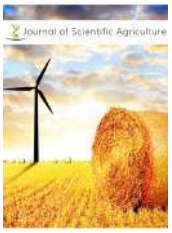
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Research Article



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Effect of potassium dosage on selected growth parameters and yield response modeling on potatoes grown in Molo, Kenya

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ABSTRACT

The Molo region of Kenya has experienced decreased potato acreage yields over the years. This has impacted negatively economic endeavors and food security of the region and Kenya at large. A preliminary study on the physical-chemical characterization of the soils indicated that they were deficient in the amount of available potassium. This finding was very important because the majority of the farmers in the region replenish phosphorous and nitrogen but not potassium. Subsequently, the present study was undertaken to determine the effect of replenishing selected farm soils with various potassium levels on the growth and productivity of 'Shangi' a variety grown in Molo Sub-county and ultimately determine the soil optimum potassium dose requirement. A field experiment was conducted with seven model-based K fertilizer treatments (0, 33.3, 41.5, 55.3, 133.3, 200 and 266.7 kg K_2O/ha) and three replications in Randomized Complete Block Design (RCBD). The potassium sorption study was conducted using soil samples as adsorbent while varying the K^+ concentration in solution. The data obtained were treated using both linearized and non-linearized Freundlich adsorption isotherms. The optimum potassium fertilizer rate was evaluated using yield response models (Quadratic, linear-plateau, quadratic-plateau, and square root). The results of the study showed that the increase in soil potassium levels led to a significant increase in growth and yield parameters. Aerial stem number, leaf number per plant, and plant height recorded increase with an increase in K levels. The sorption data were found to fit best in linearized Freundlich isotherm based on correlation coefficient values (R^2) and error function analysis. The potassium buffering capacity ranged from 13.667-46.068 with a mean of 33.6 ± 17.4mg/Kg. The quadratic model fitted the data better than other models with R^2 (0.9559) and SSE (18.237). K_2O fertilizer application at 200 Kg/ha maximized the potato tuber yield to 30.111 Ton/ha. The result showed clearly that there is a need to adopt the use of potassium-based fertilizer according to soil requirements in this region to realize good tuber yield.

KEYWORDS: Acreage yield, buffering capacity, food security, modeling, potassium, potato

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INTRODUCTION

In Kenya, the potato is the second most important food crop after maize and therefore merits consideration as a potential focal crop [1]. Potato (*Solanum tuberosum* L.) plays a significant role in food security in Kenya and contributes to the alleviation of poverty through income generation and employment creation. Studies have shown that potatoes in the form of French fries (chips) are the meal that is most consumed in Kenyan urban centers. The potato crop is also a key economic earner for the population in rural areas of Molo Sub County. However, the region has experienced a decline in the acreage yield of the crop over the past few years. This decline has been attributed to the lack of clean seeds, fertilizers, and chemicals. Therefore, it is important to not only determine the cause but also the corrective measures necessary to unlock the immense potential the region possesses in the production of potatoes in the quest to attaining food security. The majority of the farmers in this region use Di-Ammonium Phosphate as the planting fertilizer due to its availability in agro vet outlets oblivious to the potassium requirements of the soils. Potato crop a heavy feeder of K with the uptake of over 300 kg K ha^{-1} under optimum K supply [2]. Consequently, the potato crop is a heavy remover of potassium from the soil and removes 1.5 times the amount of nitrogen and 4-5 times the amount of phosphate [3]. It is documented that K affects potato quality and yield. Decreased potato yield and smaller sized tubers emanate from an inadequate amount of K in the soil [4]. DAP supplies soils with nitrogen and phosphorous but lacks potassium, a vital plant primary macronutrient. A preliminary study suggested that potassium deficiency was the

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main cause of the decline in potato acreage yield in the region over the years. Indeed other literature reports have indicated that the use of potassium fertilizer for potato crops is not common [5]. According to Singh and Jones [6], the amount of potassium adsorbed provides a better index of soil fertility. It can also be used to predict the critical solution level for plant growth for a particular soil and crop. Potassium adsorption/buffering capacity (PBC) is the soils' capacity to resist change in the concentration of potassium in soil solution. PBC is a soil's key indicator of its K^+ availability. High values are indicative of adequate potassium availability for long periods while low values imply that there is a need for frequent fertilization [7]. Low values also indicate that the soils are frequently depleted K^+ through leaching. The use of yield response models is critical to accurately determine the optimal potassium-based fertilizer dose requirement for maximum crop yield. This study, reports the impact of replenishing selected farm soils with various potassium doses on some selected growth parameters, and tuber yields, as well as the optimal potassium dosage rate of the soil in the selected farms in Molo sub-county, Kenya.

MATERIALS AND METHODS

Field Study Sites

Molo Sub County is located in Nakuru county Kenya. It is situated in an altitude that ranges between 2980-3050 m.a.s.l and receives annual rainfall between 1200-1900mm/year [8]. The soils found in the region are mainly classified as planosolic with clay and are poorly drained [8]. Most of the farmers practice small scale mixed farming due to the high population density in the region. There has been a decline in potato tuber yield due to the recycling of seeds and limited alternative fertilizer to boost the macronutrient levels in the soils. The main crops grown in this region are maize, potatoes, cabbages, peas, and carrots. The experimental study was conducted on three different sites.

Soil Sampling

Samples were obtained using a stainless metallic tube soil auger from three sites. They were collected in triplicates at depths of 0-10 cm from five points per site and soils mixed to form representative samples. The samples were placed in plastic bags and transported to Kibabii University laboratory where they were air-dried, ground, sieved through a 2 mm sieve size, and stored in stoppered plastic containers ready for analysis according to Scrimgeour [9].

Analysis of pH and Selected Macronutrients of Soil Samples

Soil pH was determined by the use of a glass electrode with calomel as standard [10]. Total nitrogen was determined by the micro-Kjeldahl method according to International [11]. Exchangeable cations (potassium and calcium) were determined according to the procedure adopted by Walingo *et al.* [12]. Olsen's method for neutral and alkali soils was used for determining the available P in soil samples [13].

Adsorption of Potassium Ion

3.0 grams of the sieved soil samples from three sites were put in 30mL solutions of 0.01M $CaCl_2$ that contained potassium concentrations of 30, 60, 90, 120, 150, 180, 210mgL^{-1} and shaken for 48 hours equilibration time at room temperature. The mixtures were filtered using Whatman filter papers No. 41. The residual levels of potassium in the filtrate were determined using a flame photometer (Model FP6410). The experimental data obtained were fitted in both linear and nonlinear Freundlich adsorption isotherms to determine the adsorption/buffering capacities of the soil samples. The model with the best correlation coefficient and less bias towards experimental data was used to determine the soil potassium buffering capacities. Equations 2.1 and 2.2 represent the linearized and non-linearized forms of Freundlich isotherms used in this study [14].

$$Log\ q_e = log\ K_F + 1/n\ log\ C_e \quad (2.1)$$

$$q_e = K_F C_e^{1/n} \quad (2.2)$$

Where; C_e= equilibrium concentration of K^+, q_e= amount of K^+ adsorbed by soil, $1/n$ = heterogeneity index, and K_F= Freundlich K^+ buffering capacity.

Equation 2.3 shows how q_e was calculated from the K sorption data.

$$q_e = (C_i - C_e)v/m \quad (2.3)$$

Where; C_i = initial K^+ ion concentration, C_e = equilibrium concentration of K^+, v= volume of solution used (L), and m= mass of soil (Kg).

Potato Yield Response Modeling

The mean experimental data on acreage yield obtained from the three sites were used in the yield response modeling to determine the optimal K dosage rate for maximum acreage tuber production. Equation 2.4, 2.5, 2.6, 2.7, and 2.8 represent quadratic, exponential, square root, linear-plateau, and quadratic-plateau models respectively.

$$Y_i = B_0 + B_1X_i + B_2X_i^2 \quad (2.4)$$

$$Y_i = B_0\ \{1\text{-}e^{-B_1\ (Xi\ +\ B2)}\} \quad (2.5)$$

$$Y_i = B_0 + B_1X_i + B_2X_i^{1/2} \quad (2.6)$$

$$Y_i = B_0 + B_1X_i\ for\ X < X_m$$

$$Y_i = Y_m\ for\ X \geq X_m \quad (2.7)$$

$$Y_i = B_0 + B_1X_i + B_2X_i^2\ for\ X < X_m$$

$$Y_i = Y_m\ for\ X \geq X_m \quad (2.8)$$

Where Y_i is the response variable, in this case, represented by the tuber yield (Ton ha^{-1}) and X_i is the predictor variable, here represented by the K fertilizer rate, is the critical rate of K fertilization that occurs at the point of intersection between the linear or quadratic response and the plateau line, is the plateau tuber yield (kg ha^{-1}) and B_2 are constants obtained by fitting the models to the experimental data [15].

Field Experiments

A field experiment was conducted during the May-August season of 2019 at one of the agricultural land of Molo. The experiments were laid out in a randomized block design with three replications having seven levels of K (0, 33.3, 41.5, 55.3, 133.3, 200, and 266.7 kg K_2O/ha). They were coded as K_0, K_{50}, K_{75}, K_{100}, K_{200}, $K_{300,}$ and K_{400} respectively. Plot K_0 was used as a control experiment. Murate of potash (MOP) (60% K_2O) fertilizer was used as a source of potassium. Phosphorous and nitrogen were applied uniformly to all potassium treatments at a dose of P (69 kg P_2O_5/ ha) and N (27kg/ha) using Di ammonium phosphate containing (46% of P_2O_5 and 18% of Nitrogen). Phosphorous, potassium, and nitrogen were applied at once at the time of planting. Well sprouted seeds of "Shangi" were planted on 28th May 2019 on plots of 3 x 3 M, 30 inches between rows, and 9 inches between plants. Earthing up was done two weeks after seed germination. The crop was sprayed after every two weeks from the time of germination to control late bright. The rest of the agronomic package practices adopted was as per recommendation for potato cultivation. During the growth period, plant height, number of leaves/ plant, number of stems/hill was recorded at 49 days after emergence. Harvesting was done when the plants were fully grown and leaves dead. Weight of tubers yield was weighed for each treatment after harvest.

Data Collection and Statistical Analysis

Observations of vegetative growth parameters like aerial stems per plant, plant height, and the number of leaves per plant were recorded when the crop was 49 days from emergence, and the tuber yield per hectare was determined at the time of harvest. Data obtained were subjected to statistical analyses with analysis of variance (ANOVA) using Mini tab 17 software. The treatment means were compared through analysis of variance techniques at a 95% confidence limit using Tukey-Krammer comparison procedure assuming equal variances [16]. Chi-square ($\chi 2$) and Root mean square error (*RMSE*) was used to evaluate models based on their biaseness levels. Equation 2.9 and 2.10 were used for calculation of $\chi 2$ and *RMSE* respectively.

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{\left(q_{e(expt)} - q_{e(cal)} \right)^2}{q_{e(cal)}} \right) \quad (2.9)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} \left(q_{e(expt)} - q_{e(cal)} \right)}{N}} \quad (2.10)$$

Where $q_{e\ expt}$ is the equilibrium capacity from the experimental data and $q_{e,\ cal}$ is the equilibrium capacity obtained by calculation from model and N is the number of observations.

RESULTS AND DISCUSSIONS

pH and Selected Macronutrients in the Soil Samples

Table 1 gives a summary of the pH and concentration mean levels of the key macronutrients found in the samples from the farm soils. The soil pH in the three studied sites ranged from 5.07 to 6.02 with a mean of 5.46 ± 0.43 as shown in the table. The recommended pH levels for normal plant growth lie within 5.0–5.5 [17]. Therefore, the soil's pH of this region was within the recommended levels for the growth of potatoes. Phosphorus, a critical macronutrient whose deficiency affects plant growth, crop yield, and quality [18] had a mean concentration level of 7.11 ± 2.77 mg/Kg. However, the values were below the critical level of 10 mg/Kg [19]. The concentration level of total nitrogen content ranged from 0.13-0.19 with a mean of 0.17 ± 0.03%. This mean was however lower than the critical level of 0.25 [20]. Nitrogen is required by plants in the greatest amount and comprises about 1.5–2.0 % of plant dry matter and approximately 16% of total plant protein [21]. Therefore, a sufficient amount of N availability in plants is required, as it is one of the major key factors of crop production [22]. The mean level of calcium was 198 ± 35.1 mg/Kg equivalent to 0.99 ± 0.18 Cmol/Kg. Calcium boosts nutrient uptake and improves the plant tissue's resistance, makes cell walls stronger, and contributes to normal root system development [23]. It is also an essential regulator of plant growth and development and its deficiency causes yellow coloration and black spots on leaves. Nitrogen and phosphorous are continuously added to the soil during planting as the farmers in this region use DAP as their planting fertilizer and therefore could not have been the main cause of yield decline over the years. The concentration levels of potassium from ammonium acetate extracts ranged from 89.6 to 110.3 mg/Kg with a mean level of 100.27 ± 8.32 mg/Kg. These potassium levels were considered as estimates of the amounts in the soil that are available for plant uptake. The values were below the critical value of 160 mg/Kg [24]. Lower levels of potassium stipulate that the available potassium in these soils was therefore insufficient as far as the growth of potatoes is concerned. The farmers in this region assume farm soils contain adequate amounts of potassium and hardly replenish it and this could be the reason for its deficiency in the soil. This primary macronutrient plays a pivotal role as a cationic inorganic element and plants cannot survive in its absence [25]. Farmers

Table 1: Summary of the physical-chemical characteristics of soil samples

Nutrient	Unit	Mean±SD
pH	-	5.46±0.43
Total nitrogen	%	0.17±0.03
Potassium	mg/Kg	100.27±8.32
Phosphorous	mg/Kg	7.11±2.77
Calcium	mg/Kg	198.2±35.1

SD- Standard deviation

can address this soil nutrient deficiency by incorporating the use of potassium-based fertilizers among others during the planting of the crop to maximize production.

Adsorption Studies of Potassium into Soil Samples

The adsorption of K^+ onto the soil samples was conducted as described in section 2.4. The adsorption parameters obtained are presented in Table 2.

The increase in the amount of potassium adsorbed (q_e) by all soil samples could also be ascribed to an increase in the collision between the high number of the ions (K^+) and the soil particles as per collision theory [27]. Comparing the C_i and C_e values it is then evident that not all K^+ added to soil was adsorbed and therefore some are available for plants use. The amount adsorbed by the soil which may either be exchangeable or non-exchangeable was more than the amount in solution, for this reason, there is a need for K^+ fertilization during planting to boost its levels which will, in turn, raise tuber production.

Potassium buffering capacity (PBC) of the soil samples

Table 3 shows the potassium adsorption parameters, buffering capacities, and statistical errors obtained when the sorption data were fitted in both linear and nonlinear Freundlich isotherm models. The correlation coefficient (R^2) ranged from 0.945–0.975. Based on R^2 values the data fitted well in both models. All the heterogeneity indices (1/n) obtained were below 1 in both models, an indication of normal adsorption [28] of K^+ by the studied soils. The buffering capacities in the linear model ranged from 13.667-46.068 with a mean of 33.6 ± 17.4mg/Kg while in the non-linear model the values ranged from 21.47-31.395 with a mean of 26.91± 5.03mg/Kg. From the two models, it is clear that potassium applied in this soil is adsorbed in unlimited sorption sites of heterogeneous medium and hence expected to give better correlations for the mixed mineralogy contained in soils. This is in agreement with the findings contained in Mbuvi *et al.* [20]. The R^2 of the two models could not be used in exclusion in this case to determine the best fit as there was no major statistical difference between them as shown in Table 3. Therefore, the error function analysis using $\chi 2$ and RMSE were used to determine the bias in the data. Both $\chi 2$ and RMSE values of the linearized model were lower than their corresponding values in the non-linearized form. Hence the linearized model recorded lower biasness as compared to the non-linearized models. Therefore linear Freundlich isotherm model was better placed in determining the soil potential K^+ buffering capacities. The low values obtained show that very little potassium supplied to the soil is preserved for future use by plants. To obtain the critical level as suggested by Al-Zubaidi and Pagel [24], then potassium fertilization during the planting of potatoes is critical if acreage yield is to be improved. Figure 1-3 shows the fitting of the experimental data on Linearized Freundlich isotherms.

Table 2: Adsorption parameters obtained using the studied soil samples

Soil sample (Site 1)			Soil sample (Site 2)		Soil sample (Site 3)	
(C_i)(mg/L)	(C_e)(mg/L)	q_e	(C_e) mg/L	q_e	(C_e) mg/L	q_e
30	12	180	10	200	15	150
60	23	370	27	330	29	310
90	44	460	51	390	55	350
120	65	550	67	530	61	590
150	84	660	81	690	79	710
180	100	800	96	840	95	850
210	120	900	124	860	117	930

Ci-Initial K^+ concentration, C_e- Residual K+ concentration, q_e- Adsorbed K^+

Effect of Potassium Levels on Selected Growth Parameters 49 Days after Emergence

The number of aerial stems, leaves, and height of stems per plant was significantly affected by the increasing K rate. Table 4 shows the summary of mean growth parameters

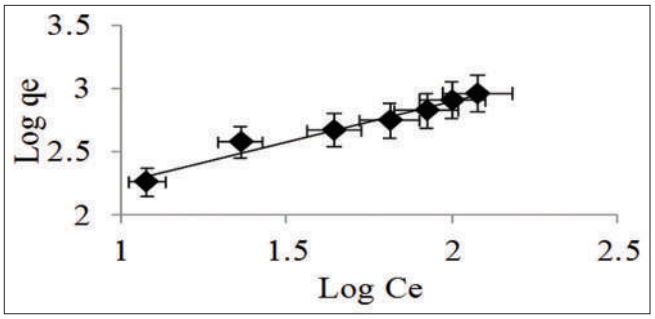


Figure 1: Linear Freundlich isotherm for site 1

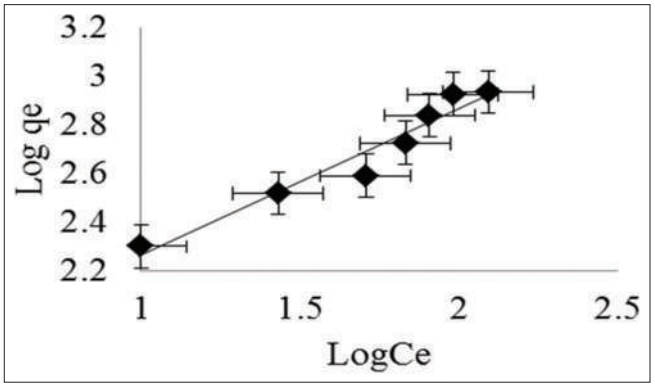


Figure 2: Linear Freundlich isotherm for site 2

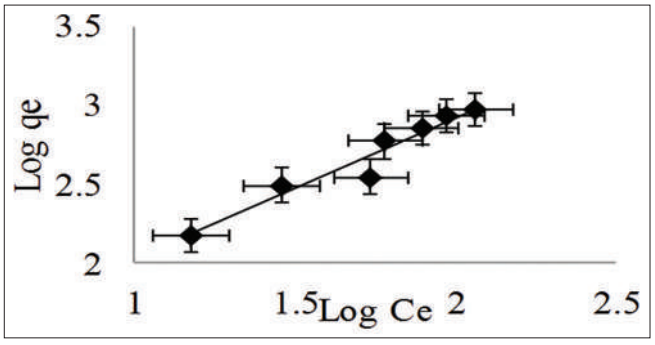


Figure 3: Linear Freundlich isotherm for site 3

Table 3: Adsorption parameters and K^+ adsorption capacities (PBC)

Linear model				
Sites	Linear model form	K_F(PBC)(mg/Kg)	1/n	R^2
1	$Log\ q_e=0.6394C_e + 1.6134$	41.058	0.6394	0.967
2	$Log\ q_e=0.6013C_e + 1.6634$	46.068	0.6013	0.943
3	$Log\ q_e=0.8903C_e + 1.1357$	13.667	0.8903	0.946
Non-linear model				
Soil sample	Non-Linear model form	K_F(PBC)(mg/Kg)	1/n	R^2
1	$q_e= 31.395C_e^{0.2579}$	31.395	0.2579	0.975
2	$q_e= 21.47C_e^{0.3689}$	21.470	0.3689	0.947
3	$q_e= 27.887C_e^{0.3045}$	27.877	0.3045	0.945

Sites	Linear model		Non-linear model	
	RMSE	X^2	RMSE	X^2
1	0.040125	0.004522	90.70111	289.0397
2	0.004754	0.006885	86.09188	274.9493
3	0.061842	0.01002545	66.44184	68.58011

RMSE-root means squared error, 1/n-Heterogeneity index, R^2-Correlation coefficient, PBC-Potassium buffering capacity

obtained from this study 49 days after emergence. Control experiment recorded the lowest mean number of aerial stems, mean number of leaves, and mean height of stems as compared with other experiments. The mean number of aerial stems increased from 5.67 ± 0.58 in plot K_{50} (55.56 K_2O Kg/ha) to a maximum of 8.00 ± 0.00 in plot K_{300} (200 K_2O Kg/ha). This increase was an indication that increased levels of potassium fertilization significantly increase the number of aerial stems. The mean number of leaves per plant increased significantly from 11.67 ± 0.58 in plot K_{50} to a high of 16.33 ± 0.58 in plot K_{300}. This clearly shows that enhanced levels of potassium in the soil contributed positively to the growth of plants. An increase in the number of leaves will increase the levels of photosynthesis and outrightly the yield. The control experiment gave the lowest value of this parameter as indicated in Table 4. The highest stem height of 17.27 ± 0.06 was attained in plot $K_{300.}$

Stem height ranged from 14.6 cm in the control experiment to 17.3 cm with an application of 200kg ha^{-1} K_2O (Plot K_{300}). The result in the control experiment shows that deficiency of macronutrients affects the growth height of the plant. Enhanced potassium levels greatly influenced the vegetative growth parameters as to when compared to the control experiment. Similar results were obtained by Zelelew *et al*. [29].

Effect of Potassium Fertilization on the Potato Tuber Yield

Table 5 shows potato yields at various potassium dosages and the same DAP fertilizer dosage. As shown, the potato yield significantly increased as the dosage of potassium fertilizer was increased. The highest yield of 30.90 ± 0.24 Tones/Ha was attained in the treatment K_{300} equivalent to 200 K_2O (Kg/Ha) was applied. Examining the effect of potassium levels on potato yield tuber ton/fed, the results show a gradual rise followed by a drop. The drop in the yield started from the application of 266.7K_2O kg/ha in plot $K_{400.}$ The tender roots of germinating seedlings get damaged when they come into contact with high

Table 4: Summary of selected growth parameters 49 days after emergence

Plots code	Number of aerial stems per plant Mean±SD	Number of leaves per plant Mean±SD	Height of stems (cm) per plant Mean±SD
K_0	4.67 ± 0.58^{d}	10.33 ± 0.58^{c}	14.77 ± 0.21^{c}
K_{50}	5.67 ± 0.58^{cd}	11.67 ± 0.58^{c}	15.30 ± 0.30^{c}
K_{75}	6.00 ± 0.00^{bcd}	12.00 ± 1.00^{c}	16.37 ± 0.35^{b}
K_{100}	6.67 ± 0.58^{abc}	14.33 ± 0.58^{b}	16.73 ± 0.12^{ab}
K_{200}	7.33 ± 1.16^{abc}	15.00 ± 0.00^{ab}	16.90 ± 0.10^{ab}
K_{300}	8.00 ± 0.00^{a}	16.33 ± 0.58^{a}	17.27 ± 0.06^{a}
K_{400}	7.67 ± 0.58^{ab}	15.67 ± 0.58^{ab}	17.10 ± 0.20^{a}

Means that do not share a letter are significantly different, SD-Standard deviation

Table 5: Impact of potassium fertilization on the yield of potato tuber

Plots code	DAP (Kg/Ha)	K_2O (Kg/Ha)	Potato yield (Tones/Ha)
K_0	150	0	11.25 ± 0.31^{e}
K_{50}	150	33.3	14.91 ± 0.19^{d}
K_{75}	150	41.5	17.21 ± 1.73^{d}
K_{100}	150	55.3	23.43 ± 1.45^{c}
K_{200}	150	133.3	27.75 ± 0.65^{b}
K_{300}	150	200	30.90 ± 0.24^{a}
K_{400}	150	266.7	29.11 ± 0.40^{ab}

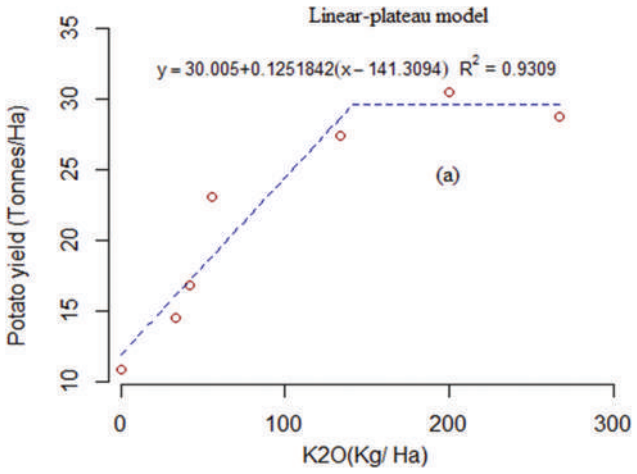
Means that do not share a letter are significantly different, DAP-Di-ammonium phosphate

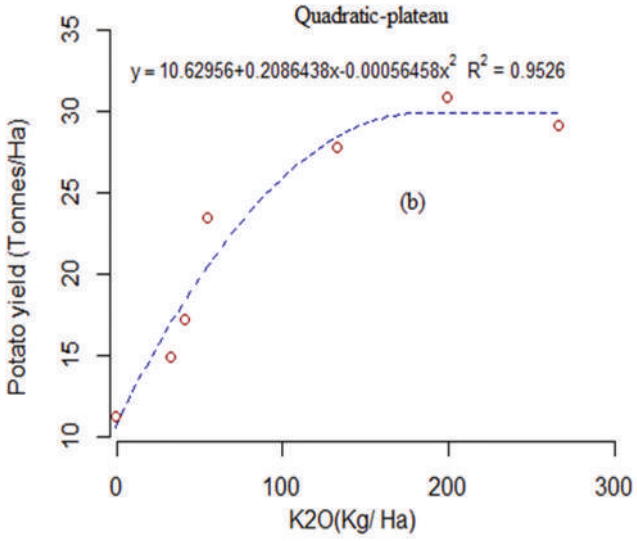
levels of fertilizer beyond the optimal level. This damage of the tender roots which would have been the future carrier of tuber contributes to yield decline. Also, excessive potassium application reduces the crop's ability to take up magnesium from the soil and its subsequent deficiency may cause premature fruit production.

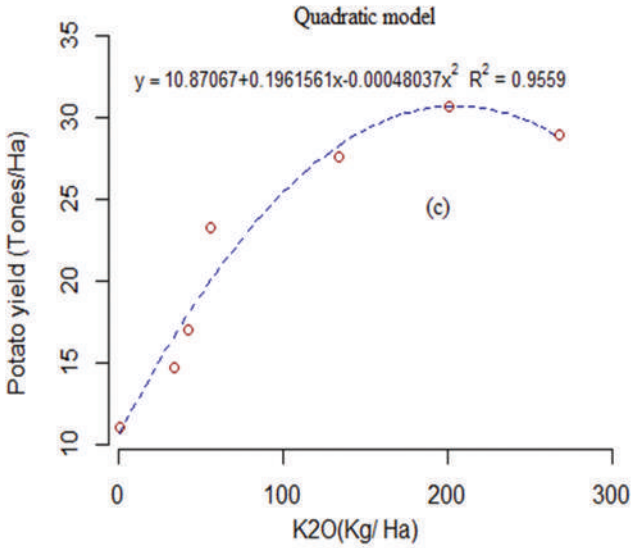
For this reason, it is important to ensure that the optimum rate of potassium fertilizer application is adhered to for optimal tuber yield. Similar results were obtained by Abdel Naby *et al*. [30]. This implies that determining the optimal K rate needed for maximum tuber yield is vital.

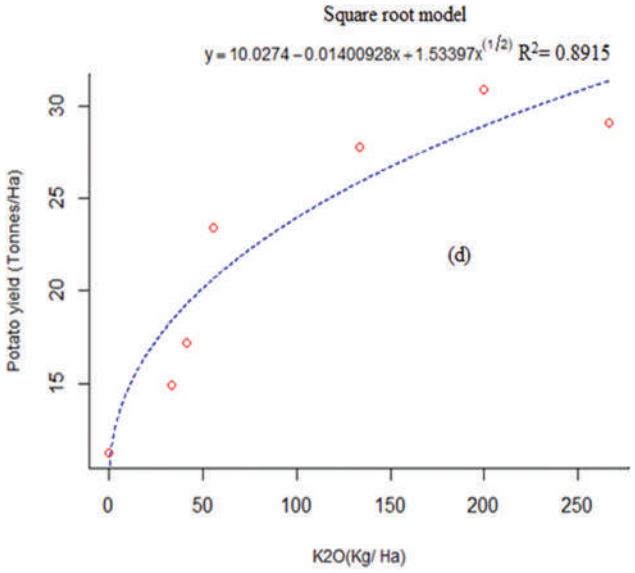
Optimal K rate based on Response Test Models

The potato yield increased significantly with an increase in potassium levels to a maximum value of 30.90 ± 0.24 and then dropped to 29.11 ± 0.40 Ton/ha. Statistically, the mean values of the tuber yield at K_{300} and K_{400} may or may not differ significantly (Table 5). Based on this trend four test models were employed to determine the optimum K dosage rate [5]. The models were quadratic, square root, linear plus plateau, and quadratic plus plateau models. The optimal K rate obtained from the graph fittings was 200, 141.309, and 184.779Kg/ha for the quadratic, linear-plateau, and quadratic-plateau models respectively. The square root model, however, was unable to provide value for this data as its graph kept on rising steadily. The quadratic model gave the best fit in terms of correlation coefficient (R^2) and also had the lowest bias based on the sum of squared errors (SSE). This indicates that optimum potassium dosage for the soils is 200Kg/ha. Figure (a)-(d) shows the graph fitting on the studied models.









An exponential model was also considered but the data did not exhibit exponentially and so was dropped from the analysis.

CONCLUSIONS

The sorption studies of potassium with soil samples using linearized Freundlich isotherm suggested low potassium buffering capacities a clear indication that potassium fertilization is required to achieve higher yields of potato tuber. The study indicates that the application of potassium fertilizers has a significant and positive effect on potato growth and an optimum threefold increment in the yield of potato tubers. The quadratic yield response model described the optimal K dosage rate best in this study. The model suggests that a potassium dosage of 200 Kg/ha is necessary for the optimum yield of potatoes.

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