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Optimization of Yields and Yield Components of Sweet Potatoes (*Ipomea batatas* (L.) Lam) Using Organic Manure and Phosphate Fertilizer

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Authors' contributions

This work was carried out in collaboration among all authors. Author IDM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author LM managed the analyses of the study. Author MM managed the literature searches. All authors read and approved the final manuscript.

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Abstract

Sweet potato production has been faced with various constraints including small land sizes and inappropriate agronomic practices, especially on management of soil fertility. Many studies that have been carried out on the effects of application of farmyard manure on sweet potatoes yields have just been used to get the best treatment within the range of treatments used. However, the designs used in data analysis are not appropriate for optimisation process. Therefore, there is need to use an appropriate design that will optimise the yields within the limited available resources for sustainable production of sweet potatoes. The objective of this study was to determine the optimum operating settings and to optimise the yields and the yield components in sweet potatoes. The study was conducted at Chuka University horticultural demonstration farm. The experiment was laid out in a Randomised Complete Block Design and replicated three times. The treatments included cattle manure and poultry manure (0, 5, 10, 15 and 20 tons per hectare) and inorganic phosphate fertilizer (0, 20, 40, 60 and 80 tons of P_2O_5 per hectare). Data was collected on number of tubers, tuber diameter, length and weight of tubers per plot. Central Composite Design (CCD) was applied in the optimization process. Data obtained was analysed using R

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statistical software and the second order mathematical model which described the response as a function of input variables, was generated. The study found that the optimal levels of inorganic phosphate, poultry manure and cattle manure that led to maximum yield were; 2.895 tons/ ha, 7.5 tons/ ha and 14.88 tons/ha, respectively. The study demonstrated that CCD can serve as an inexpensive tool in optimization of the sweet potato yield. The study was also useful to the farmers in the area of study since they can get information on the optimal levels of application organic manure and phosphate fertilizer that would lead to maximum yields.

Keywords: Central composite design; sweet potato; randomized complete block design; cattle manure; poultry manure; inorganic phosphate; optimization.

1 Introduction

Sweet potato production has been constrained by many factors including small sizes of land and poor agronomic practices. Among the poor agronomic practices is poor soil fertility management due suboptimal or over-optimal application of fertilizers [1]. Many studies have carried out in an attempt to address the problem of decreasing soil fertility in crop production. For example, Studies have revealed significant effects of application of organic manure and inorganic phosphate on the yields of sweet potatoes [1,2]. However, organic and inorganic fertilizer showed no significant differences on vine length, number of leaves, number of branches and total dry matter [1,2]. Higher phosphorous rate was found to significantly increase total seed tuber yield compared to low rate of phosphorous [3]. The lack of significant response exhibited by the sweet potato varieties can be attributed to the innate quality of the crop itself, for example low input requirements [2]. Moreover, lack of detection of significant differences may be attributed to poor designing of the experiments.

Different experimental designs have been applied to study effect of organic and inorganic fertilisers on crop performances. The split plot design has been used to study the effects of organic and inorganic fertilizers on rice yields, with the findings showing that the fertilizers application levels had a significant effect on rice yield [4]. However, the study did not attempt to optimise the application of the fertilizers that would led to maximum rice yield. A study using randomized complete block design showed a significant effect of farmyard manure and inorganic fertilizers on production of common beans [5]. [6], using Randomized Complete Block Design, found a significant effect of poultry manure and NPK fertilizer on common bean production. Using lattice design, phosphorus application was found to have a significant effect on sweet potato yields with the yield increasing with increased phosphorus application [7].

In a study laid in a randomized complete block design, effective micro-organisms as a microbial inoculant was found to have a significant effect on the yields of sweet potatoes [8]. A combination between superphosphate at the recommended P level and VAM-fungi inoculation treatment was found to significant increase sweet potato root production and quality [9]. In investigating the effect of tillage methods and phosphorus fertilizer on growth and yield response of sweet potato, results showed that plant growth was not significantly affected by tillage but highest growth and yield was observed from phosphorus treatment [10]. Poultry manure and NPK fertilizers had a significant effect on the yield of sweet potatoes [11]. These studies on effect of organic and inorganic fertilizers on yields of sweet potatoes generally lack of appropriate recommendation on the optimum rates of application [2], consequently, limiting sweet potatoes productivity and profitability through suboptimal and/or over- optimum application of fertilisers. Therefore, there is need to design studies that can optimise fertiliser application in order to maximise sweet potatoes return per unit area.

Modelling and optimization of crop yields have broad implications for economic trading, food production monitoring and global food security [12]. Modelling of crop yields entails studying the effects of different components in order to predict the production patterns [13]. Optimization studies have been done on water and nitrogen use efficiency in crops, photo assimilate partitioning to grain while maintaining lodging resistance, crop production through controlling water and salinity levels in the soil; multiple responses of water melon using organic manure; potato tuber yield [14,15,16,17]. However, information on optimization of yields and yield components of sweet potatoes (*Ipomea batatas* (L.) Lam) using manure and phosphate fertilizer is lacking.

Generally, most of the agricultural research use analysis of variance and linear models for nested analyses to find out whether there is significant treatments effect on the response variable [18]. These models can only determine if there is a significant relationship between the input variables and the response variable. There is need, therefore, to use an appropriate design that can describe the relationship between input variables and the response as well as optimize the response. Central Composite Design is one of such designs [19,20].

Central Composite Design is used in Response Surface Methodology to fit a second order model [21]. This approach develops a suitable experimental design that integrates all of the independent variables and uses the input data from the experiment to finally come up with a set of equations that can give a theoretical value of an output. The outputs are obtained from a well-designed regression analysis that is based on controlled values of the independent variables [22].

Central Composite Design has been applied in several modelling and optimization studies. For instance, a Central Composite Design was employed to investigate the effect of critical parameters of organosolvent pretreatment of rice straw including temperature, time, and ethanol concentration [23]. The study was able to determine the effect of the independent variables on the dependent variables as well as optimization of the response [23]. Central Composite Design has also been applied in modelling of the phenol adsorption process in a fixed-bed reactor [19]. The residual solid, lignin recovery, and hydrogen yield were selected as the independent variables since they were significant in explaining the response. The use of Central Composite Design allows for optimization of the response [19].

Central Composite Design has also been applied in optimization of the desirability function for adsorption of methylene blue from aqueous solution onto *Lemna major* [20]. The use of Central Composite Design allowed for optimization of the response [20]. Optimization of multiple responses of watermelon to organic manure was also done using Central Composite Design [17]. In all these studies, Central Composite Design has been shown to be a superior optimization design. The objective of this study was to optimize the yield and yield components of the sweet potato using Central Composite Design.

2 Methodology

The study was conducted at Meru South in Chuka University Horticultural Demonstration Farm, Kenya. The experiment was laid down in Randomized Complete Block Design (RCBD) and replicated three times. The treatments consisted of cattle manure and poultry manure (0, 5, 10, 15 and 20 tons/Ha) and inorganic phosphate fertilizer (0, 20, 40, 60 and 80 tons/Ha of P_2O_5). The treatments (manure and organic phosphorous levels) were then assigned at random to the experimental units. The Central Composite design (CCD) consisting of 20 experimental runs was also used in this study. A 3-factor 5-level Central Composite Design was applied in the growth process of sweet potatoes, optimization requiring 20 experimental runs. Inorganic phosphate fertilizer (X_1), Poultry manure (X_2) and cattle manure (X_3) were the independent variables to optimize the response value of interest (weight of tubers, length of tubers, number of tubers and the diameter of tubers).

The collected data was subjected to analysis using R statistical software. Optimization was done by obtaining a general mathematical solution of the second order models for the location of the stationary points. Once the stationary points were found, it was necessary to characterize the response surface in the immediate vicinity of the points. Characterizing meant; determining whether the stationary point was a point of maximum or minimum response or a saddle point. The optimization process was summarised as shown in Fig. 1.

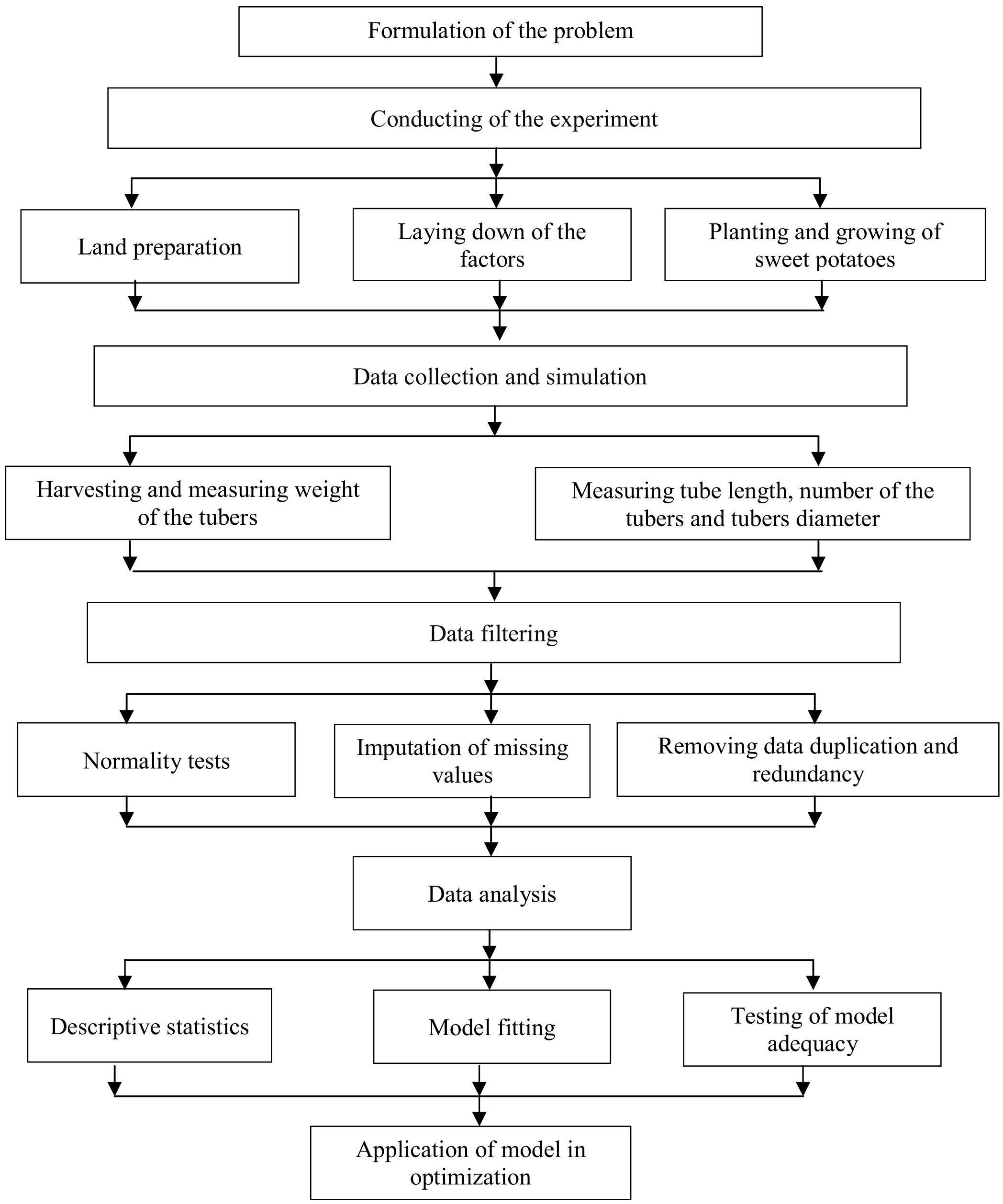

Fig. 1. Optimization process

3 Results and Discussion

3.1 Descriptive statistics for weight of tubers

The skewness and kurtosis values showed that the data satisfied the normality assumptions. For inorganic phosphorus levels 0, 20, 40, 60 and 80, the average weights of tubers were 12.14, 12.560, 12.982, 12.742 and 13.416 tons per hectare respectively. This shows a positive effect of inorganic phosphorus on weight of tubers.

Table 1. Effects of organic manure and inorganic phosphate on weight of tubers

	Levels	Mean	SD	Md	Skew	Kurt	Max	Min
Inorganic	0	12.140	8.64	13.761	-0.153	-2.059	21.561	1.15
	20	12.56	7.873	13.754	0.2138	-2.213	20.325	3.26
	40	12.982	7.102	13.735	-0.066	-2.367	19.094	5.38
	60	12.742	4.644	13.497	0.084	-2.008	17.885	6.92
	80	13.345	0.649	13.235	0.323	-1.956	14.213	12.71
Poultry	0	10.082	3.857	10.761	-0.194	-2.212	13.432	5.38
	5	11.749	5.582	12.263	-0.218	-2.012	17.495	4.20
	10	13.416	7.306	13.760	-0.242	-1.811	21.563	3.03
	15	14.831	5.293	15.178	-0.155	-2.085	20.325	7.86
	20	16.245	3.280	16.595	-0.067	-2.359	19.095	12.7
Cattle	0	8.264	8.144	5.543	0.678	-1.426	21.561	1.15
	5	10.649	6.230	9.205	0.449	-1.644	20.272	4.81
	10	13.034	4.317	12.877	0.221	-1.8627	18.980	8.48
	15	10.669	6.912	9.682	0.187	-2.400	20.325	3.27
	20	13.075	5.681	13.820	-0.303	-1.853	19.091	5.38

For poultry manure levels 0, 5, 10, 15 and 20, the average weights of tubers were 10.082, 11.749, 13.416, 14.831 and 16.245 tons per hectare respectively. This shows that the average weights of the tubers increased with increase in the levels of the poultry manure. For cattle manure levels 0, 5, 10, 15 and 20, the average weights were 8.264, 10.649, 13.034, 10.669 and 13.075 tons per hectare respectively. It can be noted that application of cattle manure increased the average weight of tubers. However, cattle manure level 10 and 20 did not have a large difference in the average weight of the tubers. The above results are in agreement with those reported by [1]. [1] evaluated different sweet potato varieties variables under inorganic and organic fertilisers amended sandy ferralitic soils, who found out that application of organic manure and inorganic fertiliser significantly ($p < 0.05$) increased the shoot length, tuber yield, chlorophyll content and harvest index in all varieties. Other similar results were found by [24] who showed that yield and yield components of potato are influenced by nitrogen and phosphorus rates.

3.2 Descriptive statistics for length of tubers

The summary statistics for the factor effects on the length of tubers showed that the normality assumptions were satisfied. For inorganic phosphorus levels 0, 20, 40, 60 and 80 the average lengths of tubers were 8.937 cm, 8.947cm, 8.957 cm, 9.075cm and 9.192 cm respectively. This shows that application of inorganic phosphate has a positive effect on the length of the tubers.

For poultry manures levels 0, 5, 10, 15 and 20, the average length 8.037 cm, 8.561cm, 9.086 cm, 9.589 cm and 10.092 cm respectively. This shows that poultry manure has a positive impact on length of tubers. Cattle manure had a positive impact on the length of the tubers. This shows that application of cattle manure increased the length of tubers. However, for cattle manure levels 10 and 20, there was no significant difference in length increase. The above results are similar to the finding of [25] who showed that application of a combination of inorganic phosphate and poultry manure fertilizers significantly increased the shoot length, tuber yield, chlorophyll content and harvest index in all sweet potato varieties. [26] also found similar results.

3.3 Optimal settings on the control variables that produce maximum response values

One of the main objectives of RSM is the determination of the optimum settings of the control variables that result in a maximum (or a minimum) response over a certain region of interest. This requires having a 'good' fitting model that provides an adequate representation of the mean response because such a model is to be utilized to determine the value of the optimum. The aim of the study was to find the optimal set of experimental parameters that produces a maximum value of weight of the tubers. The best solution satisfying the above criteria was obtained using R software. The optimum values of selected variables were obtained by solving the regression models and also analyzing the response surface contour plots.

Table 2. Effects of organic manure and inorganic phosphate on length of tubers

Factor	Levels	Mean	SD	md	Skew	Kurt	Max	Min
Inorganic	0	8.937	2.693	9.755	-0.553	-1.826	11.150	5.091
	20	8.947	2.566	9.237	-0.166	-1.850	11.575	5.590
	40	8.957	2.438	8.721	0.219	-1.874	12.000	6.093
	60	9.075	1.567	9.075	-0.214	-1.808	10.870	7.133
	80	9.192	0.697	9.430	-0.647	-1.741	9.740	8.178
Poultry	0	8.037	2.068	8.667	-0.544	-1.834	9.741	5.092
	5	8.561	2.014	8.692	-0.138	-1.687	10.872	5.877
	10	9.086	1.959	8.723	0.268	-1.539	12.000	6.654
	15	9.589	1.394	9.3075	0.269	-1.837	11.575	8.048
	20	10.092	0.831	9.895	0.271	-2.136	11.153	9.436
Cattle	0	7.912	2.455	6.656	0.771	-1.358	12.000	6.096
	5	8.692	1.847	7.971	0.545	-1.609	11.575	7.131
	10	9.475	1.245	9.292	0.319	-1.861	11.158	8.171
	15	8.732	2.431	8.117	0.042	-1.542	11.186	5.594
	20	9.555	2.407	9.585	-0.691	-1.722	10.361	5.099

3.4 Determining optimal conditions for maximum weight of tubers

The aim of the study was to find the optimal set of experimental parameters that produces a maximum value of weight of tubers. The best solution satisfying the above criteria was obtained using R software.

The optimum values of selected variables were obtained by solving the regression model and also analyzing the response surface contour plots. It was found that for maximum (optimal) production of sweet potato weight, 17.5 tons/Ha of poultry manure, 12.89 tons/Ha of inorganic phosphate and 14.88 tons/Ha of cattle manure are required to produce 56.24 ton/Ha of sweet potatoes weight in the study area (Table 3).

Table 3. Optimal conditions for maximum weight of tubers

Variable	Description	Optimal Value
X_1	Inorganic Phosphate	12.890 tons/ ha
X_2	Poultry Manure	17.500 tons/ ha
X_3	Cattle Manure	14.880 tons/ ha
Y_1	Weight of Tubers	56.240 tons/ha

3.5 Response surface and contour plots

Contour plots aids in the study of the response surface. They characterize the shape of the surface and locate the optimum with reasonable precision. Graphical visualization helps in understanding the second-order response surface. Three dimension (3D) plots for different combination of variables (inorganic phosphate, poultry and cattle manure) which exhibit the trend of variation of responses within the selected range of input variables are as shown in Fig. 2.

The results of this study showed that poultry manure and inorganic phosphorus had positive effect on sweet potato production (Fig. 2). The graphical visualizations show that the maximum weight of the tubers was 56.24 tons/ha obtained after application of 12.890 tons/ha of inorganic phosphate, 17.500 ton/ha poultry manure and 14.880 tons/ha of cattle manure. The response surface corresponding to the second order model indicates that moderately low cattle manure and high poultry manure increase sweet potato yields. This is because poultry manure has been reported to be rich in nutrient concentration especially nitrogen which enhance crop production [27].

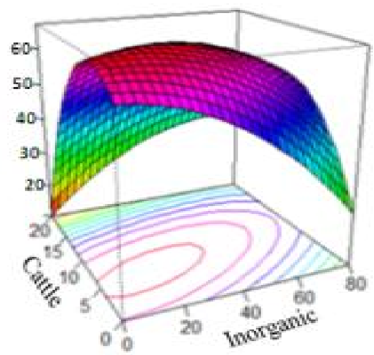

Fig. 2. Response surface for weight of tubers as a function of poultry manure and inorganic phosphorus at constant level of cattle manure

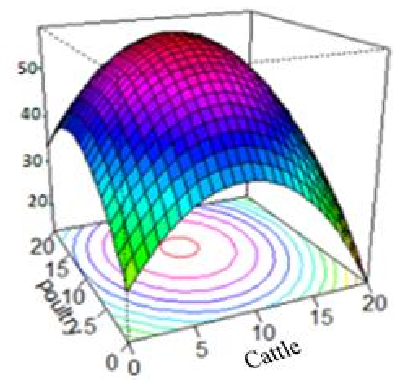

Fig. 3. Response surface for weight of tubers as a function of poultry manure and cattle manure at constant level of inorganic phosphate

3.6 Determining optimal conditions for maximum length of tubers

The aim of the study was to find the optimal set of experimental parameters that produces a maximum value of length of tubers.

It was found that for maximum (optimal) production of length of sweet potatoes, 16.86 tons/Ha of poultry manure, 13.34 tons/Ha of inorganic phosphate and 13.28 tons/Ha of cattle manure are required to produce 8.64 cm of sweet potatoes length in the study area (Table 4).

Table 4. Optimal conditions for maximum length of tubers

Variable	Description	Optimal value
X_1	Inorganic Phosphate	13.340 tons/ ha
X_2	Poultry Manure	16.860 tons/ ha
X_3	Cattle Manure	13.280 tons/ ha
Y_2	Length of Tubers	13.640 cm/tuber

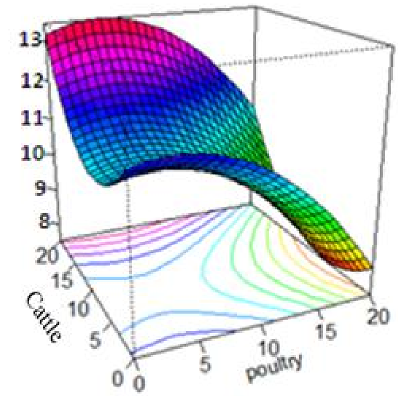

Fig. 4. Response surface for length of tubers as a function of cattle manure and poultry manure at constant level of inorganic phosphorus

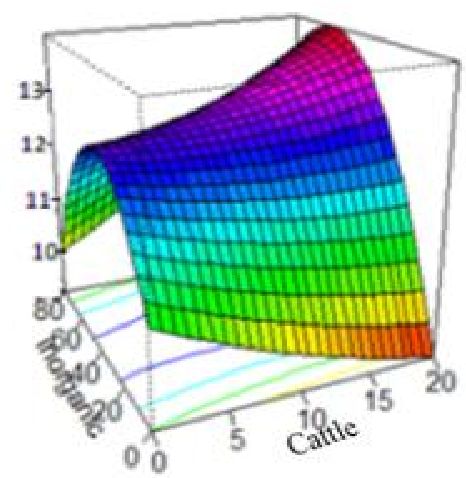

Fig. 5. Response surface for length of tubers as a function of cattle manure and inorganic phosphorus at constant level of poultry manure

It was observed that, increasing cattle manure and poultry manure resulted to high length of tubers in sweet potato production. Poultry manure and inorganic phosphate clearly influenced the growth of sweet potatoes. The graphs also made a visualization of the optimization values presented in Table 4. The response surface corresponding to the second order model indicates that moderately high poultry manure and inorganic phosphate increased the length of sweet potato tubers.

3.7 Determining optimal conditions for maximum number of tubers

The aim of the study was to find the optimal set of experimental parameters that produces a maximum value of number of tubers.

It was found that for maximum (optimal) production of length of sweet potatoes, 18.27 tons/Ha of poultry manure, 15.26 tons/Ha of inorganic phosphate and tons/Ha of 14.33 cattle manure are required to produce 4 tubers per plant in the study area. This is optimal condition for maximum number of tubers for sweet potato plant (Table 5).

Table 5. Optimal conditions for maximum length of tubers

Variable	Description	Optimal value
X_1	Inorganic Phosphate	15.260 tons/ ha
X_2	Poultry Manure	18.270 tons/ ha
X_3	Cattle Manure	14.330 tons/ ha
Y_3	Number of Tubers	4 tubers/plant

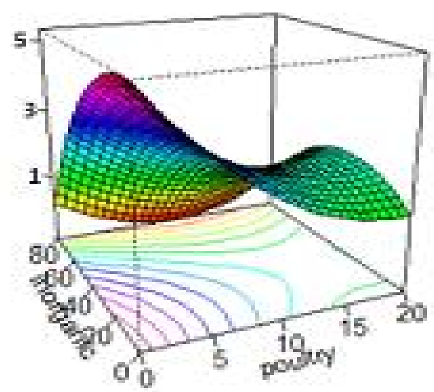

Fig. 6. Response surface for number of tubers as a function of poultry manure and inorganic phosphorus at constant level of cattle manure

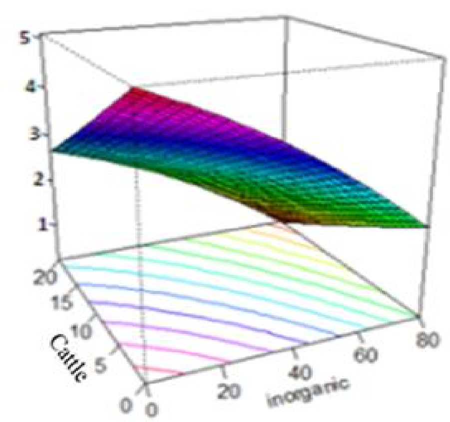

Fig. 7. Response surface for number of tubers as a function of cattle manure and inorganic phosphorus at constant level of poultry manure

It was observed that, increasing inorganic phosphate and poultry manure resulted to high number of tubers for sweet potato plant. Poultry manure and inorganic phosphate clearly influenced the growth of sweet potato plant. The response surface corresponding to the second order model indicates that moderately high inorganic phosphate and high poultry manure increase number of tubers of sweet potatoes. The graphical presentations made a visualization of the values indicated in Table 5.

3.8 Determining optimal conditions for maximum diameter of tubers

The aim of the study was to find the optimal set of experimental parameters that produces a maximum value of diameter of tubers.

It was found that for maximum (optimal) production of diameter of tubers of sweet potatoes, 17.37 tons/Ha of poultry manure, 14.06 tons/Ha of inorganic phosphate and tons/Ha of 15.13 cattle manure are required to produce 6.5cm in diameter of tubers per plant in the study area. This is optimal condition for maximum number of tubers for sweet potato plant (Table 6).

Table 6. Optimal conditions for maximum diameter of tubers

Variable	Description	Optimal value
X_1	Inorganic Phosphate	14.060 tons/ ha
X_2	Poultry Manure	17.370 tons/ ha
X_3	Cattle Manure	15.130 tons/ ha
Y_4	Diameter of Tubers	6.500 cm/tuber

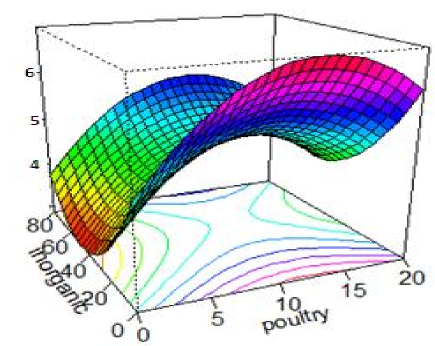

Fig. 8. Response surface for diameter of tubers as a function of poultry manure and inorganic phosphorus at constant level of cattle manure

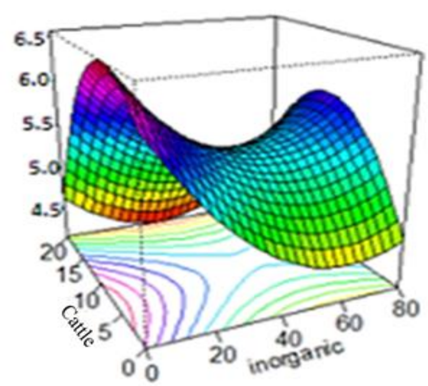

Fig. 9. Response surface for diameter of tubers as a function of cattle manure and inorganic phosphorus at constant level of poultry manure

Poultry manure and inorganic phosphorus had a direct effect on the diameter of the tubers. The results show similarity with other studies such as a study by Muriithi et al. [17] which showed the response surface corresponding to the second order model indicating that moderately low cattle manure and high poultry manure increased growth and production of water melons. This was attributed to poultry manure being reported to be rich in nutrient concentration especially nitrogen which enhance crop growth and production [27]. Other similar finding reported that water and phosphorus nutrient had a direct effect on the yield of potato (Muriithi, 2015). Admas et al. [28] and Buriro et al. [29] also obtained similar results.

4 Conclusion

In conclusion, the optimal settings of the inorganic phosphate and the organic manure were obtained by solving the fitted second order models and using the response surface contour plots. The optimal settings for inorganic phosphate, poultry manure and cattle manure that produced maximum values tuber weight, tuber length, number of tubers and diameter of tubers were analyzed obtained by solving the regression models and also analyzing the response surface contour plots. The best solution was found to be 17.5 tons/Ha of poultry manure, 12.89 tons/Ha of inorganic phosphate and 14.88 tons/Ha of cattle manure to produce 56.24 ton/Ha of sweet potatoes weight, 8.64 cm of sweet potatoes length, 4 tubers per plant and 6.5 cm in diameter of tubers per plant.

Competing Interests

Authors have declared that no competing interests exist.

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