Original Research Article

Effects of source and rates of potassium fertilizer on yield traits and potassium use efficiency of potato in a Kenyan ferralsol

ABSTRACT

Aims: Potassium (K) is one of the nutrient elements taken up in large amounts by potato, yet there is little research output on K fertilization of the crop in Kenya, due to the assumption that its natural soil reserves are sufficient for production of most crops.The study objective was to determine the influence of two K sources (muriate of potash – KCL and sulphate of potash – K_2SO_4) on K use efficiency and tuber yield components of potatoin one agro-ecological zone of Kenya.

Place and Duration of Study: The experimental site was the University of Eldoret farm in Kenya, located at latitude 0^o574942' N and longitude 35^o300772'E, during the middle - second rains season (S1) and middle rains season (S2) of 2020 and 2021 respectively.

Methodology: Treatments were: 0 kg K ha^{-1} (control), 60,120,180 and 240 kg K ha^{-1} in S1 and 0, 30, 60, 90, 120 and 180 kg K ha^{-1} in S2, supplied in form of KCL and K_2SO_4. Treatments were laid in a Randomized Complete Block Design in a 2x5 and 2x6 factorial arrangements in S1 and S2 respectively.The potato variety planted was Destiny. Data collected included: Agronomic efficiency of K (AE_K), total tuber yield, two categories of seed yield (Size 1 tubers with diameters of 28- 45 mm; Size 2 tubers with 46 - 60mm diameter), total seed yield and ware yield (tubers with diameters over 60mm).

Results: During the drier S1, application of 120 kg K ha^{-1} in form of K_2SO_4 significantly (P< .001) increased yield of size 1 tubers, total seed yield and total tuber yield. The total tuber yield increment from this K rate was only 12.6 % of the 40 tonnes potential yield, and its AE_K was 0.042tonnes of tubers kg^{-1}K. Therefore its application may not be economically viable. During the moisture sufficient S2, all K fertilizer treatments in the form of KCl and 90 kg K ha^{-1} in form of K_2SO_4, contributed yield increase of 58.1 - 68.6% and slightly exceeded varietal yield potential. Additionally, 30 kg K ha^{-1} of KCL gave the highest AE_K of 0.5 tonnes of tubers kg^{-1}K and consistently enhanced yield of all potato sizes, except size 1.

Conclusion: Under similar ecological conditions as S2, potato farmers can achieve the highest AE_K and potential tuber yield with application of 30 kg K ha^{-1} of KCL. However, more trials on K nutrition in potato need to be done in diverse environments.

Keywords: Potato, potassium sulphate, potassium chloride, seed potato

1. INTRODUCTION

Potato is the fourth most important food crop after rice, wheat and maize[1]. It is commonly used for making chips and crisps, and has many industrial applications such as manufacture of starch. The annual world production volume is slightly over 376 million metric tonnes, and the world average productivity is 20.7 tonnes ha^{-1}[3]. Potato yields in Africa are still low, with only six countries recording average yields above 20 tons ha^{-1}[2]. In the Eastern Africa region, the productivity of potato is 10.4 tons ha^{-1}, while the average productivity in Kenya is 9.8 tons ha^{-1} against a potential of 40 $tons^{-1}$[2,3]. The yield gap of 30 tons ha^{-1} in Kenya can be attributed to a number of factors such as moisture deficiency during the cropping season, since most farmers produce the crop under rain-fed conditions[4]. Bacterial wilt disease and poor soil health have been named as the second and third causes of wide yield gap in Kenya and other Sub-Saharan countries [5]. Low soil fertility which is a component of poor soil health, has been cited as a key driver of low potato yields in Kenya[6]. Nitrogen (N) and phosphorous (P) deficiency contributes the most to low soil fertility and low potato yields in Kenyan soils[7,8]. Potassium (K) was thought to be sufficient for potato production in most soil types of Kenya [9], and has received little research attention. However, in a study done in the major potato growing areas of central and Eastern Kenya, 15-22% of farms sampled had K levels below the critical value of 200 mg kg^{-1} soil[8]. Moreover, potato is known to take up more K than N and P for every ton of tuber produced[10]. In support of our hypothesis that K was likely to enhance tuber yields of potato, a supply of 45 kg K ha^{-1} and optimal N, P and soil moisture yielded 63 tonnes ha^{-1} of tubers in Andosols of Kenya[4]. Nonetheless, there is a knowledge gap on the choice of K source/type and fertilizer rates for tuber yield improvement in various soil types and seasons in Kenya. The results ofthis study will partly fill this information gap. The study was done in ferralsols of Uasin-Gishu County, whose staple food crop for the past 50 years has been maize, and farmers are slowly adopting potato farming for food and income security. This is due to its short maturity period and a potential yield higher than three times that of maizeP.

Comment [RL1]: Provide a separate sub-section on: **Objectives of the Study**.

2. MATERIAL AND METHODS

2.1 Site description

The experiment was conducted at the University of Eldoret farm, located at latitude of 0^{o}574942' N and longitude 35^{o}300772' E, in lower highland 3 (LH3) agro-ecological zone. The site has a nearly unimodal rainfall pattern, which is subdivided into three: First rainy season (end of March – end of June), middle rains (end of June to October) and second rains (November to February). The site is located at an altitude of 2135m above the sea level, receives mean annual rainfall and temperature of 1020mm and 17.3^{o}C, respectively[11]. The initial soil analysis showed that the site has pH (H_2O) of 5.71, total N of 0.18%, available P of 17.60 ppm, exchangeable K of 448.50 ppm, and organic carbon of 2.04%. The soil textural class is sandy clay. Soil analyses were done at the University of Eldoret soil laboratory following the procedures recorded in:[12]. During the middle-second rains season (September-December of 2020) (S1), the total rainfall received was 300mm, with the tuberisation – senescence growth stages receiving average of 6.25 mm per week. During the middle rains season of 2021 (S2), the average seasonal rainfall was 645mm, and tuberisation to senescence growth stages received mean of 50mm of rainfall per week; the mean temperature for S1 and S2 seasons were 17.4^o C and 17.0^o C respectively (Fig 1).

Comment [RL2]: Better to have a map to show the location of what you are describing.

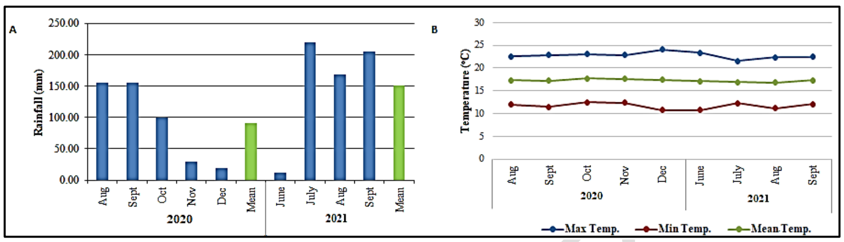

Figure 1: Mean monthly rainfall (A) and temperature (B) during the middle-second rains season of 2020 and middle rains season of 2021

*2.2*Treatments, experimental design and crop management

The treatments for S1 season were: 0 kg K ha^{-1} (absolute control) 60, 120, 180 and 240 kg K ha^{-1} in form of KCL (muriate of potash - MOP) and K_2SO_4 (sulphate of potash - SOP). During S2 season, the rates of K in form of both KCL and K_2SO_4 were: 0 kg K ha^{-1} (absolute control), 30, 60, 90, 120 and 180 kg K ha^{-1}. The additional rates during the second season were meant to give a better understanding of how K influences the parameters studied. K fertilizer was applied once during planting. Nitrogen fertilizer, (173.9 kg ha^{-1}) was applied in two splits in the form of urea, half rate at planting and half rate during second earthing-up (fourth week after crop emergence). Phosphorus, 224.9 kg P_2O_5 ha^{-1} was applied in form of triple super phosphate at planting. Destiny potato variety obtained from AGRICO limited was subjected to the treatments above. Planting furrows (about 23 cm deep) were made, and then potato seeds were placed in the furrows with no direct contact with fertilizer, and then covered completely with soil. The treatments were laid out in a randomized complete block design (RCBD) in a 2x5 factorial arrangement in S1 and 2x6 factorial arrangement in S2. Treatments were replicated three times. The plot size was 4.5 m x 4.5 m and crop spacing was 75 cm x 30 cm, giving a total of six crop rows. Weeding and earthing up of the crop was done manually using a hand hoe, during the second and fourth week after crop emergence. The crop was sprayed on a fortnightly basis using famoxadone-cymoxanil and acetamiprid, for crop protection against fungal diseases and insect pests. Crop harvesting was done carefully using a hand hoe, at harvest maturity - indicated by complete senescence and drying of crop shoots.

*2.3*Data collection

Harvesting of potato tubers was done on four inner rows, and the harvested tubers were graded based on sizes, before weighing of tubers as per the sizes using a digital weighing scale in kilograms (kg). Grading of potato into various sizes was done in each plot using an improvised hand held measuring cardboard with holes of different diameters that correspond to potato sizes stipulated in Kenya Plant Health Inspectorate Service (KEPHIS) manual[13]. The sizes are: chatts (tubers with diameter of less than 28mm); Size 1 (tubers with diameter between 28mm - 45mm); Size 2 (tubers with diameter between 46mm - 60mm) and ware (tubers with diameter over 60mm). Size 1 and 2 are sold to the farmers for seed and ware is sold for culinary or industrial processing. Chatts are often utilised as animal feeds. Total seed weight was obtained by adding weights of size 1 and 2 tubers in each plot; total tuber weight was obtained by the sum of the weights of chatts, size 1, size 2 and ware potato tubers in each plot. Tuber weights of each potato size were converted to tonnes ha^{-1} based on the harvested area. Agronomic efficiency of applied potassium fertilizer (AE_K) was determined by: $AE_K = (Y-Y_0)/F$, where Y is the tuber yield with application of K fertilizer, Y_0 is tuber yield without K fertilizer application and F is the amount of K applied[14].

2.3.1 Data analysis

Data collected was subjected to analysis of variance (ANOVA) using GenStat software 16th Edition (VSN International ltd) at 5% level of significance. Means were compared using Tukey's test.

3. RESULTS AND DISCUSSION

3.1 Results

It was observed that application of 120 kg K ha^{-1} in form of SOP significantly increased the yield of chatts, size 1, total seed yield and total tuber yield during the September-December rain season of 2020 (Table 1). It was further noted that potato supplied with 120 kg K ha^{-1} in the form of K_2SO_4 had 5 more tons of the total tuber yield than the control, which was 29.5% of the actual yield (17.1 tons) and 12.6% of the potential yield (40 tonnes ha^{-1}). The K rate also gave highest agronomic efficiency of K (Table 1).The larger tubers (ware) required 180kg K ha^{-1} in the form of SOP to obtain the highest yield of 4.04 tonnes ha^{-1}, a 2.14 ton increase from the control mean (Table 1). Application of 240 kg K ha^{-1} of either MOP or SOP reduced yield of ware potato by 23 and 21% respectively, and total tuber yield by 11.7 and 3% respectively compared to the means of the control (Table 1).

Table 1: Effects of potassium (K) fertilizer source and rate ontotal yield and yield of different sizes of potato tubers in a field experiment conducted at LH3 agro-ecological zone of Uasin-Gishu County of Kenya, between September and December of 2020 (end of middle - second rain season)

		Yield of potato tubers in tonnes ha^{-1}						
K Source	**K rate**	**Chatts**	**Size 1**	**Size 2**	**Total seed yield†**	**Ware**	**Total yield**	**AE_K (kg tuber kg^{-1}K**
MOP	0 kg ha^{-1}	0.28_{d}	3.32_{c}	6.48	9.80_{cd}	2.95_{b}	13.03_{bcd}	-
MOP	60 kg ha^{-1}	0.29_{d}	3.98_{bc}	7.97	11.96_{ab}	1.70_{cde}	13.94_{bc}	31.50
MOP	120 kg ha^{-1}	0.44_{bcd}	3.40_{c}	5.14	8.54_{d}	3.18_{ab}	12.15_{bcde}	0.83
MOP	180 kg ha^{-1}	0.61_{b}	3.64_{c}	5.96	9.60_{cd}	2.45_{bcd}	12.66_{bcde}	3.39
MOP	240 kg ha^{-1}	0.38_{cd}	3.64_{c}	5.16	8.80_{d}	1.46_{de}	10.64_{e}	-5.90
SOP	0 kg ha^{-1}	0.28_{d}	3.33_{c}	6.61	9.93_{cd}	0.85_{e}	11.06_{de}	-
SOP	60 kg ha^{-1}	0.56_{b}	4.82_{b}	6.08	10.90_{bc}	2.28_{bcd}	13.73_{bc}	28.00
SOP	120 kg ha^{-1}	0.83_{a}	6.02_{a}	7.69	13.71_{a}	2.56_{bc}	17.10_{a}	42.08
SOP	180 kg ha^{-1}	0.51_{bc}	3.30_{c}	6.31	9.61_{cd}	4.04_{a}	14.16_{b}	11.72
SOP	240 kg ha^{-1}	0.47_{bc}	4.04_{bc}	5.64	9.68_{cd}	1.50_{cde}	11.66_{cde}	-1.63
Mean		0.46	3.95	6.3	10.25	2.3	13.01	
P value		<.001	<.001	‡	<.001	<.001	<.001	

Means followed by similar subscript letters along a column are not significantly different ($P \leq 0.05$). † Sum of size 1&2, MOP- KCL, SOP- K_2SO_4. ‡- means similar to controls though P value was =.05

During the middle rainy season of 2021, application of 60 and 180 kg K ha^{-1} in form of MOP and SOP respectively, gave similar but significantly higher yield of chatts compared to the control (Table 2). Plants supplied with 60 kg K ha^{-1} of both SOP and MOP and 120 kg K ha^{-1} in form of MOP significantly enhanced yield of size 1 potato tubers; the yield contribution from the three K rates was between 41- 63%. The highest increment was attributed to the higher K rate (Table 2). All K rates from 30 kg ha^{-1} in the form of MOP and only 180 kg K ha^{-1} of SOP gave similar but significant yield increase of size 2 potato tubers compared to the controls (Table 2). The highest size 2 tuber yield increase (55%) was recorded in plants treated with 30 kg K ha^{-1} of MOP. Generally, all plants treated with MOP at K rates from 30 kg ha^{-1} significantly enhanced total seed yield of potato tuber, but SOP form of K enhanced the same seed yield only at rates of 60 and 180 kg K ha^{-1} (Table 2). However, the highest total seed yield increment due to K fertilization was 44.1%, recorded in plants supplied with 60 kg K ha^{-1} in form of MOP. In summary, all potato plants supplied with K fertilizer irrespective of the form, had significantly higher total potato tuber yield compared to the controls during the middle rainy season (Table 2). Further analysis showed that all K fertilizer treatments in the form of KCl and 90 kg K ha^{-1} in form of K_2SO_4, contributed yield increase of 58.1 - 68.6% and exceeded varietal yield potential of 40 tons ha^{-1} (Table 2).

Table 2: Effects of potassium (K) fertilizer source and rate ontotal yield and yield of different sizes of potato tubers in a field experiment conducted at LH3†agro-ecological zone of Uasin-Gishu County of Kenya, between June and October of 2021 (middle rainy season)

		Yield of potato tubers in tonnes ha^{-1}						
K Source	**K rate**	**Chatts**	**Size 1**	**Size 2**	**Total seed yield†**	**Ware**	**Total yield**	**AE_K (kg tuber kg^{-1}K)**
MOP	0 kg ha^{-1}	0.43_{bcde}	3.78_{cd}	9.99_{d}	13.77_{e}	11.75_{c}	25.95_{c}	-

MOP	30 kg ha^{-1}	0.51_{abcde}	3.79_{cd}	15.57_{a}	19.36_{a}	21.18_{ab}	41.05_{a}	503
MOP	60 kg ha^{-1}	0.65_{a}	5.33_{ab}	14.52_{ab}	19.85_{a}	22.59_{a}	43.08_{a}	286
MOP	90 kg ha^{-1}	0.43_{bcde}	4.94_{abc}	14.20_{abc}	19.14_{ab}	23.67_{a}	43.24_{a}	192
MOP	120 kg ha^{-1}	0.62_{ab}	6.19_{a}	13.22_{abc}	19.42_{a}	23.27_{a}	43.31_{a}	145
MOP	180 kg ha^{-1}	0.31_{e}	4.07_{bcd}	13.70_{abc}	17.77_{abcd}	25.68_{a}	43.77_{a}	99
SOP	0 kg ha^{-1}	0.43_{bcde}	3.78_{cd}	9.99_{d}	13.77_{e}	11.75_{c}	25.95_{c}	-
SOP	30 kg ha^{-1}	0.37_{de}	3.7_{cd}	12.03_{bcd}	15.73_{cde}	16.27_{bc}	32.37_{b}	214
SOP	60 kg ha^{-1}	0.56_{abc}	5.73_{a}	11.92_{cd}	17.65_{abcd}	14.24_{c}	32.47_{b}	109
SOP	90 kg ha^{-1}	0.57_{abcd}	3.98_{bcd}	12.33_{bcd}	16.32_{bcde}	24.88_{a}	41.77_{a}	176
SOP	120 kg ha^{-1}	0.38_{cde}	3.09_{d}	11.79_{cd}	14.89_{de}	16.23_{bc}	31.49_{b}	46
SOP	180 kg ha^{-1}	0.71_{a}	4.04_{bcd}	14.23_{abc}	18.26_{abc}	13.12_{c}	32.09_{b}	34
Mean		0.50	4.37	12.79	17.16	18.72	36.38	
P value		<.001	<.001	.003	.001	<.001	<.001	

Means followed by similar subscript letters along a column are not significantly different ($P \le 0.05$). † Sum of size 1&2, MOP- KCL, SOP- K_2SO_4.

Generally, it was observed that MOP increased total tuber yield more than SOP in the middle rains season of 2021, but during the moisture depressed middle and second rains season of 2020, SOP fertilizer gave more tuber yield compared to MOP (Fig. 2).

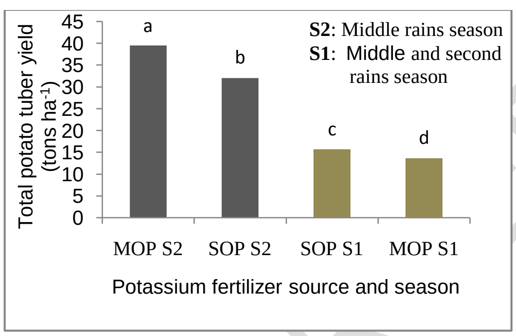

Fig. 2: Effects of potassium source and season on total tuber yield of potato in a field experiment conducted at the University of Eldoret farm during the middle and second rains season of 2020 (September –December) and middle rains season of 2021 (June – October)

3.2 Discussion

3.1.1 K source and season interactions

Application of KCL form of K fertilizer can lead to attainment of potential tuber yield of potato in the semi-humid tropical soil when soil moisture is adequate for crop production. However, during periods of soil moisture deficiency, K_2SO_4 form of K can give better tuber yields compared to KCL. Previous researchers have reported higher yield contribution of K_2SO_4 than KCL[15,16], but similar yield increase from KCL than K_2SO_4 has been reported in one potato genotype[17]. A review of 48 papers on K nutrition in potato show that there is no consistent superiority of either K_2SO_4 or KCL on tuber yield increment in potato[18]. The same authors observed that response of potato to K may be influenced by genotype, moisture availability, and soil physio-chemical conditions among others. In this study, higher yield response due to KCL may be attributed to sufficient moisture, which was within weekly recommended range between 12.7mm (at emergence) - 50mm (at tuberisation to senescence) (https://cropwatch.unl.edu /potato /plant_g rowth). Results from this study also confirm that certain potato varieties are less sensitive to Cl^- in KCL [19]. Higher yield increase due to K_2SO_4 than KCL in drier season may be attributed to drought stress tolerance conferred by potassium sulphate[20], possibly due to improvement of water use efficiency in potato[21]. However, the yields were generally lower than 50% of the potential yield during the drier season. This observation may have been caused by low moisture availability which declined from 25mm per week during emergence to a mean of about 6.25 mm/week from 45th day to senescence, a short fall of over 40mm/week (https://cropwatch.unl.edu /potato /plant_growth).

Therefore, the contribution of K_2SO_4 to yield enhancement of potato may not be economically viable during the moisture depressed season, owing to the higher fertilizer costs in Africa compared to the rest of the world[22].

3.1.1 K source and K rate interactions

Potassium sulphate application at rate of 120 kg K ha^{-1} enhanced 28 - 45mm sized tubers, total seed and total tubers yields during the drier season, but agronomic efficiency of K at this K rate was low, and this can explain why the contribution of the K rate to the potential yield was less than 13%. However, beyond 120 kg K ha^{-1} of K_2SO_4 application, tuber yield started declining and negative yields relative to the control were recorded at 240 kg K ha^{-1}. This was a contradiction of earlier findings where yield response of potato to K_2SO_4 was recorded up to 280 kg ha^{-1}[23]. In spite of report that increasing K_2SO_4 fertiliser rates can enhance water stress tolerance by crops[24], the physiological explanation for reduced potato yields with increasing K_2SO_4fertiliser in this study, needs further investigation.

On the other hand, all K rates of KCL above 30 kg K ha^{-1} in this study enhanced yield of tubers above 45mm, total seed and total tuber yield during the middle rains. Although the yield increases were statistically similar at rates between 30-180 kg K ha^{-1} of KCL, the agronomic efficiency of K was highest at 30 kg K ha^{-1}, which indicates that the plants treated with higher K rates were taking up K luxuriously, with no significant yield contribution[25]. Most studies have reported higher yield response to K in form of KCL at rates beyond 300 kg K ha^{-1}[23], but the yield contribution of K at lower rates in this study may be attributed to higher level of exchangeable K (448 mg kg^{-1} soil). In a related study conducted in tropical acidic soils, potato yield response to 165 kg K ha^{-1} in form of KCL was attained when available soil K was up to 145 mg kg^{-1}[26]. In Central highland soils of Kenya with available soil K of 156 mg kg^{-1}, slight potato yield decline was observed when KCL fertilizer was applied at rates of 224 kg K ha^{-1}[8]. It was interesting observation to report yield increment due to K in this study, beyond the recommended critical soil K level of 200 kg ha^{-1}[18]. This suggests that there might be other ecological factors that may influence potato response to K other than the available soil K.

Comment [RL3]: Provide a sub-section on: **Summary Discussion of Results** to show relationship/correlation of individual results.

4. CONCLUSION

Seasonal moisture variation is likely to be one of the key ecological factors influencing response of potato to KCL or K_2SO_4 forms of K in the tropical semi-humid soils that depend entirely on rainfall for crop production. K rates of 30 kg K ha^{-1} supplied as KCL is sufficient for production of significant yield of potato tubers above 45mm, and general seed and total tuber yield in similar ecological conditions recorded in middle rainy season.

It is recommended that farmers relying on rainfall for potato production in similar agro-ecological zones as the study area can apply 30kg ha^{-1} of KCL for optimal tuber yield of potato in seasons when soil moisture is sufficient. Detailed season-based studies need to be done to understand K fertilizer use efficiency in diverse soil types.

Comment [RL4]: This should be part of sub-section: **Recommendations of the Study**.

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Comment [RL5]: Arrange your references in alphabetical order.