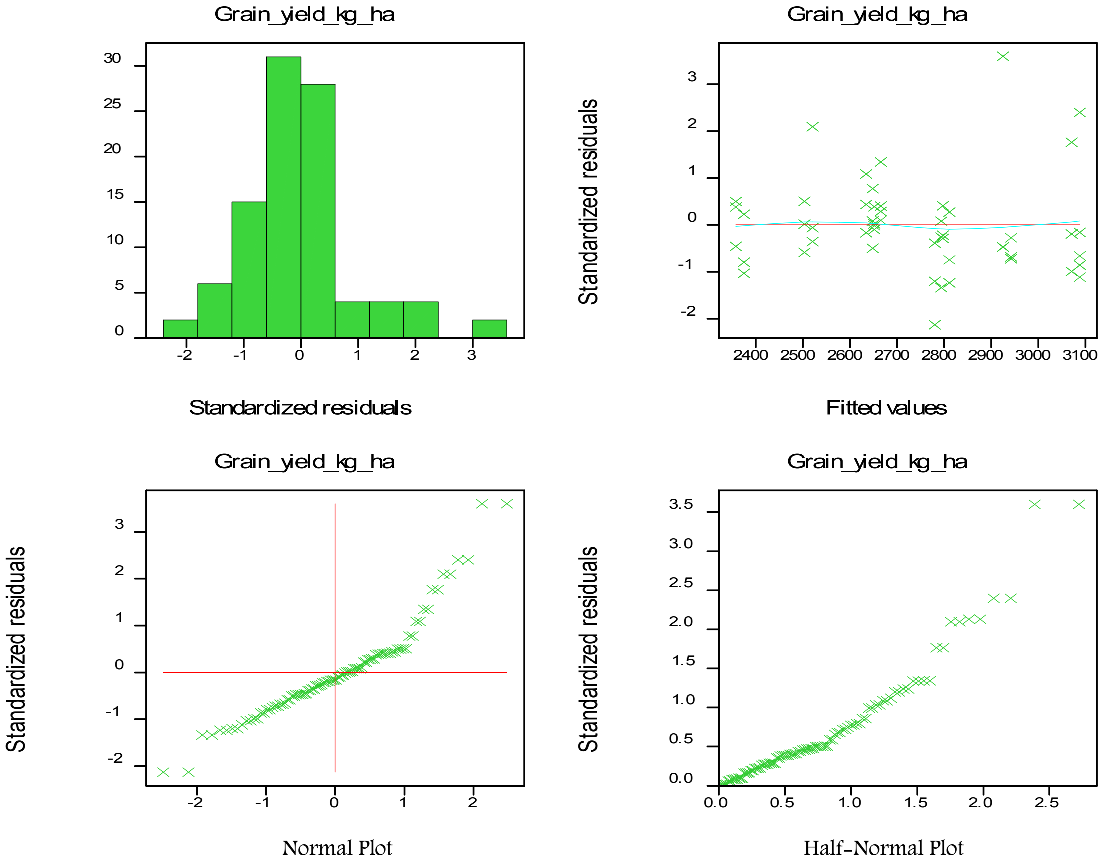

Fig. 1. Residual plots used for the verification of assumptions

The histogram assesses the normality assumption of the grain yield. Observing the plots, it can be deduced that the grain yield is not perfectly normal but well approximates the normal distribution. The second graph test the assumption of the generalized linear distribution which requires that the grain yield is normally distributed within each group. The third graph is a follow-up test to the normality test, which requires that for normality assumption to be met, a meaningful straight line through the origin should be fit. As observed, a meaningful straight line through origin which passes through majority of the point can be obtain, hence satisfies the normality assumption. The half normality plot is an emphasis of the earlier normality test.

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