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Appropriate Central Composite Design for Manure Nutrients Application for Cucumber Yields in Akwa Ibom State

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Abstract

Cucumber a popular creeper plant that produces a spherical shape and bright green colour fruits that are used as vegetables is among the profitable agribusiness in Southern Nigeria. This study models a response surface design that fits the cucumber nutrient requirements for specific optimal yield in Akwa Ibom State. The spherical central composite design was designed to have 33 experimental runs and with number of replications included. The variance of the fitted response at different levels of interest were kept constant. Nitrogen fertilizer, pig slurry, and vegimax folia were utilize as the independent variables. The application setting for nitrogen fertilizer, pig slurry and vegimax folia were 100 kg / ha, 10 kg/ha and 5 ml / 20 litres of water respectively. Study results revealed that nitrogen fertilizer and pig slurry in the main effect had a positive significant effect on cucumber yield at 95% level of significance (P-value = 0.000 < 0.05 and P-value = 0.000 < 0.05 respectively). From the result, it was seen that the model was adequate and also significant as the P-value = 0.001 < 0.05. About 91.30% of variation in the model can be accounted for by the variables. Finally, 167.09 kg/ha of nitrogen fertilizer, 87.27 kg/ha of pig slurry and 19.28 ml/20 litres of vegimax folia was found to be the optimum production conditions for the cucumber yield in Akwa Ibom State.

Keywords: *Response Surface Design; Spherical Central Composite Design;Cucumber; Nitrogen Fertilizer.*

I. INTRODUCTION

Cucumber farming business in Southern Nigeria, is one of the most profitable and fast growing areas of agribusiness because cucumber are in high demand all year round for food, health and commercial purposes. Cucumber, a good source of vitamins, minerals, phytochemical compounds and dietary fiber is important for the human health. The business of cucumber farming are relatively fast-growing, require modest capital to start, and can generate high returns within a short time compared to many other crops. The climate and fertile soils in Southern Nigeria support cucumber farming and many other vegetables. Successful cucumber production relies on providing the appropriate nutrients at the correct growth stages. Fertilizers supply these essential nutrients, but determining the proper application rate per unit area is crucial for maximizing plant health and yield. Recently, the decline in cucumber production in Akwa Ibom state has turn people away to other environs. The decline of cucumber farming may be as a result of continuous farming on a particular land which reduces major soil nutrients like nitrogen, phosphorus and some trace elements. Sustainable and successful cucumber farming is tied to soil nutrient improvement. To supply nutrients for vegetable farming, manures are better source of organic nutrients that can also help to enhanced production. Many studies have been conducted on the effects of various input factors, such as fertilizers, irrigation rate, seed density, etc., on the yield of some crops and vegetables [1]. However, these studies did not find the optimum setting for maximum vegetable yield and did not develop an empirical model where the vegetable yield is a function of the input factors. As stated by [2], organic and inorganic fertilizers added into soil creates optimal growing environment for the crops through improvement of its fertility and consequently promotes the crop performance. Climate change is now a big concern and researchers have started to study its effect on crop growth and yield. According to [3], researchers are concerned with identifying management strategies suitable for sustaining crop productivity under projected climate change scenarios. To achieve a quantitative understanding of how crops are response responding to climate shifts, researchers are developing statistical models that consider the crop's time-series behaviour along with various climatic factors. According to [4], summer crops are extremely sensitive to low temperatures during reproductive stages and the variation of their responses to lowered temperatures may have a significant effect on crop yields. The challenge is how to incorporate this relevant information into the forecasting process, and then into decision-making processes and for an operational yield model to be widely adopted, it is important to have access to data.

II. LITERATURE REVIEW

Response surface methodology (RSM) is a vital aspect statistical design of experiment. Based on [5] findings, RSM has been successfully used to develop and improve an optimization process. In addition to [6] that first point the attention of response surface methodology in agricultural and biometric research, RSM has been used to model performance of agricultural experiments. For instance, [7] employed inverse polynomials to simulate maize production as a function of three control variables; specifically amounts of nitrogen, phosphorous and potassium. See also [8-11] for optimization processes demand in Agriculture. They also looked through biological and agricultural publications for papers that used response surface approach to create and optimize parameters for a procedure to improve its performance [12]. The design of experiment (DOE) and response surface approach are used as a powerful and effective tool for modelling and obtaining the optimum experimental conditions of a system under investigation [13]. For its application it is necessary to select and configure the design matrix appropriate to the type of research, to carry out experiments (according to the combination of levels required by the design), to apply methods of mathematical modelling and analysis. However, [14] gave the appropriate criteria in selecting the right central composite design for any experiment while [15] provided the required number of runs needed to execute the experiments if the central composite design were employed. On the other hand, [16] provided a holistic view of vegetable production, covering a wide range of topics including plant physiology, genetics and breeding, crop production systems, pest and disease management, post-harvest handling, and emerging trends in vegetable science. Also, [8] employed central composite design for watermelon crop experiment and optimization required 20 experimental runs. The independent variables were Poultry manure, Cow manure and Goat manure to optimize the response of interest (fruit Weight of water melon at maturity. Cassava yield optimization using the response surface method (RSM) and central composite design (CCD) was done by [17]. Also, [18] studied the effect of three organic manures on the nutritional composition of three leguminous forages (Soybeans, Cowpeas and Groundnuts) grown in the coastal Rainforest of Akwa Ibom State, Nigeria. The impact of various manure on the development and yield of maize in Southern Nigeria was done by [19]. The experiment was laid out in randomized complete block design (RCBD) with three different manures (poultry dropping, pig dung and goat dropping). Similarly, [20] evaluated spatially explicit optimal application rates of manure as fertilizer in Nitrogen and Phosphorus. They did this by balancing their inputs with the crop demand for Nitrogen and Phosphorus and using attainable nitrogen use efficiency values for manure and fertilizer. Furthermore, the influence of various input factors like inorganic and organic manures, irrigation rate, seed density etc. on some crop and vegetable yield has also been shown in the research of [1]. However, the study did not determine the optimal conditions for the maximum vegetable yield nor develop a realistic model making the vegetable yield a function of the input factors. The incorporation of organic and inorganic manures into the soil provides an optimal growing environment for the crops by improving its fertility as cited by [2] and consequently promote the crop performance.

This research will explore the applications of CCD in optimizing analytical methods for obtaining optimal cucumber yield in Akwa Ibom State.

- *Response Surface Model*

In designing an experiment, the ultimate goal of the researcher is to build a design which gives better estimation of relationship between the explanatory variables and response of interest. This is expressed as.

$$y = \eta(s_1, s_2, \cdots, s_t) + \varepsilon \tag{1}$$

From the expression in equation (1), y is the response, η is the true unknown function, $s_1, s_2, \cdots, s_t$ are the explanatory variables and ε is the random error that represents sources of variables not analyzed for η.

In most cases, the true response function η is unknown. To develop a proper approximation for the function, the experiment usually starts with a low order polynomial. If the response can be defined by a linear function of an explanatory variable, then the approximation function is a first order model expressed as.

$$y = \delta_0 + \delta_1 s_1 + \cdots + \delta_t s_t + \varepsilon \tag{2}$$

When curvature exist in the response surface, a higher degree polynomial is applied. For an approximating function with two variables, it is called a second order model written as.

$$y = \delta_0 + \sum_{u=1}^{t} \delta_u s_u + \sum_{u=1}^{t} \delta_{uu} s_{uu}^2 + \sum_{v=u+1}^{t} \sum_{u=1}^{t-1} \delta_{uv} s_u s_v + \varepsilon_{uv} \tag{3}$$

In RSM, the most used design is the central composite design which utilizes the above stated model in (3).

It consists of 2^t full or 2^{t-1} half replicate factorial portion (t is the number of independent variables) coded as (±1,±1, …,±1), the 2t axial portion coded in the form (±α, 0,…, 0), (0,±α,… , 0), and lastly, n_0 the center point coded as (0,0,…,0). The center points give information on the presence of curvature in the system. The number of center points in the CCD also give flexibility and better estimate of the pure error and power for the test. The total number of design points or number of runs for a CCD is given as.

$$N = 2^t + 2t + n_0 \tag{4}$$

- *Analysis of Variance (ANOVA)*

To cross check the effect of the factors in the linear, quadratic and interactions terms of the model in (3) when CCD were applied, is by method of ANOVA. ANOVA is used to examine the unresolved error involved in Lack-of-Fit (LOF), check whether the model fairly represents the exact response surface and finally validate if the model is statistically fit for the approximation of the response pattern. When the effect of each factor does not correspond to the level of statistical accuracy measure, ANOVA can help predict the experiment adequately when varied factor is removed. The calculated value of F is the ratio of average (Mean) sum of squares of regression model (MSM) and average (Mean) sum of squares of error (MSE). The ratio of the model sum of squares to the total sum of squares gives a squared sample correlation shown.

$$r^2 = \frac{SSM}{SST} \tag{5}$$

Squared sample correlation is the proportion of variation in the dependent variable that is explained by the independent variable in a regression model. It makes the interpretation of explaining the fraction of variability formal. Model summary statistics focus on the model maximizing the adjusted r^2 and the predicted r^2. Adjusted r^2 is used to adjust the statistic according to the number of independent variable in the model. It compares the explanatory power of regression model that include different independent predictors. In this case, the adjusted r^2 is the most preferable since the multiple regression models has more than one variable.

III. MATERIALS AND METHOD

This experimental investigation was designed to visit at least 8 hectares of farm sites where the farmers plant only cucumber as the major crop. Nitrogen fertilizer, Pig slurry and vegimax folia are major source of nutrient requirement. The central composite design (CCD) was designed to have at least 33 experimental runs. The variance of the fitted response at different points of interest are kept constant. Nitrogen fertilizer, Pig slurry, and Vegimax folia are utilize as the explanatory variables, with their effects on cucumber output recorded as the response surface. The region of exploration for this study was (80-150) kg ha-1 of nitrogen fertilizer, (5-15) tonnes ha-1 of pig slurry and (3-7) ml / 20 litres of water of vegimax folia depending on the soil nutrient level before planting.

- *Three Factor Central Composite Design*

The spherical CCD was the choice of design for this study as the other variations of CCD were not significant. The factorial and axial portion of the CCD were replicated twice with five center points. This provided a 33 number of experimental runs for this study.

$$N = 2(2^3) + 2(2*3) + 5n_0$$

The CCD was centered about the current operating conditions of the system and to simplify the arithmetic operations, the independent variables were coded to (-1, 1) interval.

$$s_i = \frac{s_i - s_0}{\omega} \tag{6}$$

Letting s_i be the i^{th} actual variable, s_0 be the mean of the high and low level of the i^{th} variable and ω be half of the difference between the levels of the i^{th} variable, then in reference to equation (6) the coded variable si for i=1,2,3 were.

$$s_1 = \frac{s_1 - 120}{30} \qquad s_2 = \frac{s_2 - 10}{5} \qquad s_3 = \frac{s_3 - 5}{2}$$

The i^{th} main variables for i=1, 2, 3 matches the axial variable coded ±α obtained through the expression;

$$s_i = s_0 \pm \alpha(\omega) \tag{7}$$

Table 1 is the estimated values of the three factors at five levels. The levels were selected based on results from preliminary studies. From CCD and experimental results, RSM was used to optimize formulation process design factors (independent variables).

Table 1 Estimated Values of Three Factors Variables at Five Levels

Factors	**variable**	**-** α	**-1**	**0**	**1**	α
Nitrogen Fertilizer	s_1	68.04	90	120	150	171.96
Pig Slurry	s_2	1.34	5	10	15	18.66
Vegimax folia	s_3	1.54	3	5	7	8.46

Table 2 depicts a complete factorial design which is replicated twice to give a 16 factorial points and 6 axial points replicated twice which gave 12 axial points with five center points. This gives grand sum of 33 number of experimental runs for the study.

The statistical combinations of variables in coded and main values along with the experimental responses are well presented in Table 2.

Table 2 Full Factorial Central Composite Design Matrix and Experimental Results.

Coded Values				**Main Values**			
S/N	s_1	s_2	s_3	**Nitrogen (Kg/ha)**	**Pig Slurry (Kg/ha)**	**Veg. Folia (ml/20 L)**	**Yield (Tons/ha)**
1	0	1.732	0	120	18.66	5	40
2	1	1	1	150	15	7	22
3	1	-1	-1	150	5	3	34
4	-1	1	-1	90	15	3	34
5	0	0	0	120	10	5	47
6	0	0	0	120	10	5	43
7	-1	1	1	90	15	7	39
8	1	1	-1	150	15	3	35
9	-1	-1	-1	90	5	3	38
10	0	0	-1.732	120	10	1.54	41
11	0	1.732	0	120	18.66	5	30
12	1.732	0	0	171.96	10	5	29
13	0	0	0	120	10	5	35
14	1.732	0	0	171.96	10	5	40
15	0	0	0	120	10	5	42
16	1	-1	-1	150	5	3	36
17	0	-1.732	0	120	1.34	5	24
18	0	0	1.732	120	10	8.46	33
19	-1	1	1	90	15	7	32
20	1	-1	1	150	5	7	42
21	-1.732	0	0	68.04	10	5	21
22	0	0	0	120	10	5	32
23	-1.732	0	0	68.04	10	5	22
24	-1	-1	1	90	5	7	33
25	-1	-1	1	90	5	7	35
26	1	-1	1	150	5	7	30
27	1	1	-1	150	15	3	35
28	-1	1	-1	90	15	3	36
29	0	0	1.732	120	10	8.46	31
30	1	1	1	150	15	7	25
31	0	-1.732	0	120	1.34	5	28
32	0	0	-1.732	120	10	1.54	30
33	-1	-1	-1	90	5	3	36

IV. RESULT AND ANALYSIS

Table 3 represents the estimates of response surface second order analysis. From the result, the study found that nitrogen fertilizer (s_1) and pig slurry (s_2) in the main effect had a positive significant effect on cucumber yield at 95% level of significance (p-value = 0.000 < 0.05 and 0.000 < 0.05 respectively). The present study deduces that a unit change of nitrogen fertilizer and a unit change of pig slurry will affect the cucumber yield by 1.54 and 1.42 respectively.

The interaction of nitrogen fertilizer and pig slurry, pig slurry and vegimax folia had a positive effect on the cucumber yield. Nitrogen fertilizer and pig slurry, nitrogen fertilizer and vegimax folia had significant effect on cucumber yield at 95% level of significance (p-value = 0.016 < 0.05 and 0.004 < 0.05 respectively).

Table 3 Estimates of Response Surface Second-Order Analysis.

Factors	Estimate	Std. Error	t-value	p-value	VIF
Constant	39.800	1.13	49.25	0.000	
s_1	1.543	0.785	-1.24	0.000	1.81
s_2	1.418	0.797	-0.72	0.000	1.82
s_3	-0.570	0.865	0.13	0.204	2.41
s_1s_2	0.190	1.03	-2.11	0.016	1.18
s_1s_3	-0.868	1.070	-0.05	0.004	1.50
s_2s_3	0.216	1.130	1.23	0.233	1.43
s_1^2	1.063	1.060	0.21	0.038	2.22
s_2^2	1.363	0.858	0.88	0.006	1.46
s_3^2	1.838	1.090	-0.88	0.389	2.15

$$R^2 = 0.9130 \qquad Adjusted \;\; R^2 = 0.833$$

In addition, Table 4 results revealed a model defined as

$$y = 39.8 + 1.543s_1 + 1.418s_2 - 0.57s_3 + 0.19s_1s_2 - 0.868s_1s_3 + 0.216s_2s_3 + 1.063s_1^2 + 1.363s_2^2 + 1.838s_3^2$$

The coefficient of determination of the model is 91.30% (R^2 = 0.9130). From this, we deduce that 91.30% of variation in the model can be accounted for by the variables (s_1, s_2 and s_3) in the study. Therefore, for a farmer to expect a maximum yield without an additional cost, it is expected for the farmer to determine the required level of the input variables that gives this maximum yield.

Table 4 Analysis of Variance

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Model	9	184.480	20.4978	3.66	0.001
Linear terms	3	9.857	3.2855	0.59	0.001
s_1	1	8.533	8.5327	1.53	0.000
s_2	1	2.924	2.9242	0.52	0.000
s_3	1	0.094	0.0942	0.02	0.065
Interaction terms	3	9.949	3.3164	0.59	0.071
s_1s_2	1	0.238	0.2382	0.04	0.005
s_1s_3	1	4.360	4.3597	0.78	0.035
s_2s_3	1	4.315	4.3154	0.77	0.389
Square terms	3	29.911	9.9702	3.78	0.178
s_1^2	1	24.796	24.7965	4.44	0.046
s_2^2	1	0.015	0.0152	0.00	0.959
s_3^2	1	8.398	8.3976	1.50	0.233
Error	23	128.594	5.5911		
Lack-of-Fit	16	108.928	6.8080	1.42	0.819
Pure error	7	19.667	2.8095		
Total	32	202.061			

The ANOVA result for the response in Table 4 were used to validate the adequacy of the model. The result (p-value = 0.001 < 0.05) shows the model is significant and also adequate. If one wants to fit a model, a non-significant lack of fit is good. The lack of fit of the model was not significant (p-value = 0.819 > 0.05) as shown in Table 4. The F-value of 1.42 indicates that the Lack of Fit is not significant relative to the pure error. There is also an 81.90% chance that a "Lack of Fit F-value" this large could be caused by white noise.

➢ *Response Surface and Contour Plots*

For a good presentation and description of shapes and location of response surface, Contour and surface plots are ideal plots for optimum yield with good accuracy. Figures 1, 2 and 3 show graphs for different combinations of variables (nitrogen fertilizer, pig slurry and vegimax folia) with the trend of variance in the response (cucumber yield) in the selected range of input variables.

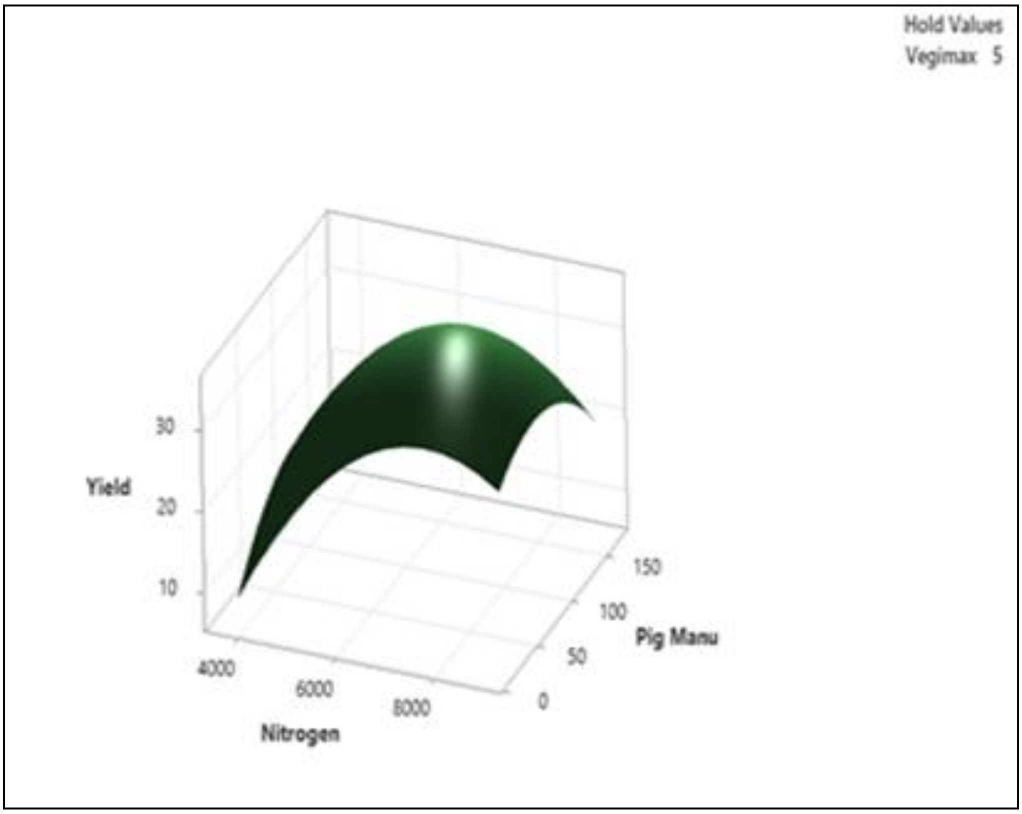

Fig 1a RSM Plot with Vegimax Held Constant

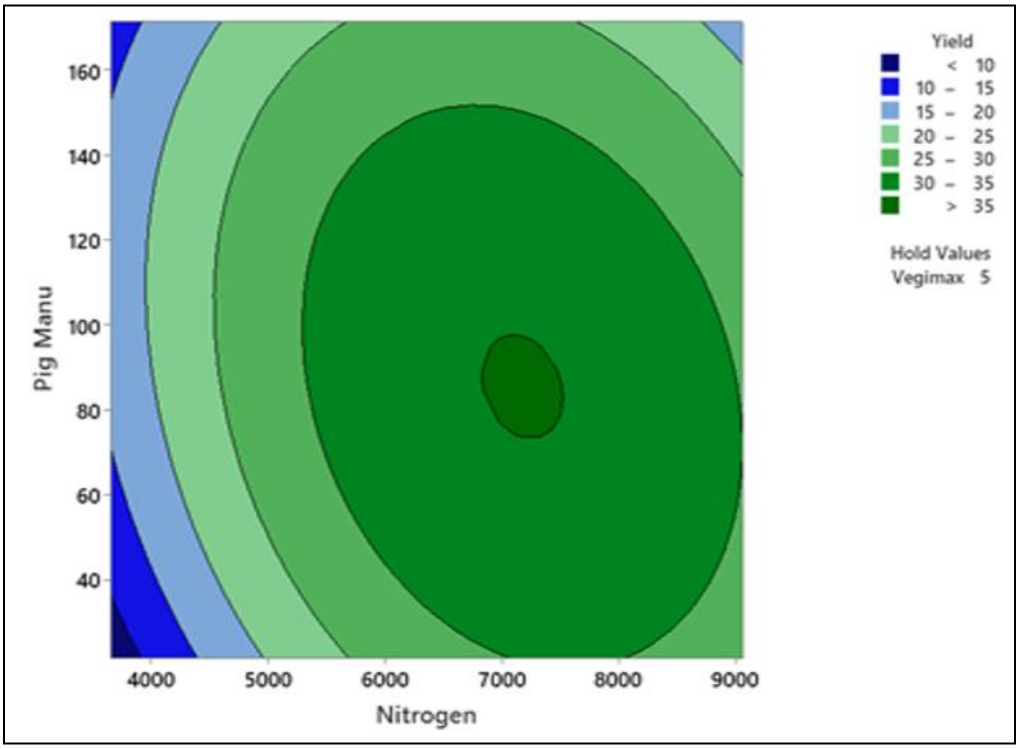

Fig 1b Contour Plot with Vegimax Held Constant

Fig 1a and Fig 1b displays the relationship between pig slurry and nitrogen fertilizer on cucumber yield. The data in the figure shows that pig slurry and nitrogen fertilizer had a positive effect on cucumber yield with folia Vegimax applied at 5 ml/20L. The results indicate that cucumber yield will increase by more than 35 tons/ha with increase of pig slurry and nitrogen fertilizer from low to high.

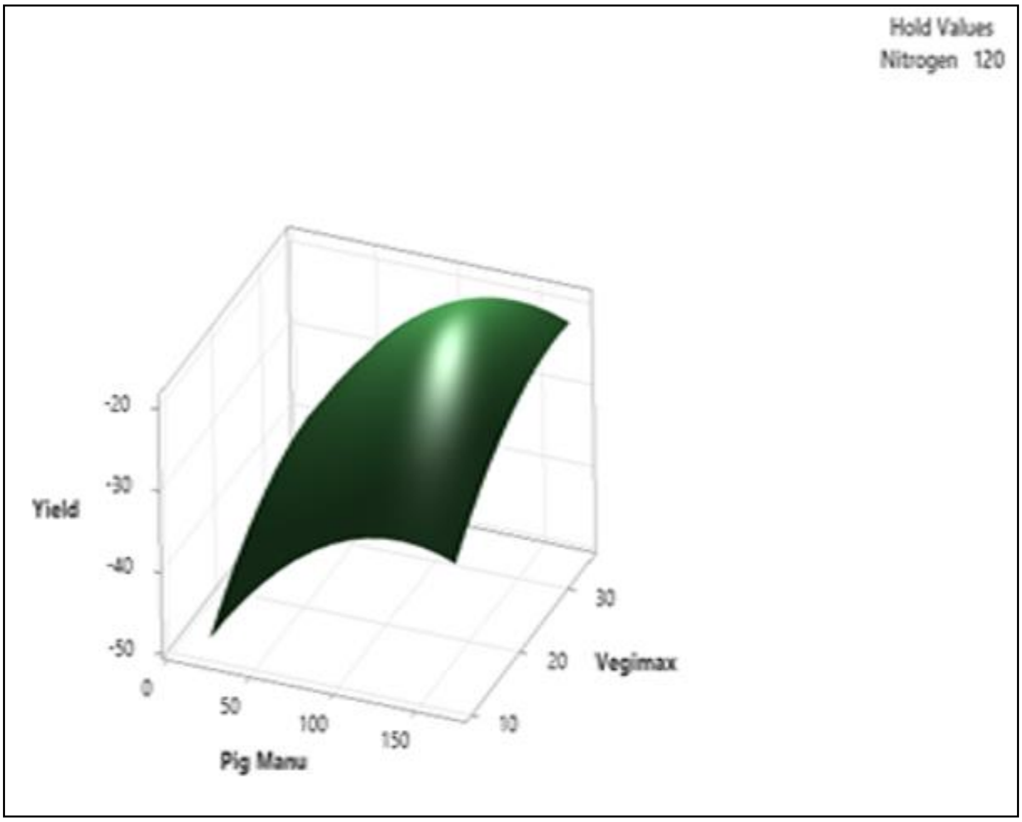

Fig 2a RSM Plot with Nitrogen Held Constant

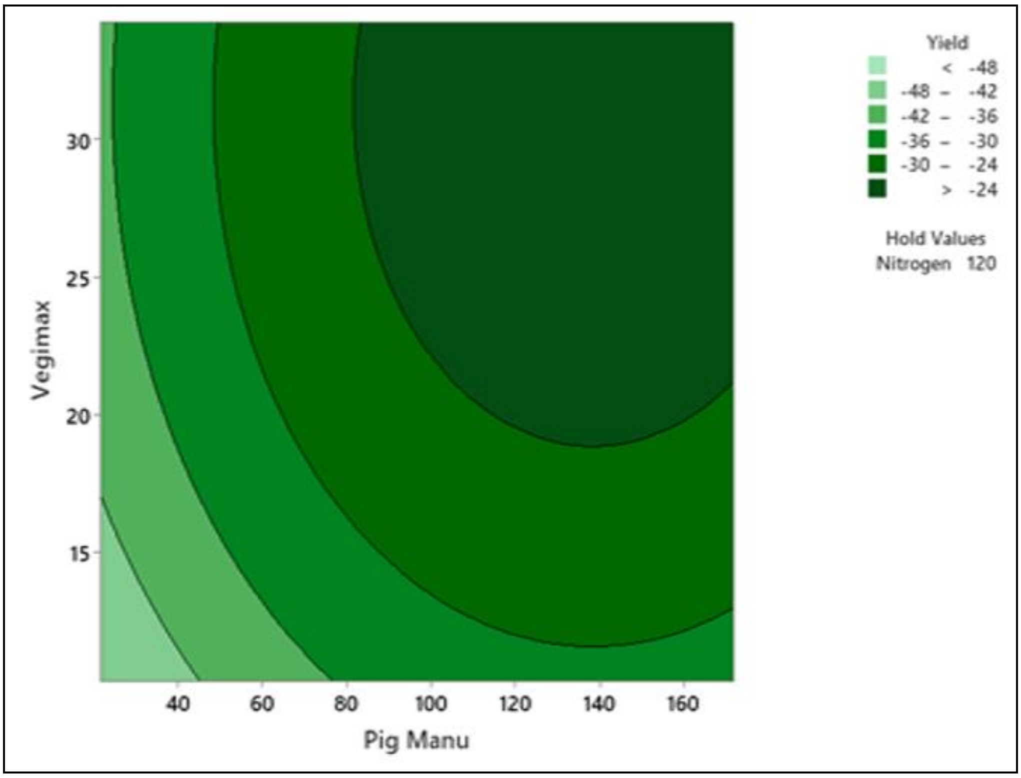

Fig 2b Contour Plot with Nitrogen Held Constant

Fig 2a and Fig 2b displays the relationship between pig slurry and vegimax folia on cucumber yield when nitrogen fertilizer is kept constant. The figure shows that the production of cucumber yield was negatively affected by pig slurry and Vegimax folia when the nitrogen fertilizer was controlled at 120kg/hectare. The results indicate that increasing the amount of pig slurry and vegimax folia from low to high will reduce cucumber yield more than 24 tons/hectare.

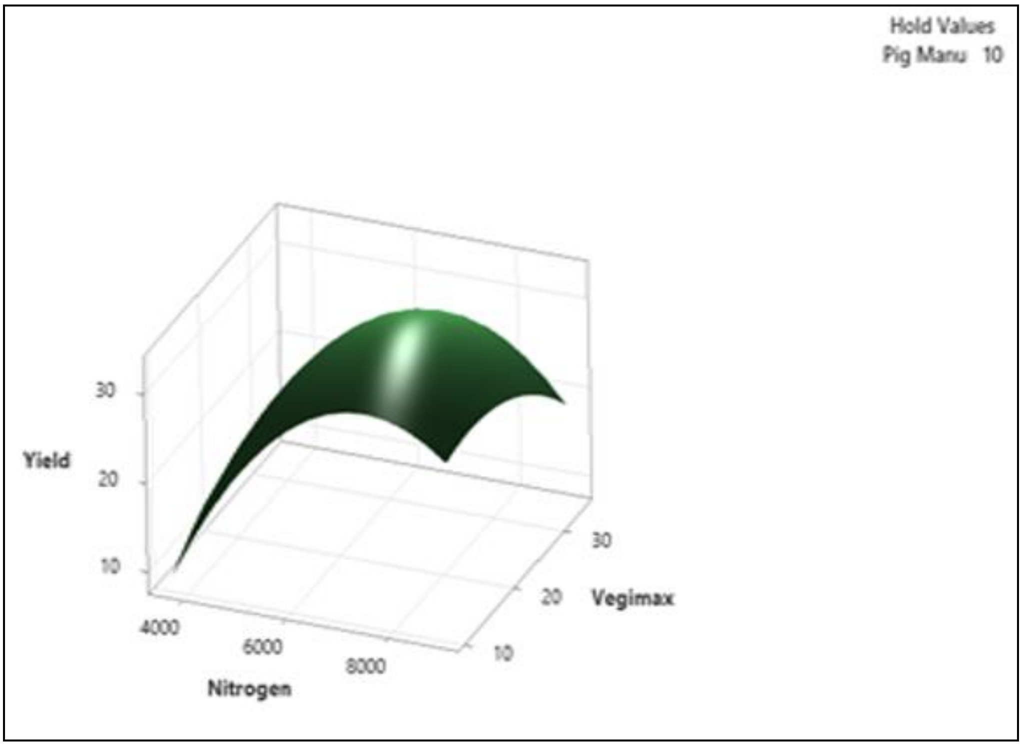

Fig 3a RSM Plot with Pig Slurry Held Constant

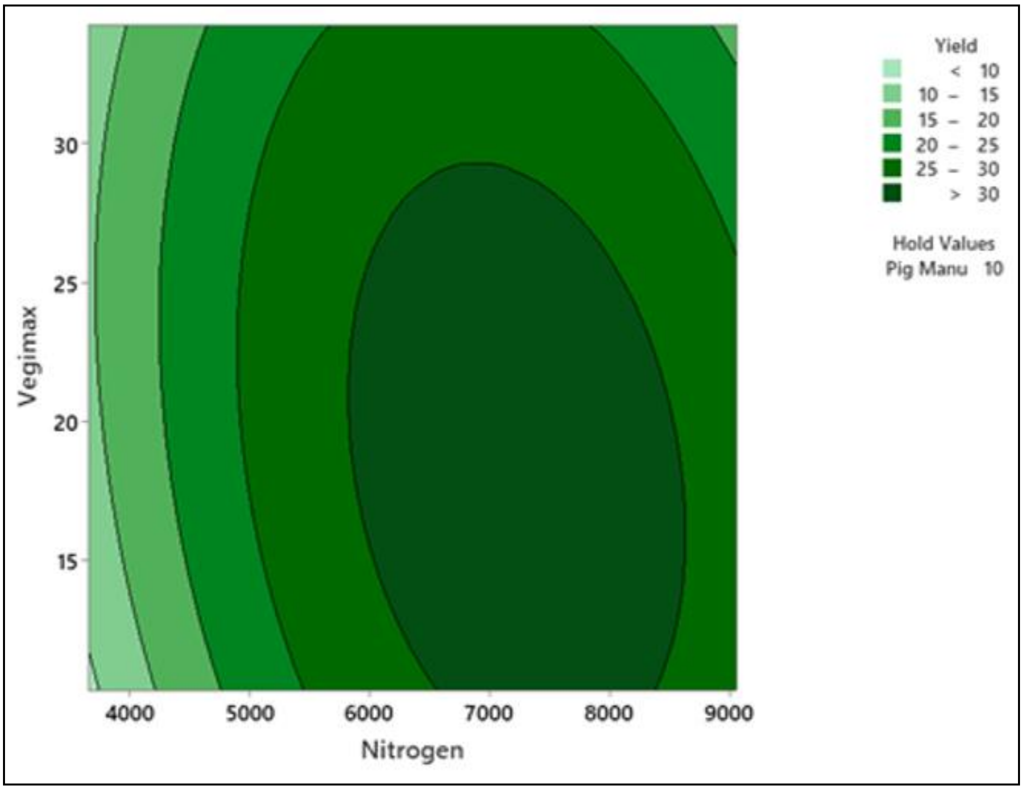

Fig 3b Contour Plot with Pig Slurry Held Constant

Fig 3a and Fig 3b displays the relationship between vegimax folia and nitrogen fertilizer on cucumber yield. The information shows that vegimax folia and nitrogen fertilizer had positive effect on yield of cucumber when pig slurry was maintained at 10 kg/hectare. This shows that the higher the dosage of vegimax folia and nitrogen fertilizer from low to high will increase the yield of cucumbers by more than 30 tons/hectare.

Table 5 Multiple Response Prediction

Variable	**Optimal Setting**
Nitrogen Fertilizer	167.09 kg/Ha
Pig Slurry	88.27 kg/Ha
Vegimax Folia Cucumber Yield	19.28 L/Ha 40.15 tons/ha

Table 5 is the multiple response prediction for maximum yield for cucumber farming in Akwa Ibom State. The result shows that 167 kg / ha of nitrogen fertilizer, 88 kg / ha of pig slurry and 19 L/ ha of vegimax folia were the optimum values that led to maximum cucumber yield of 40 tons/ha.

V. SUMMARY AND CONCLUSION

The research was designed to model the appropriate relationship that gives optimal cucumber yield and the optimal quantity of Nitrogen fertilizer, pig slurry and vegimax folia that leads to maximum cucumber yield production in Akwa Ibom State. The Spherical central composite design was successfully adopted and the experiment was designed by selecting the input variables for the chosen levels. RSM based design of experiments was applied to study the optimal conditions for yields of cucumber. The second order model tested did not show lack of fit after ANOVA test and values of R^2 = 0.9130 and Adjusted R^2 = 0.833 showed that higher level of variations in the response variable was explained and model had a good fit. The study has shown that nitrogen fertilizer and pig slurry in the main effect had significant positive effect on cucumber yield at 95% level of significance (P-value = 0.000 < 0.05 and 0.000 Response surface plots generated show the trend of different responses by varying the 2 input parameters keeping the 3rd parameter constant. The multiple response prediction for maximum yield for cucumber farming in Akwa Ibom State shows that 167 kg / ha of nitrogen fertilizer, 88 kg / ha of pig manure and 19 L/ ha of vegimax folia were the optimum values that led to maximum cucumber yield of 40 tons/ha < 0.05 respectively).

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