APPLICATION OF DESIRABILITY FUNCTION FOR OPTIMIZATION OF MULTIPLE RESPONSES OF WATERMELON USING ORGANIC MANURE

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ABSTRACT
Field experiment was conducted at horticultural research and teaching farm of Chuka University to evaluate the responses of watermelon to organic manure using Central Composite Design (CCD) to formulate optimal organic manure that maximizes growth and yield of watermelon. The objective was to optimize the multiple responses of watermelon to organic manure using desirability function. A 5-level-3-factor central composite design was employed where optimization required 20 experimental runs. The parameters assessed were vine length, number of branches per plant and fruit weight of watermelon. A statistical model of the second-order that best fits the data was used to achieve the objective. Desirability function approach for simultaneous optimization of several response variables was adopted in this study. The findings revealed that the process was well optimized, because the indices were very close or equal to the condition great value of one. The study found that the optimal values of watermelon responses are 93.73 t/ha of fruit weight at maturity, 9 branches/plant and vine length of 225.43 cm at 8 weeks. Based on the findings of the present study, it was recommended that farmers in the study area apply 17.64 t/ha, 11.17 t/ha and 18.05 t/ha of poultry, goat and cow manure, respectively, for increased growth and yield of watermelon. Further research may be commissioned with CCD, Box–Behnken and Doehlert design approach to plan the experiments for growth and yield of watermelon with an overall objective of optimizing the responses (such as number of fruits per plant and number of leaves per plant) of watermelon to organic manure (poultry manure, goat manure, rabbit manure and donkey manure). The study exemplified that the development of statistical models for crop production can be useful for predicting and understanding the effects of experimental factors.
Keywords: Central composite design; Response surface methodology; Fruit weight

INTRODUCTION

Watermelon *(Citrullus lanatus* Thumb*)* is a member of the cucurbitaceous family. According to Jarret *et al*., (1996) it originated from the Kalahari and Sahara deserts in Africa. In Kenya, the crop is mainly grown in lower and dry semi-arid areas, namely Nyanza, Central, Eastern, Coast and Rift Valley. Watermelon is a crop with huge economic importance to man, as well as highly nutritious, sweet and thirst-quenching (Mangila *et al*., 2007). It is mostly used to make a variety of salads, juice and food flavour. It is a cash crop for farmers due to its high returns on investment. Watermelon contains vitamin C and A in form of the disease-fighting beta-carotene. In spite of the increasing relevance of watermelon in Kenya, yields across the country are decreasing and not encouraging because of rapid reduction in soil fertility caused by both continuous cropping and use of inappropriate soil amendment materials (Boyhan et al., 1999; Dauda *et al*., 2008; IITA, 2006). One of the ways of increasing the soil fertility is by application of organic material such as poultry manure, cow manure, and goat manure which are available in most parts of the country. Animal waste is essential for establishing and maintaining the optimum soil physical, chemical and biological condition that are appropriate for plant growth and development. Although readily available, utilization of organic manure in watermelon production has not been optimized for increased plant growth and fruit production (Boyhan et al., 1999; Dauda et al., 2008; IITA, 2006). The study sought to optimize the multiple responses of watermelon to organic manure using desirability function.

In order to get the most efficient result in the approximation of empirical model, the proper experimental design must be used to collect data. The data is then used to develop an empirical model that relates the process response to the factors. The method of Least Squares is used to estimate the parameters in the empirical model (Box *et al*., 1987). Regression models are used for the analysis of the response, as well as the nature of the relationship between the response and the factors. Details of experimental designs for fitting response surfaces are found in Montgomery (2005; 2013); Khuri and Siuli (2010) and Muriithi (2015).

In the present study, Central Composite Design was used for experimental design model with 5-level- 3 factors experiment. A 5-level-3-factor central composite design was employed in watermelon experiment where optimization required 20 experimental runs. Poultry manure, cow manure, and goat manure were the independent variables to optimize the responses of interest that include; fruit weight at maturity, number of branches and vine length per plant. Also, the study optimized three responses of watermelon simultaneously. Multi-response problem is often difficult due to different factors taken into account during problem-solving. Optimizing multiple responses is of main concern among decision makers. Derringer and Suish (1980) proposed desirability function approach for simultaneous optimization of several response variables. The proposed procedure optimizes multiple responses simultaneously and overcomes the limitations of RSM when dealing with a large number of responses. Desirability function was used to consider several responses as efficiency response surface (Muriithi, 2015).

MATERIALS AND METHODS

Materials

Sukari F1 watermelon seed, a newly developed variety from East Africa Seed Company was used in the study. Similarly, poultry, goat and cow manure used for the experiment was sourced from Chuka University Agricultural farm and from local community. Data was obtained from an experiment carried out at horticultural research and teaching farm of Chuka University. A land measuring 448 m^2 (28 m x16 m) was selected for the study and prepared for planting. Twenty plots of 4 m x 3 m each was made and composite samples collected from the plots at 0-15 cm depth in order to assess the initial physical-chemical properties of the soil. The composite soil samples collected from individual plots was analyzed in the laboratory to determine initial physical-chemical properties of soils for the study. Similarly, the chemical analysis of poultry, goat and cow manure used for the experiment was evaluated using appropriate method. Each plot had 3 seeds per stand at a depth of 3 cm, using a spacing of 200 cm x 100 cm, with 100 cm alley pathways. Data on watermelon fruit weight at maturity, number of branches and vine length per plant were collected.

Design of the Experiment

The experiment was carried out as a CCD consisting of 20 experimental runs determined by the $\mathbf{2^3}$ full factorial design with six axial points and six center points as shown in Figure 1.

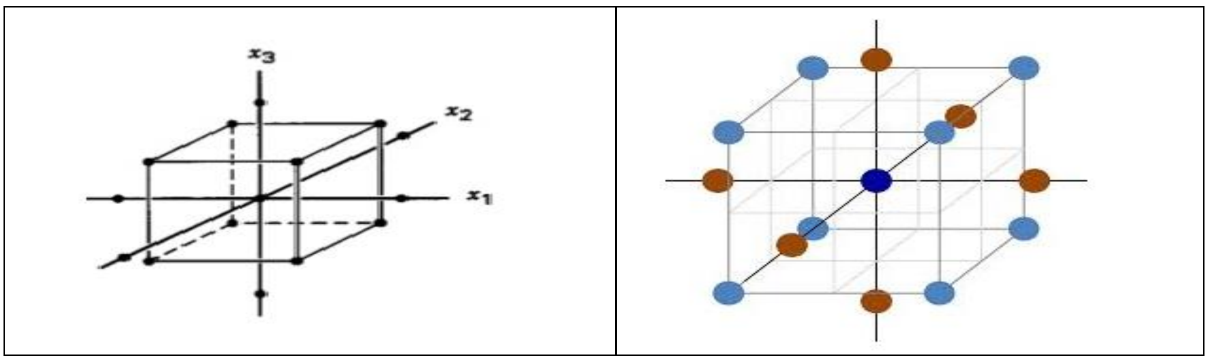

Figure 1: Layout of the Central Composite Design (CCD) for 3 variables at 5 levels

A 5-level-3-factor central composite design was employed in watermelon crop experiment where optimization required 20 experimental runs. Poultry manure (X_1), cow manure (X_2) and goat manure (X_3) are the independent variables to optimize the response values of interest (Fruit weight of watermelon at maturity, number of branches and vine length per plant). In developing the regression model, the test factors were coded according to the formulae given as $x_i = \frac{X_i - X_0}{X}$ where x_i is a coded value of the i^{th} variable, X_0 is an average value of the variable in high and low level, X is (variable at high level-variable at low level)/2 and X_i is an encoded value of the i^{th} test variables. Analysis of data was done using R- Program and Design Expert version 10. The second- order model representing the watermelon fruit weight at maturity, number of branches and vine length per plant each were expressed as a function of poultry manure, cow manure and goat manure being in the input variable of watermelon response.

Table 1: Three factors at five levels estimated values

Symbols	Predictor Variable	Code Levels				
		-1.682	-1	0	+1	+1.682
X_1	Poultry manure (Tons/Ha)	1.6	5	10	15	19.4
X_2	Cow manure (Tons/Ha)	1.6	5	10	15	19.4
X_3	Goat manure (Tons/Ha)	1.6	5	10	15	19.4

Table 2: Full factorial central composite design matrix and experimental results

	Coded values			Fruit Weight (Tons/Ha)		Number of Branches		Vine Length (cm)	
Runs	X_1	X_2	X_3	EXPV	PREDV	EXPV	PREDV	EXPV	PREDV
1	-1.682	0	0	51.6	50.2	5	5	170.5	168.1
2	-1	1	1	54.0	56.7	6	7	176.0	180.6
3	-1	-1	1	46.0	49.2	3	4	169.2	167.2
4	-1	-1	-1	50.0	52.7	5	5	169.0	167.9
5	-1	1	-1	46.0	45.2	4	5	165.4	165.6
6	0	0	0	60.8	60.6	6	6	180.2	181.2
7	0	0	-1.682	50.0	50.0	5	5	168.6	167.1
8	0	0	0	68.0	60.6	7	6	190.6	181.2
9	0	1.682	0	58.0	50.8	6	5	178.9	177.2
10	0	0	0	56.0	60.6	6	6	174.9	181.2
11	0	0	1.682	76.0	71.2	7	7	200.9	195.3
12	0	0	0	56.0	60.6	6	6	175.8	181.2
13	0	0	0	58.0	60.6	6	6	179.6	181.2
14	0	-1.682	0	48.0	50.8	5	5	169.2	167.8
15	0	0	0	64.0	60.6	6	6	185.7	181.2
16	1	1	-1	48.0	49.0	4	4	172.9	171.6
17	1	-1	1	66.0	70.1	7	7	188.4	192.5
18	1	1	1	76.0	77.6	7	8	208.1	205.9
19	1	-1	-1	56.0	56.5	6	7	174.1	173.8
20	1.682	0	0	72.0	71.0	7	7	195.9	194.4

Mathematical Models

To define the response equation, X_1, X_2 and X_3 are assigned to poultry manure, cow manure and goat manure respectively. An appropriate polynomial (second-order) models were expressed as:

$$Y_1 = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_{11} X_1^2 + \alpha_{22} X_2^2 + \alpha_{33} X_3^2 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{23} X_2 X_3 + e$$

$$Y_2 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + e$$

$$Y_3 = \delta_0 + \delta_1 X_1 + \delta_2 X_2 + \delta_3 X_3 + \delta_{11} X_1^2 + \delta_{22} X_2^2 + \delta_{33} X_3^2 + \delta_{12} X_1 X_2 + \delta_{13} X_1 X_3 + \delta_{23} X_2 X_3 + e$$

Where Y_i ; (i=1,2,3) is the i^{th} predicted response (1= for Fruit weight of watermelon at maturity, 2= for Number of branches per plant and 3= for Vine length at 8 weeks), X_i represent the control factors in the experimental data, α_0, β_0 and δ_0 the constant, α_i, β_i and δ_i the linear coefficients, α_{ii}, β_{ii} and δ_{ii} are the quadratic coefficients and α_{ij}, β_{ij} and δ_{ij} the cross-product coefficients (For *i=123; j=2,3 and i<j)*.

Method of Optimization

In this study, the experimenter optimized a number of responses at the same time. The problem in dealing with multiple responses is that the three might be conflicting objectives because of the difference requirement of each of the responses (Candioti et al., (2014). In such a case, experimenter could opt to involve the use of desirability function. The Desirability method is very effective in optimizing processes that have multiple responses, which should be optimized simultaneously. Under this study, each i^{th} response was assigned a desirability function, d_i where the value of d_i varies between 0 and 1.The function d_i is defined differently based on the objective of the response. The objective of the responses was to maximize: the fruit Weight of watermelon at maturity, number of branches and vine length per plant. Then d_i is defined as follows:

$$d_i = \begin{cases} 0 & y_i < L \\ \left(\frac{y_i - L}{T - L}\right)^w & L \leq y_i \leq T \\ 1 & y_i > T \end{cases}$$

where T is the target value of the i^{th} response y_i, L is acceptable lower limit value for this response and w the weight. When $w=1$, the function is linear, $w>1$, more weight is assigned to achieving the target for the response and $w<1$ less weight is assigned to achieve the target for the response.

Once a desirable function is defined for each of the responses, an overall desirability function is defined as the weighted geometric average of the individual desirability (d_i) according to the following equation.

$$D = (d_1^{r1}.d_2^{r2}.d_3^{r3})^{\frac{1}{(r1+r2+r3)}} = f(y_1, y_2, y_3)$$

Where the *ri's* represent importance of each response. The greater *ri* the more importance the response with respect to the other responses (Myers, 1989; Myers, 2004; Myers, 2009). The objective is to find the setting that returns the maximum value of D (global index) that is maximum response surface of efficiency in the feasible region (Muriithi, 2015; Wang and Wan, 2009).

RESULTS AND DISCUSSION

Models Summary Statistics

The researcher sought to evaluate the component of the second order models in order to assess their suitability and the results are portrayed in Table 3

Table 3: Model summary statistics

Statistics	Model 1	Model 2	Model 3
R-Squared	0.9337	0.959034	0.956697
Adjusted R^2	0.8591	0.912947	0.907981
Predicted R^2	0.5489	0.764972	0.790799

Model summary statistics focus on the model maximizing the Adjusted $R^2$and the Predicted R-Squared. The R^2 refer to a measure of proportion of the variation in the dependent variable that is explained by the independent variable for a regression model. Adjusted R^2 it is used to adjust the statistic based on the number of independent variable in the model. It compares the explanatory power of regression model that contain different independent predictors. In this case, since the multiple regression models have more than one variable, Adjusted R^2 is the most preferred. The study found that quadratic models were more appropriate for the data fitting with an R^2 = 85.91%, 91.3% and 90.8% for model 1, model 2 and model 3 respectively. Model 1 explains about 85.9% of the variability in the response variable.

Mathematical Model

The data obtained from the experiment were analyzed to develop mathematical models. The multiple regressions were obtained by employing a least square technique to predict quadratic polynomial model for the fruit weight, number of branches and vine length of watermelon (Table 4).

Organic manure (especially poultry manure) is most important parameter affecting growth and production of watermelon, (Boyhan et al., 1999; Enujeke, 2013a). In order to study the interaction factors (combined effect of poultry, cow and goat manure) experiment were conducted varying physical parameter using CCD. A multiple regression data analysis was carried out with "R-Gui" statistical package. The study found that poultry and goat manure had positive significant effect on fruit weight of watermelon at P=0.00052 and 0.00046, respectively). In addition, it was observed that goat manure was slightly superior in terms of its effect on fruit weight of watermelon. In the findings, one unit change of goat or poultry manure influenced the fruit weight by a factor of 1.57 and 1.54 respectively. However, cow manure had insignificant effect on the fruit weight of watermelon at 5% level (P=0.204). The study found that combined poultry and goat manure had a significant effect on the fruit weight of watermelon at P<0.05.

Poultry manure is the richest known animal manure (Enujeke, 2013b) and Mangila et al., (2007). It is essential for establishing and maintaining optimum soil physical condition for plant growth and production. In this study, combining cow and goat manure had a significant effect on watermelon production. The results indicates that 1 unit change in combined poultry and goat manure led to change in watermelon fruit weight by a factor of 1.0625, whereas combining cow and goat manure changed the same by a factor of 0.9375. This implies that combined poultry and cow manure would be more superior compared to combine cow and goat manure in influencing watermelon fruit weight. The adjusted model obtained as a function of the significant variables is indicated in Model 1.

The regression coefficient estimates shows that for one unit change in poultry manure and goat manure, number of branches of watermelon would increase by a factor of 0.6856 and 0.5392, respectively. This implies that poultry manure is slightly more effective than goat manure on growth (number) of branches of watermelon plant. In addition, it was found that combined application of poultry and goat manure had a regression coefficient (r) = 0.5 and a P = 0.022423, hence statistically significant at 5% significance level. This implies that for one unit change in combine poultry and goat manure (X_1X_3), growth of branches (in number) of watermelon plant would increase by a factor of 0.5. Moreover, it was observed that quadratic terms were not statistically significant except goat manure where the parameter estimate was -0.3544 with P = 0.028. The results indicate that for one unit increase of quadratic term goat manure, growth of watermelon would be negatively affected by a factor of 0.3544. The predicted model for number of branches of in terms of coded factors is as shown in Model 2.

The study found that goat and poultry manure were statistically significant at 5% significance level with a P=0.00008 and 0.00014, respectively. The regression coefficient estimates shows that for one unit change in goat manure and poultry manure, vine length of watermelon would increase by a factor of 8.3926 and 7.8065, respectively. This implies that goat manure is slightly more effective than poultry manure on growth of watermelon plant. In addition, it was found that combined application of poultry and goat manure had a regression coefficient (r) = 4.8375 and P=0.018, hence statistically significant at 5% significance level. This implies that for one unit change in combined poultry and goat manure (X_1X_3), growth of watermelon plant (vine length) would increase by 4.84.

Similarly, it was noted that quadratic terms were not statistically significant except goat manure where the parameter estimate was -3.0840 with a P = 0.035956. The results indicate that for one unit increase of quadratic term of goat manure, growth of watermelon would be negatively affected by a factor of 3.0840. The adjusted model obtained for watermelon growth (vine length) as a function of the significant variables is given in Model 3.

Analysis of Variance

Analysis of variance was used to check the adequacy of the model for the response (fruit weight, number of branches and vine length) of watermelon in the experimentation at 95% confidence level and the result are as shown in Table 5.

Table 5: Analysis of variance

Source	DF	SS	MSS	F	F-critical	Pr(>F)
Model 1	9	95.647	10.627	8.239	3.0204	0.00141
Residuals	10	12.899	1.290			
Total	19	108.546				
Model 2	9	21.4480	2.3831	8.6690	3.0204	0.00114
Residuals	10	2.7493	0.2749			
Total	19	24.1973				
Model 3	9	2392.47	265.83	11.37	3.0204	0.00036
Residuals	10	233.80	23.38			
Total	19	2626.27				

***F (9, 10, 0.95)=3.0204

ANOVA results revealed that the predicted response models were statistically significant since F-values were 8.239>3.02038, 8.669>3.02038 and 11.37>3.02038 (critical value) and P=0.00141, 0.001143 and 0.00036 respectively. The suggested regression model is statistically significant in the prediction of fruit weight, number of branches and vine length of watermelon as a measure of growth and production of watermelon plant in the study area. From Table 5, it is observed that the model 1, model 2 and model 3 satisfy the adequacy conditions in non-linear form. In general, the overall models are adequate for prediction purpose in this study.

Application of desirability function for optimization

Process optimization through the use of the desirability function, started with defining the specifications required for increased growth and production of watermelon. In this case, the data was analyzed separately to optimize the variable responses. Specifications (minimum, target and maximum) are related to the experimental data and they are presented in Table 6. In this case, the study sought target value to fruit weight, the number of branches and vine length of watermelon, search the maximization because the higher value is better for the increased growth and production of watermelon in the study area.

The desirability (D) is the global index calculated from the combination of each of the variables response processed through a geometric mean and this index is responsible for showing the best condition for optimization of all variable responses at the same time. To achieve the greatest possible value for D which reflects, in the best condition variable responses in relation to the attendance of their specification, the best settings using standardized variables of the factors are as shown in Table 7.

Table 4: Regression coefficient estimates

	Model 1				Model 2				Model 3			
Variable	**Estimate**	**SE**	**t-Value**	**P-value**	**Estimate**	**SE**	**t-Value**	**P-value**	**Estimate**	**SE**	**t-Value**	**P-value**
Constant	15.14838	0. 46321	32.703	1.69e-11 ***	6.1848	0.2139	28.921	5.69e-11 ***	181.2218	1.9721	91.893	5.70e-16 ***
X_1	1.54326	0.30731	5.022	0.00052 ***	0.6856	0.1419	4.832	0.000689 ***	7.8065	1.3084	5.967	0.000138 ***
X_2	0.41770	0.30731	1.359	0.20395	0.1231	0.1419	0.868	0.405743	2.7833	1.3084	2.127	0.059286
X_3	1.56923	0.30731	5.106	0.00046 ***	0.5392	0.1419	3.800	0.003485 **	8.3926	1.3084	6.415	7.69e-05 ***
X_1^2	-0.09017	0.29912	-0.301	0.76924	-0.1777	0.1381	-1.287	0.227124	0.1502	1.2735	0.118	0.908443
X_2^2	-0.86780	0.29912	-2.901	0.01580 *	-0.3544	0.1381	-2.567	0.028050 *	-3.0840	1.2735	-2.422	0.035956 *
X_3^2	0.01587	0.29912	0.053	0.95874	-0.1777	0.1381	-1.287	0.227124	0.6981	1.2735	0.548	0.595603
X_1X_2	-0.06250	0.40154	-0.156	0.87941	-0.5000	0.1854	-2.697	0.022423 *	1.9125	1.7095	1.119	0.289412
X_1X_3	1.06250	0.40154	2.646	0.02448 *	0.5000	0.1854	2.697	0.022423 *	4.8375	1.7095	2.830	0.017861 *
X_2X_3	0.93750	0.40154	2.335	0.04171 *	0.7500	0.1854	4.046	0.002340 **	3.9125	1.7095	2.289	0.045119 *

$$Y_1 = 15.148 + 1.543X_1 + 0.418X_2 + 1.569X_3 - 0.868X_2^2 + 1.063X_1X_3 + 0.938X_2X_3 \quad \text{Model 1}$$

$$Y_2 = 6.1848 + 0.6856X_1 + 0.1231X_2 + 0.5392X_3 - 0.3544X_2{}^2 - 0.500X_1X_2 + 0.500X_1X_3 + 0750X_2X_3 \quad \text{Model 2}$$

$$Y_3 = 181.2218 + 7.8065X_1 + 2.7833X_2 + 8.3926X_3 - 3.084X_2^2 + 4.8375X_1X_3 + 3.9125X_2X_3 \quad \text{Model 3}$$

Where Y_i ;*(i=1,2,3)* represent the fruit weight, Number of branches and vine length of watermelon plant respectively

$X_{1,}$ is the poultry manure
$X_{2,}$ is the cow manure
X_3 is the goat manure

These are coded equations, useful for identifying the relative impact of the factors by comparing the factor coefficients.

Analyzing the Table 7, it was found that the value of D, belong to the range from 0 until 1 and is maximized when all the answers are approaching their specifications, because the nearest one in D, closer to the original answers will be their respective specifications limits. The great general point of the system is achieved by maximizing the geometric mean, calculated from the individual desirability functions (d_i) which in this case are the value for each of the variable responses as shown in Table 8.

The values obtained for the compound desirability (D) and individual desirability (di) demonstrate that the process was well optimized, because these indices are equal to the condition great value of one (1.0). Thus under the best parameter setting all the responses were maximized as shown in Table 9.

The aim of the study was to optimize the multiple responses of watermelon to organic manure. It was revealed that, 17.64 tons/ha of poultry manure, 11.2 tons/Ha of cow manure and 18.1 tons/ha of goat manure was essential or required to simultaneously optimize the multiple responses of watermelon. These optimal conditions (requirement of organic manure) could attain a maximum of 93.73 tons/ha of fruit weight of watermelon. Also under the same conditions nine (9) branches per watermelon plant were achieved. Indeed, the length of about 225.4 cm was attained at the same optimal conditions. An increase of poultry manure led to an increase in fruit weight, numbers of branches and vine length of watermelon plant as well as desirability compound D (Figure 2). Noting the increase of cow manure factor, it is possible to perceive that there will be fall in the value of the response variables and increased desirability compound D.

Also an increase of poultry manure led to an increase in fruit weight, numbers of branches and vine length of watermelon plant. Multiple response optimization using desirability functions have until now had its utilization limited to the chromatographic field, its related techniques, and to electrochemical methods, (Candioti *et al*., (2014). However, its principles can be applied to the development of procedures using various analytical techniques, which demand a search for optimal conditions for a set of responses simultaneously.

Table 6: Specification for increased growth and production of watermelon

Response Variable	Minimum	Target/Average	Maximum
Fruit weight (Kgs)	17.0	23.287	29.574
No. of branches	4	8	12
Vine length (cm)	165.4	223.743	282.09

Table 7: Optimal parameter-setting of responses

Symbols	Organic manure	Optimal values (coded)	Actual optimal values
X_1	Poultry manure	1.52754	17.6377 tons/ha
X_2	Cow manure	0.233256	11.1663 tons/ha
X_3	Goat manure	1.61003	18.05015 tons/ha

Table 8: Desirability function values

Response variable	Individual desirability (d_i) values	Global index (D)
Fruit weight	1.0	1.0
No. of branches	1.0	
Vine length (cm)	1.0	

Table 9: Simultaneous optimization of multiple responses

Symbols	Responses	Maximum value	
Y_1	Fruit weight	23.295 kg/plant	93.73 tons/ha
Y_2	Number of branches	8.97122 branches/plant	9 branches/plant
Y_3	Vine length (cm)	225.43 cm	225.43 cm

Figure 2: Desirability function applied in multiple responses

CONCLUSIONS AND RECOMMENDATIONS

The great general point of the system was achieved by maximizing the geometric mean, calculated from the individual desirability functions which in this study were the value for each of the variable responses. The findings revealed that the process was well optimized, because the indices were very close or equal to the condition great value of one. In the study, the best solution was found to be 17.64 t/ha, 11.17 tons/Ha and 18.05 t/ha of poultry, goat and cow manure respectively that is required to achieve maximum response values as 93.73 t/ha of fruit weight, 9 branches/plant and 225.43 cm of vine length of watermelon plant. The responses were used to assess the increased growth and production of watermelon plant in the study area. Finally, this study exemplified that the development of mathematical models for crop production based on statistics can be useful for predicting and understanding the effects of experimental factors. What must be noted here is that RSM does not explicate the mechanism of the studied crop production, but only a certain the effects of variables on response and interactions between the variables. It can also be stated that it would be a scientific and economic approach to obtain the maximum amount of information in a short period of time and with the lowest number of experiments.

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REFERENCES

Box, G.E.P., Hunter, W.G. and Hunter, J.S. 1987. *Statistics for Experimenters: An Introduction to Design, Data Analysis and Model Building*, John Wiley, New York.

Boyhan, G.E., Granberry S.M. and Kelley, W.T. 1999. *Soils and fertilizer management for water melon production*. The University of Georgia College of Agricultural and Environmental Sciences and the U.S. Department of Agriculture Bulletin 996

Candioti, L.V., Zan De, M.M., M.S. and Goicoechea, C.H. 2014. Experimental design and multiple response optimization. Using the desirability function in analytical methods development. Talanta, 1241: 123-138.

Dauda, S.N., Ajayi, F.A. and Ndor, E. 2008. Growth and yield of watermelon *Citrullus lanatus* as affected by poultry manure application. Journal of Agriculture and Social Sciences; 121–124.

Derringer, G. and Suish, R. 1980. Simultaneous optimization of several response variables. Journal of Quality Technology, 12: 214-219.

Enujeke, E.C. 2013a. Effects of poultry manure on growth and yield of improved maize in Asaba Area of Delta State, Nigeria. Journal of Agriculture and Veterinary Science. 45: 24-30.

Enujeke E.C 2013b. Response of watermelon to five different rate of poultry manure, Journal of Agriculture and Veterinary Science, 52: 45-50.

IITA, 2013. Growing watermelon commercially in Nigeria: An illustrated guide. International Institute of Tropical Agriculture IITA, pp. 1-16.

Jarret, B., R. Bill, W. Tom and Garry, A., 1996. Cucurbits Germplasm Report, pp. 29-66. Watermelon National Germplasm System, Agricultural Service, USDA.

Khuri, A. and Siuli M. 2010. Response Surface Methodology. John Wiley and Sons Inc, Wileys Coup Stat 2: 128-149.

Mangila, E., Tabiliran, F.P., Naguit, M.R.A and Malate, R 2007. Effects of organic fertilizer on the yield of watermelon, *Threshold* 2: 27-35.

Montgomery, D.C. 2013. *Design and analysis of experiments*, 8th Ed., New York: John Wiley and Sons; 203 pp.

Montgomery, D.C. 2005. *Design and Analysis of Experiments: Response surface method and designs.* New Jersey: John Wiley and Sons, Inc.

Muriithi, D. K. 2015. Application of response surface methodology for optimization of potato tuber yield. American Journal of Theoretical and A:lied Statistics, 44: 300-304.

Myers, R.H., Montgomery, D.C., Vining, G.G., Borror, C.M. and Kowalski, S.M. 2004. Response surface methodology: A retrospective and literature survey. J. Qual. Technol., 36: 5377.

Myers, R.H., Montgomery, D.C., Christine, M, and Anderson, C. 2009. *Process and product Optimization Using Designed experiments* 3rd Edition, John Wiley and Sons, New Jersey

Myers, Raymond H., Khuri, Andre I. and Carter, Walter H., Jr. 1989. Response surface methodology: Technometrics, 31(2): 137-153.

Wang, J. and Wan, W. 2009. Application of desirability function based on neural network for optimizing biohydrogen production process. International Journal of Hydrogen Energy, Sidney 341: 1253-1259