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Application of Response Surface Methodology (RSM) to Cucumber Yield under Different Tillage Methods

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Response surface methodology (RSM) was used in the modeling of cucumber (*Cucumissativus)* yield under different Nitrogen, phosphorus, potassium (NPK) fertilizer application rates and tillage methods at the experimental farm of the Department of Agricultural and Bio-Resources Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. From the field experiment conducted, three tillage methods; conventional tillage (CT), manual tillage (MT) and no tillage (NT), were varied with three levels of NPK application; 0.04kg/m^2, 0.05kg/m^2 and 0.06kg/m^2. All the cucumber plants for no tillage wilted and didn't survive to maturity, while the highest cucumber yield of 3.29kg/m^2 was obtained at conventional tillage/0.06kg/m^2 NPK application rate. In optimizing the yield using optimal design of response surface methodology, it was observed that increasing NPK application rate beyond the maximum 0.06kg/m^2 increased cucumber yield for the area. The optimized values obtained in the area were: the best tillage method; conventional tillage, NPK application rate of 0.064kg/m^2 and cucumber yield of 3.376. The study revealed that no tillage at the

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chosen NPK application rates is not adequate for the study area. It was also evident that conventional tillage with increased NPK is the best management practice for the area, but care must be taken not to add excess NPK that will not be favourable to the crops and the soil of the area.

Keywords: Response surface methodology; conventional tillage; manual tillage; no tillage; cucumber yield.

1. INTRODUCTION

Cucumber (*Cucumis sativus)* is a green vegetable with green flesh, it belongs to Cucurbitaceae family comprising of 118 genera and 825 species [1] however, poor agricultural practices affect the yield especially in regions with soil infertility and poor structure. Vegetables supply us vitamins and minerals needed for living. Because of the increase in demand for cucumber, there is need to produce sufficient quantity with good quality in Nigeria. Some factors limiting the productivity of Nigerian soils for cucumber production include low fertility, slope, poor effective depth, stoniness and low nutrient/moisture retention [2]. According to Williams et al. [3], cucumber grows well on well drained, slightly acidic fertile sandy loam soils with good moisture retention ability and rich in organic manure. There is need for proper soil management to attain sufficient management of cucumber production. Some of the various soil managements are tillage and NPK application. Cucumber requires certain level of Nitrogen for growth [4]. Tillage is the mechanical disturbance of soil for the purpose of crop production [5]. Improper tillage and NPK application can lead to poor soil quality and structure and this leads to low crop yield. According to Magdoff and van Es, 2009, tillage is a major cause of soil degradation in agricultural system because it leads to compaction, high rates of runoff and loss of soil nutrients. Reducing tillage may increase root diseases and weed [6]. Soil tillage consists of loosening the soil surface to a certain depth, so that the roots of the crop will have room for growth [7]. Tillage improves soil structure and this affects crop yield, but indiscriminate tillage may be hazardous to the soil, and this will lead to poor crop yield [8]. Jilani et al. [9] stated that NPK improves growth and yield of cucumber and enhances its production. Improper tillage can affect the soil properties leading to runoff, erosion and loss of soil nutrients, also improper NPK application may affect crops as over application may be too harsh to the crops which will lead to wilting. There is need to monitor the different soil treatments for cucumber yield in the area.

The main objective of the research was to use response surface methodology (RSM) to model the impact of NPK application rates and different tillage methods on yield of cucumber. The obtained model can help in proper tillage and NPK combination, for obtainment of optimum cucumber yield in the study area.

2. MATERIALS AND METHODS

2.1 Study Area

Field experiment was conducted at the Department of Agricultural and Bioresources Engineering Experimental Site/ Farm Workshop, NnamdiAzikiwe University, Awka. The site lies between latitudes 6°15'11.8N to 6°15'5.3E and longitudes 7°7'118N to 7°7'183N and altitude of 142m. during the dry season, previous studies carried out in the area shows that the soil in the area is sandy loam.

2.2 Initial Soil Properties Determination

Soil samples were collected from 0-25cm soil depth and various soil physicochemical properties were determined.

For the chemical properties; pH was measured using the laboratory pH meter Hana model H1991300 [10]. Soil electrical conductivity was determined according to APHA 2510 guidelines model DDS-307 [11]. Soil nitrogen was determined according to [12]. Soil potassium was determined using [11];

For the physical properties; bulk density was determined using equation 2.1

$$BD = \frac{weight\ of\ dry\ soil\ (g)}{total\ volume\ of\ soil(cm^3)} \quad (2.1)$$

Particle density was determined using equation 2.2.

$$PD = \frac{weight\ 0f\ dry\ soil\ (g)}{volume\ of\ sand\ particle\ (cm^3)} \quad (2.2)$$

Porosity was determined using equation 2.3

$$porosity\ (\%) = \left(1 - \frac{bulk\ density}{particle\ density}\right) X\ 100 \quad (2.3)$$

2.3 Experimental Set up

The experiment had 9 treatment combinations and the total experimental plot was 9. The experiment was laid out using optimal design in design expert 13.0.12.0 software. The experimental field consists of 3 major plots with 3 sub plots (each measuring 3 m X 3 m). The experimental design was performed as follows:

Tillage: conventional tillage (ploughing with tractor) , Manual tillage and No tillage.

NPK fertilizer application rates: 0.04kg/m^2, 0.05 kg/m^2 and 0.06 kg/m^2. The experiment was conducted from 28th May 2022 to 30th July 2022

2.4 The Test Crop

The crop for the experiment was Cucumber (*Cucumis sativus*), obtained from Anambra Development Programme (ADP) Awka. The seeds were planted in the subplots at 50 cm x 50 cm spacing.

2.5 Response Surface Methodology

The response surface analysis was performed using RSM package [13], this was done using the optimal design. There were two independent variables with three levels: NPK Application rates (0.04kg/m^2, 0.05kg/ m^2, and 0.06kg/ m^2) and tillage methods (conventional tillage, manual tillage and no tillage). Tillage is a categoric factor, while NPK application rate is a numeric factor. The experimental design layout is shown in Table 1.

The values presented in Table 2 were used for the design of the experiment. The factors are NPK Application Rate (Kg/m^2) and Tillage, while the response is Crop Yield (Kg/m^2). NPK Application rate which is a numeric factor with a minimum value of 0.040Kg/m^2 and Maximum of 0.06Kg/m^2 has mean of 0.05 and standard deviation of 0.087. Tillage is a categorical factor with three levels; no tillage, conservative tillage and conventional tillage. Crop yield has the maximum value as 3.29 and minimum as 0 with a mean of 1.55 and standard deviation of 1.32.

Table 1. Experimental design layout

	Factor 1	Factor 2	Response 1
Run	A:NPK	B:Tillage	Crop yield
	KG/M^2		KG/M^2
1	0.04	NT	
2	0.06	CT	
3	0.06	NT	
4	0.06	MT	
5	0.05	CT	
6	0.04	CT	
7	0.05	MT	
8	0.04	MT	
9	0.05	NT	

Table 2. Design summary

Factor	Name	Units	Type	Sub Type	Min	Max	Coded Low	Coded High	Mean	Std. Dev.
A	NPK	KG/m^2	Numeric	Discrete	0.04	0.06	1 ↔ 0.04	+1 ↔ 0.06	0.05	0.0087
B	Tillage		Categoric	Nominal	NT	CT			**Levels:**	3

Response	Name	Units	Observations	Min	Max	Mean	Std. Dev.
R1	Crop yield	KG/m^2	9	0	3.29	1.55	1.32

2.6 Yield Components

2.6.1 Plant height

Five cucumber plants were selected from each subplot, and the plant heights were measured weekly, up till the 9th week.

2.7 Grain Yield

Cucumber yields were determined by harvesting fruits from five selected plants from each sub-plot, and determining the yields in kilogramme weights per square meter (for each sub-plot).

2.8 Statistical Analysis

The experimental data obtained from optimal design were analyzed by Response Surface Methodology (RSM). A mathematical model, following a second order polynomial which includes interaction terms was used to calculate the predicted response.

2.9 Experimental Design and Optimization Parameters

Response Surface Methodology (RSM) was used to investigate the influence of NPK fertilizer application rates and Tillage methods on cucumber yield. The optimal design and their values are shown in Table 3. For this research, the factors NPK Application rate (kg/m^2) and Tillage were represented with A and B respectively.

Table 3. Independent variables and levels used for response surface design

Independent variables	Symbols	Ranges and levels		
		-1	0	+1
NPK Aplication rate (kg/m^2)	A	0.04	0.05	0.06
Tillage	B	NT	MT	CT

3. RESULTS AND DISCUSSION

3.1 Initial Soil Properties

Table 4. Initial soil properties of the study area

Soil Property	Value	Unit
Field Capacity	9.69	%
Bulk Density	1.4	g/cm^3
Porosity	60	%
Organic Carbon	27	%
pH	7.50	-
Conductivity	4.5	us/cm
Nitrogen	0.784	%
Phosphorous	3.487	mg/kg
Potassium	0.011	Ppm

3.2 Emergence Rate

Table 5. Emergence Rate

Tillage Type	Survival Rate (%)
Conventional Tillage	**95**
Manual Tillage	**70**
No Tillage	**50**

There were 95%, 70% and 50% emergence rates for conventional tillage, manual tillage and no tillage crops respectively, but non of the plants in no tillage sub-plots survived beyond the 5th week.

3.3 Plant Height

This is the number of grains contained in a corn cob and the values for different treatments are presented in Table 6.

From the result of plant height in Table 6, NPK was applied to the different levels of tillage on the third week. Highest plant height was obtained in manual tillage (apart from conventional tillage / 0.06kg/m^2), until the introduction of NPK, where the highest plant heights were obtained in conventional tillage throughout the growing period. By sixth week, all the crops in no tillage subplots wilted and died, that's why there is no recordings from sixth week.

3.4 Cucumber Yield

From the result of cucumber yield in Table 7, conventional tillage at 0.06kg/m^2 NPK application rate produced the highest cucumber yield of 3.29kg/m^2, while all the sub-plots in no tillage treatment didn't produce any fruit, the plants didn't survive to maturity.

3.5 Statistical Analysis for Crop Yield

Table 8 Sequential Model Sum of Squares for Crop yield.

From the sequential model (linear, two factor interactions 2FI, Quadratic and Cubic polynomial) in Table 8, the 2FI and linear model were selected by design expert 13.0.12.0 version due to its highest order polynomial.

The analysis of variance (ANOVA) was carried out to determine the significance of the fitness of the selected Quadratic Model as well as the significance of individual terms and their interaction on the chosen responses. From Table 9 the regressors incorporated in the model F-value of 1347.67 with P-value of <0.0001 implies that the model is significant at 95% confidence level. The P-value (probability of error value) is used to check the significance of each regression coefficient and the interaction effect of each cross product. In the case of the model terms, the p-value less than 0.05 shows that the model terms are significant, In this case A, B, and AB, are significant model terms.

Table 6. Plant height (cm), 1-9 weeks after planting

Npk application rate	Weeks after planting	Conventional tillage	Manual tillage	No tillage
No NPK	1	4 ±1	6 ±3	4 ±0.9
No NPK	2	5.5 ±.4	10 ±1	7 ±2
0.06 Kg/m^2	3	15 ±2	14 ±1	13±1
0.05 Kg/m^2	3	15 ±1	10±1	12±1
0.04 Kg /m^2	3	13±2	9±2	6±3
0.06 Kg/m^2	4	50±4	15±1	13±1
0.05 Kg/m^2	4	46±1	14±1	12±1
0.04 Kg /m^2	4	40±3	10±3	11±1
0.06 Kg/m^2	5	100±5	85±5	64±5
0.05 Kg/m^2	5	70±5	25±5	14±3
0.04 Kg /m^2	5	60±5	14±5	13±5
0.06 Kg/m^2	6	140±3	99±4	-
0.05 Kg/m^2	6	107	60±1	-
0.04 Kg /m^2	6	90	45±5	-
0.06 Kg/m^2	7	190	110±5	-
0.05 Kg/m^2	7	150	70±5	-
0.04 Kg /m^2	7	110	59±5	-
0.06 Kg/m^2	8	230	146±5	-
0.05 Kg/m^2	8	200	85±5	-
0.04 Kg /m^2	8	140	66±3	-
0.06 Kg/m^2	9	300±10	150±10	-
0.05 Kg/m^2	9	256±4	136±3	-
0.04 Kg /m^2	9	210±5	110±4	-

Table 7. Cucumber yield

	Conventional Tillage (kg/m^2)	Manual Tillage (kg/m^2)	No Tillage (kg/m^2)
0.06Kg/m^2 NPK	3.29	1.75	0
0.05Kg/m^2 NPK	3.01	1.55	0
0.04Kg/m^2 NPK	2.80	1.53	0

Table 8. Sequential Model sum of squares for crop yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	21.56	1	21.56			
Linear vs Mean	13.90	3	4.63	348.71	< 0.0001	
2FI vs Linear	**0.0602**	**2**	**0.0301**	**14.53**	**0.0286**	**Suggested**
Quadratic vs 2FI	0.0035	1	0.0035	2.53	0.2526	
Cubic vs Quadratic	0.0027	2	0.0014			Aliased
Residual	0.0000	0				
Total	35.53	9	3.95			

Table 9. Analysis of variance (ANOVA) for the fitted quadratic model for crop yield

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	13.96	5	2.79	1347.67	< 0.0001	**Significant**
A-NPK	0.0840	1	0.0840	40.54	0.0078	
B-Tillage	13.82	2	6.91	3334.36	< 0.0001	
AB	0.0602	2	0.0301	14.53	0.0286	
Residual	0.0062	3	0.0021			
Cor Total	13.97	8				
Std. Dev.	0.0455	**R²**		0.9996		
Mean	1.55	**Adjusted R²**		0.9988		
C.V. %	2.94	**Predicted R²**		0.9940		
		Adeq Precision		88.2024		

The model as fitted presents an R- square of 0.9996 and standard deviation of 0.0455. The two factors (NPK Application rate, and Tillage) were found to be statistically important (significant) at confidence level of 95%.

The predicted values versus actual value for the Crop yield with R^2 value of 0.9996 shows a model with 99.96% of variability (Fig. 1). The Predicted R-Squared of 0.9940 is in reasonable agreement with the Adjusted R-Squared of 0.9988; i.e. the difference is less than 0.2 and their R^2 values close to unity. This indicates that the data fits with the model. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 88.2024 indicates an adequate signal. This model can be used to navigate the design space.

The residuals were investigated to validate the adequacy of the model. The plot of actual versus predicted (Fig. 1) is used to examine the effects of the observed response and predicted response. Fig. 1 shows that there is a very good correlation between the observed value and the values predicted by the model, from the model, there was no variation of the constant variance.

3.6 Model Equation for Crop yield

$$\text{Crop yield (NT)} = -7.77156E\text{-}16 + 1.42109E\text{-}14NPK \quad (3.1)$$

$$\text{Crop yield (MT)} = 1.06 + 11.0NPK \quad (3.2)$$

$$\text{Crop yield (CT)} = 1.80833 + 24.5NPK \quad (3.3)$$

Equations 3.1, 3.2 and 3.3 can be used to make predictions about the response for given levels of each factor cucumber yield for no tillage, manual tillage and conventional tillage respectively.

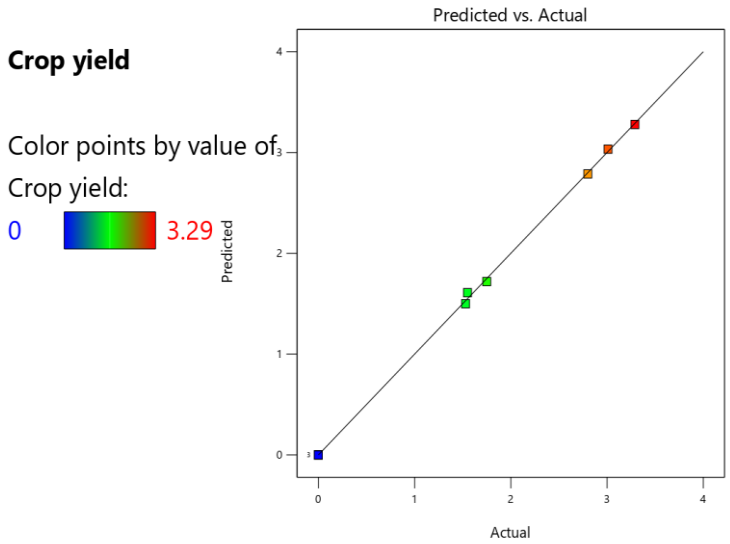

Fig. 1. Diagnostics plots of the fitted quadratic model for crop yield

Table 10. Optimization solutions

Number	NPK	Tillage	Crop yield	Desirability	
1	0.064	CT	3.376	1.000	Selected

3.7 Optimization of the Process

The optimization of the process was performed to determine the optimum operating conditions at which the maximum yield will be achieved.

The response of the variables in Table 10 were generated by Design Expert 13.0.12.0 software for the optimization based on the model obtained and the experimental data input. From Table 10, the run 1 order gave the optimum condition and was selected. The optimum values based on the run order 1 gave NPK application rate as 0.060 kg/m^2, best tillage method as conservative tillage, Crop yield of 3.278 kg/m^2.

4. CONCLUSION

Increase in NPK application rate increased cucumber yield in the area; Eifediyi [14] reported increase in yield components of cucumber with increase in fertilizer application rates. From optimization result, conventional tillage by ploughing with tractor and increasing the NPK beyond 0.06 (the maximum used for the study) will increase cucumber yield in the study area

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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