

Influence of Phosphorus Fertilizer on “Ware” Potato Production in Acid Soils in Kenya

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Abstract

One of the major challenges facing potato (*Solanum Tuberosum* L) production in Kenya is low and declining yield. This trend is caused by several factors which include low quality and quantity of seed, climate change, inadequate extension services, pests and diseases and more importantly low and declining soil fertility, particularly phosphorus (KEPHIS, 2016 and Karanja *et al.*, 2014). Unfortunately, the current phosphorus fertilizer rate recommendation available for “ware” potato production in Kenya is “blanket” or general (90 kg phosphorus ha⁻¹) and has not been updated for a long time to address the declining soil fertility. This prevents proper utilization of phosphorus fertilizers in achieving optimal production of “ware” potatoes. Therefore, this study investigated influence of different rates of phosphorus (TSP) fertilizer on “ware” potato yield and quality in three acidic (pH ≤ 5.8) test sites: Lari, Ainabkoi and Saboti sub Counties. Two varieties, Unica and Shangi, were tested. The field experiment was a split plot arrangement in Randomised Complete Block Design (RCBD) with six treatments (0 N & 0 P), 0, 30, 60, 90 and 120 kg ha⁻¹ phosphorus, replicated three times. Data collected included weight, quantity and quality of tubers. The data was analysed using analysis of variance (ANOVA) at 5 % confidence levels with General Statistics (GENSTAT) and excel soft wares. Results indicated that phosphorus fertilizer influenced “ware” potato yield. At Saboti application of 120 and 90 kg phosphorus ha⁻¹ for Shangi and Unica resulted in highest “ware” yield of 19.6 and 40.2 t ha⁻¹, respectively. At Ainabkoi application of 120 kg ha⁻¹ phosphorus produced highest “ware” potato yields of 10.7 t ha⁻¹ and 26.8 t ha⁻¹ of Shangi and Unica, respectively. At Lari, application of 90 and 120 kg ha⁻¹ phosphorus produced highest “ware” potato yield of 7.0 t ha⁻¹ and 17.5 t ha⁻¹ for Shangi and Unica, respectively. During the season, there was a build-up of soil available phosphorus. Thus, there is need for farmers to test their soil at the beginning of every potato growing season.

Keywords: phosphorus rate, highest yield, “ware” potato, available soil phosphorus, tuber phosphorus, physical quality

1. Introduction

Potato (*Solanum tuberosum* L) is the second most important food crop after maize in Kenya and also the world’s most important tuber crop grown in more than 150 countries (FAO, 2019; Wang, 2008). Currently one out of eight billion people in the world eats potato (CIP, 2020). It originated from Andes, in South America (FAO, 2008), was taken to Ireland and later introduced into Kenya by the white settlers in 1880s (Spooner *et al.*, 2005). In Kenya, it is commonly called “Irish potato” because it came from Ireland in 1800s when the country was hard hit by the great Irish famine that was the worst agricultural, social and cultural disasters of the time that claimed one out of eight million people (FAO, 2008). In 1880s, it was grown for the first time in Kiambu, Nyeri and Muranga counties (NPCK, 2016). About 800,000 farmers (Out of which 500, 000 are small scale) grow potato mainly in five counties (Nyandarua, Uasin-Gishu, Meru, Nakuru and Nandi) on about 192,341 ha (FAO, 2019; Shawiza, 2017).

Potato is a food and cash crop with multipurpose domestic and industrial uses. Domestic uses include consumption as French fries, “bhajia”, crisp and mashed potato, etc as well as livestock feed while industrial uses include production of starch, soap and ethanol (KEPHIS, 2016). It is a good source of carbohydrate; protein;

vitamin B1, B3, B6 and C; fibre; Iron; Zinc and Potassium (Carl *et al.*, 2014). It is also naturally low in fat, cholesterol and sodium with antioxidants properties, making it healthy for human consumption (Duroy *et al.*, 2009). Thus it greatly contributes to alleviating poverty and food insecurity (Abongo & Kabira, 2013).

Potato grows best in altitudes of 1500 to 3000 m above sea level (KEPHIS, 2016). However, with proper management and proper use of technology, the crop can grow well in lower altitude areas (Lutaladio *et al.*, 2009). Rainfall of about 750 mm and optimal temperatures of between 15 °C and 20 °C are required during the growing period (KEPHIS, 2016 and MOA, 2011).

The crop requires well drained, high organic matter, fertile and loam textured soils with pH ranging 4.5 to 8.5 (MOA, 2011 and KEPHIS, 2016). The major nutritional requirements of the crop are potassium (K), nitrogen (N) and phosphorus (P). It is suggested to have the three nutrients in the ratio of 1:1:1 to avoid spoiling tuber quality (Lutaladio *et al.*, 2009). In 2017, Kenya with a production of about 1.5 million tones was the 6th best African country in potato production after Algeria, Egypt, South Africa, Morocco and Tanzania. Between 2007 and 2017, on average, Kenya's area under production, yield and total annual production were 135,677 ha, 16.6 t ha⁻¹ and 2.3 million tones, respectively. In the same period, area under potato production increased by about 56,664 ha. However, potato yield declined by about 8.7 t ha⁻¹ in the same period (FAO, 2019). This could be caused by the many challenges facing potato production which include high incidences of pests and diseases; weak research-extension linkage; poor market infrastructure; declining soil fertility; use of low quality and/or low supply of clean and certified seed (Muthoni, 2016; Karanja *et al.*, 2014).

There is great need for rapid interventions to improve yield of potato production in Kenya. Unfortunately, this is hindered by inadequate extension services, erratic rainfall, pests, diseases and most importantly low and declining soil fertility (Karanja *et al.*, 2014).

Deficiency of phosphorus has been reported in major potato producing areas in Kenya (Muthoni, 2016; NAAIAP, 2014). This could impact negatively on the “ware” potato yields. The nutrient affect tuber skin setting; dry matter accumulation; time to maturity; storage quality of tubers; tuber size and tuber protein, nitrate and reducing sugar content (Tuhin *et al.*, 2007; Lutaladio *et al.*, 2009; Muthoni, 2016;). The current “ware” potato fertilizer recommendations are “blanket” and outdated. Updated and more specific phosphorus fertilizer rate recommendations are expected to contribute to improving “ware” potato yields and production in Kenya. Therefore, this research focused on influence of application of phosphorus fertilizer on “ware” potato yields in Lari, Ainabkoi and Saboti Sub Counties. The broad objective of the study was to increase “ware” potato production in Kenya through enhanced soil fertility particularly phosphorus in the main potato producing sub - counties of Kenya while the specific objective of the same study was to determine influence of phosphorus fertilizer on “ware” potato yield and quality.

2. Materials and Methods

2.1 Description of the Study Sites

This study was carried out in three locations: Saboti, Ainabkoi and Lari (Figure 1). Saboti (0.94 °N, 34.84 °E) is in Trans Nzoia County at an elevation of 1923 m above sea level. Its soils are humic nitosols while its agro ecological zone is Upper midland (Maize and coffee zone). It receives 1000 to 1200 mm of rainfall annually and has temperature range of 10 to 27 °C. Ainabkoi (0.18 °N, 35.53 °E) is in Uasin Gishu County at an altitude of 2300 m above sea level. Its agro ecological zone is Upper Highland Zone 2 (UH2) which is a pyrethrum and wheat zone. The area receives annual rainfall of about 1200 to 1400 mm. Its annual temperature ranges between 13.3 to 15.7 °C. Its soil type is humic Nitisols. Lari (1.11 °S, 36.64 °E) is in Kiambu County. It has an elevation of 2550 m above sea level, annual rainfall of 1400 mm, temperature of 12 to 21 °C and an agro ecological zone of Upper highland 1 (Pyrethrum and Dairy zone). Its soils are planosols (NAIAAP, 2014; Jaetzold and Schmidt, 2009; Jaetzold *et al.*, 2011).

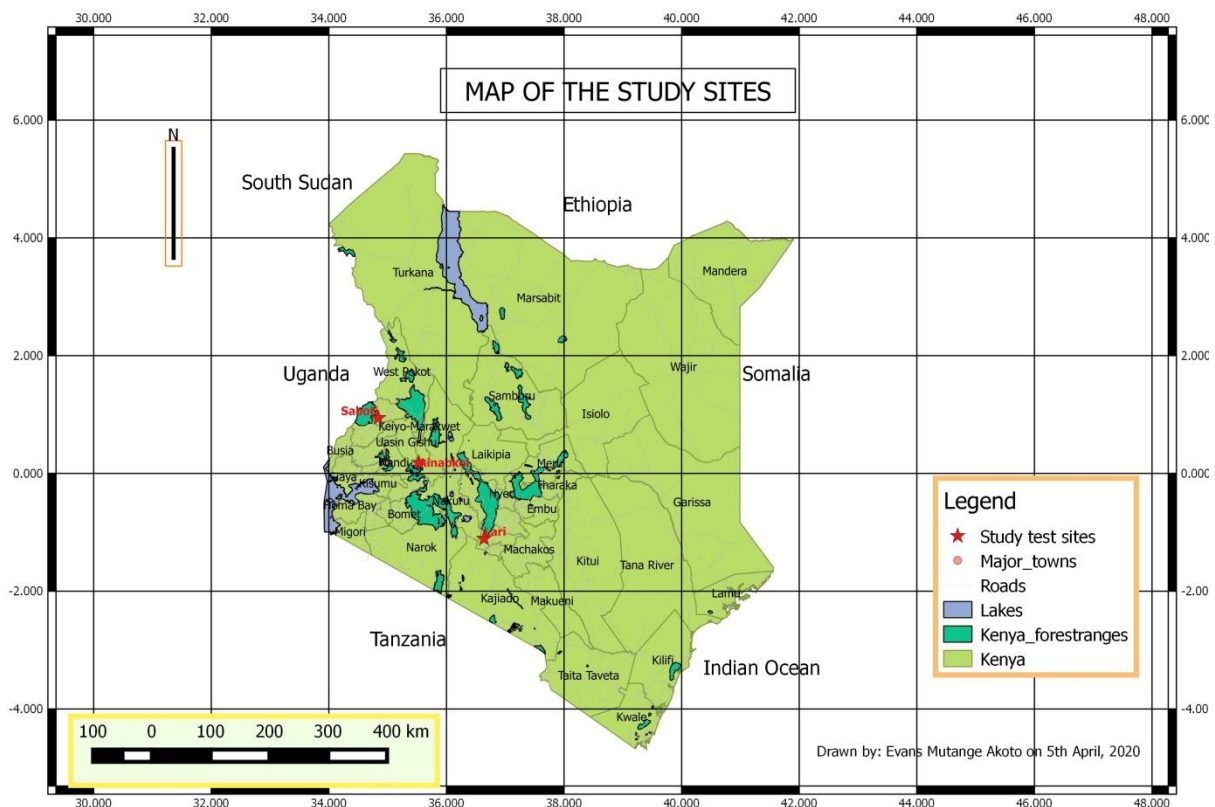


Figure 1. Location of the study sites (Source: First hand data by GPS machine; ILRI (2015) and Open Africa (2020)

2.2 Test Potato Varieties

The test varieties were Unica and Shangi. Unica was selected based on its high yielding potential (> 45 t ha⁻¹) and suitability for chips, crisps and domestic uses. It is rich in vitamin C, iron and zinc. Shangi was selected based on its popularity with farmers and its local availability. Unica is an alternative to Shangi which has low storage time (NPCK, 2019).

2.3 Experimental Treatments and Coding

Table 1 below gives experimental treatments, starting with (0 N & 0 P) where both nitrogen and phosphorus fertilizers were not applied. In the remaining treatments, nitrogen was applied as a basal fertilizer at the rate of 90 kg nitrogen ha⁻¹ as urea. Phosphorus was also applied at the same time at the rate of 0, 30, 60, 90, 120 kg phosphorus ha⁻¹ as Triple Super Phosphate. The Nitrogen rate of 90 kg ha⁻¹ and phosphorus rate of 90 kg ha⁻¹ were based on (Kaguongo *et al.*, 2008; MOA, 2011, KARI, 2008 and NPCK, 2013). These recommendations are backed by Lutaladio, 2009 who recommends nitrogen: phosphorus ratio of 1:1 for potato production. They are recommended rates for “ware” potato production. Potassium was not tested as it was found to be high or adequate in the test sites.

Table 1. Phosphorus fertilizer treatments and coding

Treatment Number	Description		Code
	Rates of P per ha	Rates plant ⁻¹ : $TSP = 0.093xP$ grams per plant (P in kg/ha) $Urea = 0.041N$ grams per plant (N in kg/ha)	
1	0N, 0P (Ideal Control)	0 g Urea, 0 g TSP plant ⁻¹	IC
2	0 kg P ha ⁻¹	0 g TSP plant ⁻¹	P0
3	30 kg P ha ⁻¹	2.8 g TSP plant ⁻¹	P1
4	60 kg P ha ⁻¹	5.6 g TSP plant ⁻¹	P2
5	90 kg P ha ⁻¹	8.4 g TSP plant ⁻¹	P3
6	120 kg P ha ⁻¹	11.2 g TSP plant ⁻¹	P4

Basal application of nitrogen at 90 kg ha⁻¹ (3.6 g Urea plant⁻¹) was applied to all plants except in ideal control plots.

2.4 Experimental Layout

As indicated in Table 2, the experimental layout had 36 experimental units in three blocks, two treatments of variety and six treatments of phosphorus rate. The main (whole) plot treatments are varieties while the sub plot treatments are phosphorus rates which included ideal controls (0N, 0P).

Table 2. Experimental layout

Block 1		Block 2		Block 3	
Main plots: Varieties		Main plots: Varieties		Main plots: Varieties	
Unica	Shangi	Shangi	Unica	Unica	Shangi
P0	P2	IC	P3	P4	P1
P4	IC	P0	P2	P3	P4
P1	P3	P4	IC	P2	P0
P3	P4	P2	P1	P0	IC
IC	P0	P1	P4	P1	P2
P2	P1	P3	P0	IC	P3

2.5 Soil Sampling and Seed Bed Preparation.

Land was ploughed before the onset of rains and sub divided into 36 experimental units. The size of each unit was 4 m by 3 m surrounded by 1 m wide path. In each site, the total area needed for the study was therefore 0.23 ha. Two composite soil samples (0-15 cm and 15-30 cm) were taken in grid style before planting. Further, soil samples (0-15 cm) were taken at harvesting in grid style in each experimental unit.

2.6 Planting, Ridging, Weeding, Diseases and Pests Management

The seed used for planting was of good quality (KEPHIS, 2016). The seed was large grade (45 mm to 60 mm diameter). The seed was planted at a spacing of 75 cm between rows and 25 cm within rows. Planting was done at the onset of long rains where fertilizers were well worked in the soil to avoid scorching the seed. Well sprouted seed tubers were then placed in the furrow and covered with soil immediately. Fertilizers were applied according to the treatment plan (Table 1 & 2). Ridging or earthing up was done concurrently with weeding at 30 to 45 days after planting. Pesticides and fungicides were applied according to need to control pests and diseases.

2.7 Dehauling, Harvesting and Post-harvest Handling

When the tops of the potatoes started to turn yellow (physiological maturity), their above ground biomass was cut ("dehaulmed") and tubers left for two weeks for their skin to harden before harvesting. Harvesting was done in the morning and late in the afternoon when temperatures were warm and soils were moist but not wet to minimize scorching of tubers caused by the bright sunlight. The harvest of the two end rows and the last two plants per row were separated from the rest of the plants before storage since they were not used in data analysis.

2.8 Potato Yield Data

Potato yields whose diameter was greater than 60 mm ("ware" potatoes according to KEPHIS, 2016) were determined using equation 1.

$$G_1 = \frac{10000}{0.25 \times 0.75 \times 1000} \times Y \quad (1)$$

Where: G_1 = Yield in $t\ ha^{-1}$; Y = Average yield (kg) of sampled plants = Weight (kg) of sampled plants/Number of plants sampled (18 plants).

2.9 Determination of “Ware” Potato Quality

The quality tested was physical. It was determined by the farmer and the trader. Some of the parameters investigated were subjective and dynamic. The parameters tested included demand, taste (palatability), peeling and cooking. They were tested through physical observations at harvest.

2.10 Laboratory Analysis

Soil samples at planting were analyzed at the National Agricultural Research Laboratories (NARL) using Mehlich 3 protocol which extracts soil nutrients using double acid decomposition. They were analyzed for pH, available phosphorus, total nitrogen, soil total organic carbon, exchangeable acidity (Lari only), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), zinc (Zn) and sodium (Na) (Harova and Spejra, 2014 ; Agro Eco Lab, 2016). Further, samples taken at planting and harvesting were also analyzed for available phosphorus using Bray 2 procedures as outlined by Okalebo *et al.*, 2002. The Bray 2 extracting solution was a solution of 0.03 M ammonium fluoride and 0.1 M hydrochloric acid. Total phosphorus in potato tubers was extracted using a digestion mixture of hydrogen peroxide + concentrated sulphuric acid + selenium powder + salicylic acid) at elevated temperatures of 110 to 330°C. After extraction of available phosphorus, the concentration of phosphorus in sample solutions was determined calorimetrically.

2.11 Statistical Analysis

All data was subjected to analysis of variance (ANOVA) using General Statistics (GENSTAT) software at 5% confidence level. Also, the same software and excel software were used in determining Pearson correlation coefficients particularly between the overall “ware” potato yield and phosphorus rates, soil available phosphorus and plant (tuber) phosphorus.

The linear statistical model for the split-plot design is:

$Y_{ijk} = \mu + V_i + B_j + \varepsilon_{1(ij)} + P_{(k)} + VP_{(ik)} + \varepsilon_{2(ijk)}$; Where Y_{ijk} = Total effect of the treatments; μ = Mean effect; V_i = The i^{th} effect of variety (V); B_j = The j^{th} effect of blocks; $\varepsilon_{1(ij)}$ = Main plot error; $P_{(k)}$ = The k^{th} effect of phosphorus (P); $VP_{(ik)}$ = Effect due to interaction between variety (V) and phosphorus (P) and $\varepsilon_{2(ijk)}$ = Split plot Error.

The Skeletal Analysis of Variance table: Each of the three sites was divided into three blocks (replicates), each block was divided into two main (whole) plots and each whole plots was divided into six (6) sub plots. Each whole plot was planted with two seed potato test varieties (Shangi and Unica) at random. Each variety was planted in six sub plots. Each sub plot was treated with its own phosphorus rate at random. Nitrogen was applied as a basal nutrient at the rate of 90 $kg\ ha^{-1}$ while the plot with 0 $kg\ ha^{-1}$ phosphorus was the normal control plot. There was provision for ideal control (IC) plots without phosphorus and nitrogen (Table 3).

Table 3. Skeletal Analysis of variance (ANOVA)

SOV	df	SS	MS	Fcal	P-value
Blocks or replications (B)	b-1 = 2	B_{cc}	B_{Mc}	$B_{cc}/E_{Mc/r}$	By GENSTAT
Main plots : Varieties (V)	v-1 = 1	V_{cc}	V_{Mc}	$V_{cc}/E_{Mc/r}$	By GENSTAT
Main plot Error (V x B) or Error (a)	(b-1)(v-1) = 2	$E_{cc/r}$	$E_{Mc/r}$		
Sub-plots: P rates	p-1 = 5	P_{cc}	P_{Mc}	$P_{cc}/E_{Mc/r}$	By GENSTAT
V x P-rates	(v-1)(p-1) = 5	VP_{cc}	VP_{Mc}	$VP_{cc}/E_{Mc/r}$	By GENSTAT
Sub plot error V(P x B) or Error (b)	v(p-1)(b-1) = 20	$E_{cc/r}$	$E_{Mc/r}$		
Total	bvp-1=35	T_{cc}	T_{Mc}		

3. Results and Discussion

3.1 Soil Characteristics of Test Sites Prior to Treatment Applications and at Harvesting

The chemical characterization of the top 0-15 cm soils from the three test sites at planting showed that they were acidic. Lari with a pH of 4.6 was strongly acidic while Ainabkoi and Saboti with pH of 5.6 and 5.8, respectively were moderately acidic. The available soil phosphorus levels were low at Lari, adequate at Ainabkoi and high at Saboti. In all the three test sites, potassium was adequate. Saboti and Ainabkoi had adequate soil zinc while Lari had low soil zinc levels. In all the test sites, total nitrogen was adequate except in the 15-30 cm depth in Ainabkoi where it was low. Total organic carbon was adequate in Saboti and Lari but moderate in Ainabkoi.

Exchangeable acidity in Lari was adequate (Table 4).

Table 4. Chemical properties of the surface soils (0-15 cm and 15- 30 cm) taken before planting (2019 long rains) at three experimental sites in Kenya. Bolded figures indicate low quantities

Soil property	Critical value	Saboti		Ainabkoi		Lari	
		0-15	15-30	0-15	15-30	0-15	15-30
Depth of soil sample (cm)	N/A	0-15	15-30	0-15	15-30	0-15	15-30
Soil pH (1: 2.5 Soil: Water)	≥ 5.5	5.83	5.67	5.62	5.59	4.6	4.83
Exchangeable acidity (me %)						0.4	0.4
Total nitrogen (%)	≥ 0.2	0.34	0.30	0.24	0.18	0.25	0.24
Total Organic carbon (%)	≥ 2.7	3.55	3.13	2.54	2.01	2.7	2.51
Phosphorus (ppm)	≥ 30	45	45	40	35	25	30
Potassium (me %)	≥ 0.24	1.00	0.41	2.03	2.03	0.71	0.69
Calcium (me %)	≥ 2.0	26.0	26.8	14.2	10.2	1.4	1.2
Magnesium (me %)	≥ 1.0	4.06	5.10	4.04	3.56	0.79	0.82
Manganese (me %)	≥ 1.0	0.96	0.62	0.64	0.67	0.48	0.36
Copper (ppm)	≥ 1.0	9.83	9.71	2.50	2.15	2.4	2.1
Iron (ppm)	≥ 10	16.1	17.2	16.2	17.8	220	224
Zinc (ppm)	≥ 5	2.46	1.40	4.31	3.84	8.58	5.29
Sodium (me %)	N/A	0.50	0.54	0.50	0.48	0.62	0.86
Soil colour	N/A	Dark brown	Dark reddish brown	Dark brown	Reddish brown	Grey	Greyish Red
Stickness	N/A	Less sticker		More Sticker		Less sticker	
Soil type	N/A	Nitisol		Nitisol		Planosol	
Vegetation		Maize, potatoes, beans, trees		Maize, potatoes, beans, trees		Scattered shrubs and trees, maize, potatoes	
Water Table		Deep(>3m)		Deep (> 3m)		Shallow (< 3m)	

Source of critical values: NAAAIAP (2014)

Soil available and plant (tuber) phosphorus in the test sites

Soil available phosphorus at planting and harvesting were highest at Saboti, average at Ainabkoi and lowest at Lari. Plant (tuber) phosphorus was highest at Saboti. The plant tuber phosphorus at Ainabkoi and Lari were not significantly different. There was a strong positive correlation ($r = +0.7$) between mean available soil available phosphorus and mean plant (tuber) phosphorus. Correlation between mean soil available phosphorus at planting and mean soil available phosphorus at harvesting was perfect ($r = +1.0$) (Figure 2 and 3).

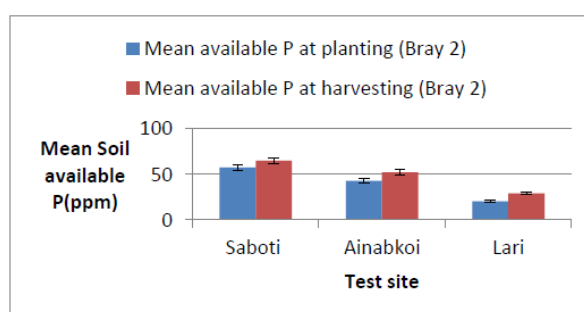


Figure 2. Soil available Phosphorus in the test sites (The error bars are percentage type (5%))

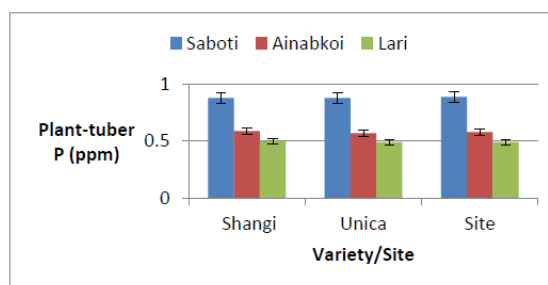


Figure 3. Plant (Tuber) phosphorus at harvesting (The error bars are percentage type (5%)

3.2 Influence of Phosphorus Fertilizer Rates on “Ware” Potato Yield

Influence of Phosphorus on “ware” potato yield at Saboti.

The results indicate that variety ($p = 0.036$), phosphorus ($p = 0.002$) and interaction between phosphorus and variety significantly ($p = 0.005$) influenced yield of “ware” potatoes. The mean yield of Shangi was 13.9 t ha^{-1} while that of Unica was 24.6 t ha^{-1} . Highest yield of Shangi (19.6 t ha^{-1}) was realized with 120 kg ha^{-1} phosphorous while Unica’s highest yield (40.2 t ha^{-1}) was achieved with phosphorus rate of 90 kg ha^{-1} . Correlation between phosphorus rate and mean tuber yield was strongly positive ($r = +0.7$). Also, correlation between phosphorus rate and tuber yield of Shangi ($r = +0.5$) and Unica ($r = +0.6$) was positive (Table 5). As much as the available soil phosphorus was high in Saboti (40 ppm Mehlich 3 phosphorus), it was necessary to add more phosphorus to maximize yield. Farmers in the area apply phosphorus fertilizers to their soils when planting potatoes. However, they need more information on the appropriate rate of fertilizers to apply. This can only happen when recommendations on fertilizer rates for potatoes are revised, updated and made area specific. The above findings compares well with those of MOA (2011), Kaguongo (2008), NPCK (2013) and KARI (2008) which notes a “blanket” recommendation of 90 kg ha^{-1} phosphorus for “ware” potato production in Kenya. Khalid *et al.*, 2003 noted that different varieties of potatoes yielded differently in response to phosphorus application. From studies done in Ethiopia by Israel *et al.*, 2012 on the influence of nitrogen and phosphorus on potato production, it was found that phosphorus rate of 60 kg ha^{-1} and nitrogen rate of 165 kg ha^{-1} gave optimum yields. The yields of Shangi (13.9 t ha^{-1}) and Unica (24.6 t ha^{-1}) varieties differed significantly. This is confirmed by NPCK (2019) which has noted that Unica ($> 45 \text{ t ha}^{-1}$) has more yield potential than Shangi ($35 \text{ to } 40 \text{ t ha}^{-1}$)

Influence of phosphorus on “ware” potato yield of potato at Ainabkoi.

The results indicate that yields of varieties had marginal significant ($p = 0.06$) difference. Phosphorus ($p < 0.001$) and interaction between phosphorus and variety significantly ($p = 0.002$) influenced tuber yield of “ware” potatoes. The mean yield of Shangi was 7.2 t ha^{-1} while that of Unica was 12.1 t ha^{-1} . The highest yield of Shangi (10.7 t ha^{-1}) and Unica (26.8 t ha^{-1}) were both realized with 120 kg ha^{-1} phosphorous. Correlation between phosphorus rate and mean “ware” tuber yield was strongly positive ($r = +0.9$). Also, Correlation between phosphorus rate and “ware” tuber yield of Shangi ($r = +0.6$) and Unica ($r = +0.9$) was strong (Table 5). The difference in the yields of varieties has also been noted by NPCK (2017) that has documented the potential yield of Unica to be greater than that of Shangi. These results are within the blanket recommendations of 90 kg ha^{-1} phosphorus for “ware” potato by MOA (2010), Kaguongo (2008), KARI (2008) and NPCK (2013). In a similar study on potatoes, Birtukan (2016) recommended phosphorous rate of 135 kg ha^{-1} .

Influence of phosphorus on “ware” potato yield of potato at Lari.

The results show that there was significant difference ($p = 0.024$) between the mean potato “ware” yields of Shangi (5.1 t ha^{-1}) and Unica (12.6 t ha^{-1}). Phosphorus rate significantly ($p < 0.001$) influenced potato “ware” yield. Correlation between phosphorus rate and mean potato yield was strongly positive ($r = +0.8$). Interaction between phosphorus rate and variety significantly ($p = 0.004$) influenced “ware” potato yield. The highest yield of Shangi (7.0 t ha^{-1}) was realized at phosphorus rate of 90 kg ha^{-1} while the highest “ware” yield of Unica (17.5 t ha^{-1}) was realized at phosphorus rate of 120 kg ha^{-1} . The correlation between phosphorus rate and mean “ware” yield of Shangi ($r = +0.9$) and Unica ($r = +0.4$) was positive (Table 5). In this site, initial soil available phosphorus status (25 ppm Mehlich 3 Phosphorus) was below the critical level of (30 ppm Mehlich 3 phosphorus). At planting, the area was surrounded with maize that was purplish in colour confirming low soil available phosphorus. The water table of the area was high (1- 3 m) necessitating construction and maintenance of drainage channels. There were indications of illuviation as the colour of the top soil was greyish brown. In this

site, additional phosphorus is justified by the above mentioned low available soil phosphorus at planting. The above findings compares well with those of MOA (2011), Kaguongo (2008), NPCK (2013) and KARI (2008) which notes a blanket recommendation of 90 kg ha⁻¹ phosphorus for “ware” potato production in Kenya. In a similar study conducted by Zelalem *et al.*, 2009 in Central highlands of Ethiopia, phosphorus application of 120 kg ha⁻¹ was optimum for potato production. Correlation between yields and tuber numbers was positive. The correlation between Shangi “ware” yield and numbers was +0.4 while the correlation between Unica’s “ware” yield and tuber numbers was +0.8. Israel *et al.*, 2012 found that phosphorus application of 60 kg ha⁻¹ was optimum for potato production. From Birturkan (2016), phosphorus needed for optimum potato production was 135 kg ha⁻¹ phosphorus. This is confirmed by Ekelorf (2007) who has said that there are several factors that contribute to fertilizer recommendations on potatoes which include soil type, nutrient availability, and economic factors of an area, moisture supply and variety. It is therefore important to base crop fertilizer requirements on soil test results (Yara International, 2019).

Table 5. Influence of phosphorus on “ware” potato yield

Phosphorus (kg ha ⁻¹)	Mean Variety yield (t ha ⁻¹)								
	Saboti			Ainabkoi			Lari		
	Shangi	Unica	Mean	Shangi	Unica	Mean	Shangi	Unica	Mean
IC	8.2	17.3	12.8	1.3	6.7	4.0	2.1	8.6	5.3
0	17.2	19.2	18.2	7.3	4.9	6.1	2.6	4.5	3.6
30	11.8	15.1	13.4	9.5	8.6	9.1	7.0	15.7	11.4
60	13.7	31.9	22.8	8.2	8.9	8.5	5.0	13.2	9.1
90	13.0	40.2	26.6	6.2	16.5	11.4	7.0	16.2	11.6
120	19.6	23.9	21.7	10.7	26.8	18.7	6.6	17.5	12.0
Mean	13.9	24.6	19.2	7.2	12.1	9.6	5.1	12.6	8.8
		LSD_{p=0.05}			LSD_{p=0.05}			LSD_{p=0.05}	
	Variety	= 9.0		Variety	= 5.3		Variety	= 5.1	
	Phosphorus	= 6.8		Phosphorus	= 4.3		Phosphorus	= 2.7	
	Phosphorus*	= 9.8		Phosphorus*	= 9.6		Phosphorus*	= 4.4	
	Variety			Variety			Variety		
CV%		29.2			37.3			25.0	

3.3 Influence of Variety on Quality of “Ware” Potato

There were similarities and differences between the physical qualities of the two potato varieties. Not much information is available on Unica by many consumers and producers since it is among the most recently released varieties in Kenya (NPCK, 2017). Both varieties can be eaten as chips or boiled. They take almost the same duration to cook but Shangi cooks faster and is tastier (Sophie, 2018). Both varieties peel easily but Unica peels more easily than Shangi. Unica is smoother and has fewer eyes than Shangi (NPCK, 2019). Consequently, on average, the time taken to peel a Unica tuber is less than that taken to peel a Shangi tuber. Some consumers prefer Shangi for its white flesh while others prefer Unica for its cream flesh. Unica is noted to be good for crisps, has unique flavour (Sophie, 2018) and its colour blends with “bhajia” type of cooked potato. Some consumers indicated that Shangi is sweeter and cooks faster than Unica. The storage time of Unica (2.5 to 3.5 months) is longer than that of Shangi (Less than 1 month) (NPCK, 2018 & NPCK, 2019). Thus, Unica is not only good for institutions (like schools, hospitals and prisons) but also for individual households. At such time when the world is faced with the challenge of corona virus (COVID, 19), Unica is preferred as it can remain in good condition for food for longer period than Shangi. Most actors on the potato value chain particularly consumers, traders, intermediaries (“middle men”), seed merchants and producers prefer Shangi. This is because it is more popular; more demanded and has short dormancy than Unica. Sophie (2018) observed that most farmers produced Shangi than other higher yielding varieties like Unica, Tigoni, “Sherehekea”, “Desire” and “Asante”. This is despite Unica being more resistant to pests and diseases and being more tolerant to other climate change impacts than Shangi (NPCK, 2019; Waikwa, 2018 & Sophie, 2018).

4. Comparisons of Key Soil Parameters That Affected Potato Tuber Yield

There was a strong positive correlation between “ware” potato yield and soil pH ($r = +0.7$); between “ware” potato yield and soil available phosphorus at planting ($r = +0.7$); “ware” potato yield and soil available phosphorus at harvesting ($r = +0.8$). There was also a positive perfect correlation between “ware” potato yield and plant (tuber) phosphorus at harvesting ($r = 1.0$). Higher soil pH in Saboti and Ainabkoi as compared to Lari

favoured potato tuber yield. According to KEPHIs (2016), potatoes are acid loving but grow optimally in soils with pH range of 5.5 to 7.0 because most nutrients they require are available in this pH range. Saboti with pH of 5.8 produced highest mean potato tuber yield (19.2 t ha^{-1}), Ainabkoi with pH of 5.6 produced moderate mean potato tuber yield (9.6 t ha^{-1}) while Lari with pH of 4.6 produced the lowest mean potato tuber yield (8.8 t ha^{-1}). Low pH hinders root growth due to toxicity of micronutrients like Manganese (CK, 2020) and/or by fixing soil phosphorus (Silvar, 2012) which is essential in root establishment. There was also a perfect correlation ($r = + 1.0$) between soil available phosphorus at planting and soil pH. Studies have shown that phosphorus is fixed in the soil by aluminium or iron ions which are more available in soil solution at low pH (Silva, 2012). Thus, the availability of phosphorus was lowest in Lari (20.5 ppm Bray 2 phosphorus), average in Ainabkoi (43.0 ppm Bray 2 phosphorus) and highest in Saboti (57.7 ppm Bray 2 phosphorus) (Fig 2). Where there was more available phosphorus, the uptake of the same nutrient by potato plant was high; the highest plant (tuber) phosphorus was highest at Saboti (0.9 %). There was however marginal significant difference between plant (tuber) phosphorus at Ainabkoi (0.6 %) and Lari (0.5 %). This contributed to mean “ware” tuber yields being highest at Saboti (19.2 t ha^{-1}), average at Ainabkoi (9.6 t ha^{-1}) and least at Lari (8.8 t ha^{-1}) (Fig 4; table 4 & 5).

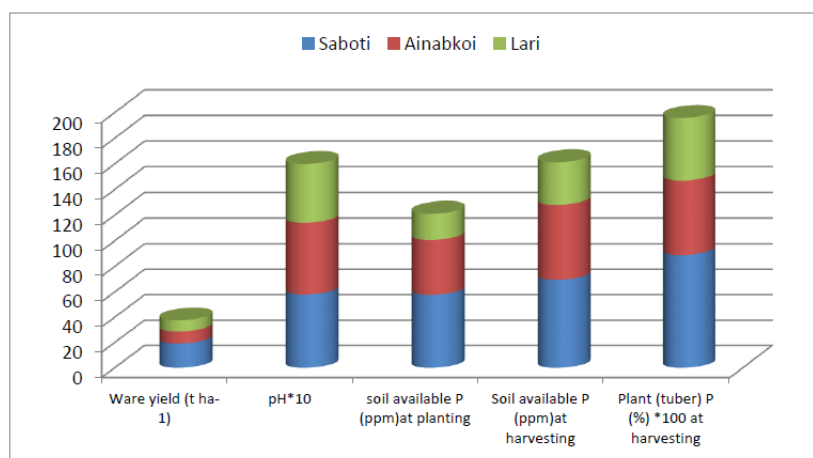


Figure 4. Comparisons of “ware” yield with soil pH, soil available phosphorus and Plant (tuber) phosphorus

5. Conclusions

Unica had better response to phosphorus rate application than Shangi (In all the test sites and at almost all levels of phosphorus rate application, the overall mean yields of Unica were higher than Shangi’s). Phosphorus positively and significantly influenced yield of “ware” potatoes in the three test sites. Highest yields of Shangi and Unica “ware” potato tubers at Saboti were realized by 120 kg ha^{-1} and 90 kg ha^{-1} phosphorus; at Ainabkoi highest yields of both varieties were realized by 120 kg ha^{-1} phosphorus while at Lari highest yields of the same were realized by 90 kg ha^{-1} and 120 kg ha^{-1} phosphorus, respectively. In general, all the test sites required 90 kg ha^{-1} phosphorus application for production of highest “ware” tuber potato yields.

Within the “ware” potato season, there was a build-up of soil available phosphorus status. The mean tuber phosphorus was highest in the harvested tubers from Saboti. There was a strong correlation between mean available soil available phosphorus and mean plant (tuber) phosphorus. Correlation between Mean soils available phosphorus at planting and at harvesting was very strong. Higher soil pH in the range of (5.5 - 6.5) favoured “ware” potato yields. Many potato value chain actors particularly farmers have very limited information on the most recent varieties introduced in Kenya.

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