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/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 (R²) 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 R² (0.9559) and SSE (18.237). K2O 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

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
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 stopped 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 50mL solutions of 0.01M CaCl₂ 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 FP6H10). 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].

\[
\log q_e = \log K_F + \frac{1}{n} \log C_r \quad (2.1)
\]
\[
q_e = K_F C_r^{1/n} \quad (2.2)
\]

Where; \(C_r\) = 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.

\[
q_e = (C_r - C_i)v/m \quad (2.3)
\]

Where; \(C_i\) = initial K⁺ ion concentration, \(C_r\) = 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.

\[
Y_i = B_0 + B_1X_i + B_2X_i^2 \quad (2.4)
\]
\[
Y_i = B_0 + (1-e^{-B[X_i + B_2]}) \quad (2.5)
\]
\[
Y_i = B_0 + B_1X_i + B_2X_i^{1/2} \quad (2.6)
\]
\[
Y_i = B_0 + B_1X_i \text{ for } X \geq X_m \quad (2.7)
\]
\[
Y_i = B_0 + B_1X_i + B_2X_i^2 \text{ for } X \leq X_m \quad (2.8)
\]

\[
Y_i = Y_m \text{ for } X \leq X_m
\]
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 $B_i$ are constants obtained by fitting the models to the experimental data [15].

**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 phosphorus 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
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 ± 17.4 mg/Kg while in the non-linear model the values ranged from 21.47-31.395 with a mean of 26.91 ± 5.03 mg/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.

**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.

| Soil sample (Site 1) | Soil sample (Site 2) | Soil sample (Site 3) |
|----------------------|----------------------|----------------------|
| \(C_i\) (mg/L) | \(C_e\) (mg/L) | \(q_e\) (mg/L) | \(C_i\) (mg/L) | \(C_e\) (mg/L) | \(q_e\) (mg/L) | \(C_i\) (mg/L) | \(C_e\) (mg/L) | \(q_e\) (mg/L) |
| 30 | 12 | 180 | 10 | 200 | 15 | 200 | 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 |

\(C_i\)-Initial K\(^+\) concentration, \(C_e\)-Residual K\(^+\) concentration, \(q_e\)-Adsorbed K\(^+\)
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_{0} (55.56 K_{0} Kg/ha) to a maximum of 8.00 ± 0.00 in plot K_{100} (200 K_{0} 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_{0} to a high of 16.33 ± 0.58 in plot K_{100}. 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 ± 0.58 was attained in plot K_{100}.

Stem height ranged from 14.6 cm in the control experiment to 17.3 cm with an application of 200kg ha\(^{-1}\) K_{0} (Plot K_{100}). 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_{100} equivalent to 200 K_{0} (Kg/ha) was applied. Examining the effect of potassium levels on potato yield tuber ton/ha, the results show a gradual rise followed by a drop. The drop in the yield started from the application of 266.7K_{0} Kg/ha in plot K_{400}. The tender roots of germinating seedlings get damaged when they come into contact with high 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.

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

| Sites | Linear model form | K_{e}(PBC)(mg/Kg) | 1/n | R\(^2\) |
|-------|-------------------|-------------------|-----|--------|
| 1     | log q=0.6394C\(_e\)+1.6134 | 41.058 | 0.6394 | 0.967 |
| 2     | log q=0.6013C\(_e\)+1.6634 | 46.068 | 0.6013 | 0.943 |
| 3     | log q=0.8903C\(_e\)+1.1357 | 13.667 | 0.8903 | 0.946 |

| Soi sample | Non-Linear model form | K_{e}(PBC)(mg/Kg) | 1/n | R\(^2\) |
|------------|----------------------|-------------------|-----|--------|
| 1          | q\(_e\)=31.395C\(_e\)+0.2797 | 31.395 | 0.2579 | 0.975 |
| 2          | q\(_e\)=21.47C\(_e\)+0.5609 | 21.470 | 0.3689 | 0.947 |
| 3          | q\(_e\)=27.887C\(_e\)+0.0345 | 27.877 | 0.3045 | 0.945 |

| Sites | 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.
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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