Effect of Phosphorus and Potassium Fertilizer Rates on Yield and Yield Component of Potato (Solanum tubersum L,) at K/Awlaelo, Tigray, Ethiopia

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Abstract
A study was conducted to evaluate the effect of phosphorous and potassium fertilizer rates on the yield and yield components of potato (Solanum tuberosum L.) grown on sandy clay loam soils of K/Awlaelo Wereda, Tigray, Ethiopia during 2012 rainy season. An Improved potato variety "Gudane" was tested with four levels of phosphorous (i.e., 0, 67.3, 89.7 & 112.2 Kg/ha of P_2O_5) and four levels of potassium (i.e. 0, 50, 100, 150Kg/ha of K_2O) in a randomized complete block design with three replications. The recommended N 110 Kg/ha rate for potato was applied as urea to all treatments equally. Data on yield attributes, marketable, unmarketable, total tuber yield, fertilizer use efficiency and soil physical-chemical were collected using standard procedure. The study revealed that the main effect of phosphorus and potassium fertilizer rates were significantly affected the number of stems and tubers per plant, average tuber weight, biomass yield, marketable yield, and total tuber yield of potato. Moreover, days to physiological maturity, dry matter content, average tuber weight, marketable tuber yield, total tuber yield, fertilizer use efficiency, were significantly affected by their interaction. The optimum marketable and total tuber yield 38.61&41.81t/ha respectively was obtained due the interaction effect of P*K fertilizer at the rates of 89.7 P_2O_5 Kg /ha of and 100 and K_2O Kg /ha. Hence, 89.7 P_2O_5 Kg /ha of and 100 and K_2O Kg /ha is recommended to apply in order to attain higher tuber yield and yield component of Gudane variety of potato in the study area and other similar areas.
Keywords: Effect, Fertilizer, Interaction, Main effect, Potassium, Potato, Phosphorus, Tuber yield

1. Introduction

Potato (*Solanum tuberosum L.*) is the fourth most important crop in the world after wheat, maize and rice with 314.1 million tons of annual production on 18.1 million hectares of land (Arslanogul *et al*, 2011) .Potato is an important source of food which contains high levels of carbohydrate, protein, vitamins and minerals. It is also source income, and employment opportunity in developing countries (FAO, 2008). Due to its correct balance between protein and calories, it is considered a good weaning food and these traits make it an efficient crop in combating world hunger and malnutrition (Berga *et al.*, 1994). The commercial value of potatoes is increased considerably when they are processed into edible products that appeal to consumers on flavor, texture, appearance, and most of all convenience (Kirkman, 2007).Potato consumption has increased in the developing world, and over the last decade world potato production has increased at an annual average rate of 4.5 percent .Furthermore; Kirkman (2007) has estimated that global consumption in processed form will increase from 13% of total food use in 2002 to nearly 18% by 2020.

The potential yield of potato can reach up to 50 t/ha (Joshi, *et al*., 2009). But the average national potato production in Ethiopia is 10.5 tones/ha, while progressive farmers who use improved agronomic practice attained yields of 25 tones/ha. The production of the crop in our country is constrained by several problems.

Potato is a high nitrogen (N), phosphorus (P) and potassium (K)-demanding crop. Deficiency of any or combinations of these nutrients can result in retarded growth or complete crop failure under severe cases (Khiari *et al.,* 2001). Fertilizer type and application rates for potato have not been extensively studied in Tigray, Ethiopia. It is common practice for extension service to apply the blanket national recommendation of 165kg/ha urea and 195 kg/ha Diammonium Phosphate (DAP) which was recommended for potato production on the black soil of Holetta, Ethiopia (IAR, 2000). But, fertilizer requirement varies across locations due to many reasons such as difference in soil types, nutrient availability of the soil, economic factors of the area, moisture supply and variety and proper nutrition is crucial in determining potato yield and quality, as well as the potato plant's ability to withstand pest, environmental, and other stresses. In Tigray NPK losses indicates that K losses 8.8 %, N 0.6 - 0.4 %, and for P 0.17 - 0.01% per ha/year. These rates are substantially higher than those found in earlier in Ethiopia (Asefa, 2004). Some of the major problems resulting in lower potato productivity in the area is inadequate agronomic practice, low soil fertility and lack of fertilizer rate recommendations based on the local condition. Potato has relatively high potassium requirement in comparison to other vegetables, and so potassium containing fertilizers should be applied in potato fields for high yield production. Adequate potassium fertilizer application can be useful because it makes potato plants adapted to the environmental stresses and may lead to increased resistance of potato to some pests AL-Moshileh *et al.*, 2004)

Therefore, to address these problems the study was initiated with the major objective of investigating the response of phosphorous and potassium fertilizer rates on yield and yield component of potato grown on sandy clay loam soil of K/Awlaelo, Tigray, Ethiopia.

2. Methodology

2.1 Description of the study area

The experiment was conducted at Mekelle Agricultural Research Center substation, K/Awlaelo, Aynalem Tabia (13º 46' 03.38" N latitude, 39º 35' 48.60'' E longitude and 2133 m above sea level) which is located in Northern Ethiopia. The experiment was conducted under rain fed condition from June to October 2012. During the study period the mean maximum temperature and minimum temperature was 26.1 ^{0}c and 11.7 ^{0}c respectively. In the same period 565 mm rain fall was received. The average annual rainfall, maximum and minimum temperature of K/Awlaelo, Aynalem is 606 mm, 28^{0}c and 11.2^{0}C respectively. The field experiment was conducted on sandy clay loam soil and the physical and chemical properties of the soil are presented in Table 1.This study site was selected based on their suitability interms of climate and soil conditions for higher potato production. With the increase in the introduction of irrigation technology, the potential for potato production in the study areas are growing also another criterion for selection.

Table1. Pre-sowing soil chemical and physical properties of the experimental site

Parameters	K/Awlaelo (Aynalem): - 0-30cm
Electrical Conductivity or E.C (dS/m)	0.27
PH	7.50
Total nitrogen or N (%)	0.09
Available prosperous or P (ppm)	3.83
Available potassium or K (ppm)	412.5
Organic carbon or OC (%)	0.38
Cation Exchange Capacity or CEC (Cmol/kg)	20.0
Sand (%)	61
Silt (%)	16
Clay (%)	23
Textural class name	Sandy clay loam
Ca^{+2} (meq/100g soil)	13.6
Mg^{+2} (meq/100g soil)	3.6
K^{+}(Cmol/kg soil)	1.023
Na^{+}(Cmol/kg of soil)	0.217

2.2 Experimental treatments, design and producers

This study was conducted in order to study the effect of P and K fertilizer on tuber yield and yield components of potato. The treatments used consisted of a combinations of four levels of phosphorus namely (0, 67.3, 89.7 Kg and 112 kg/ha of P_2O_5) and four levels of potassium (i.e., 0, 50,100& 150 Kg/ha of K_2O).The recommended N rate of 110 Kg/ ha was applied to all treatments equally as based in split. The entire rate of P, K and half of N fertilizers were applied at the time of planting. The remaining half of N was applied 45 days after planting. Urea (46% N), Triple Super Phosphate (46% P_2O_5), Potassium Chloride (62% K_2O) were used as fertilizer source for N, P and K respectively. The experiment was laid out as a 4x4 factorial experiment arranged in Randomized Complete Block Design, and 16 factorial treatment combinations were assigned to the 16 experimental plots randomly and replicating three times. The plot size was four rows each 2.4 m long and medium size and well sprout Gudane variety of potato tubers were planted at spacing of between rows and plants 70cm and 30 cm respectively. A distance of 1 meter was maintained between plots and 1.5 meters between the blocks. The sowing depth was 12-13 cm and planting was done by placing a tuber manually per hill. Cultural practice such as weeding, cultivation and ridging were practiced per recommendation.

2.3 Data collection and procedures

Days to flowering were recorded when 50% of the plant population attained the flowering stage. Plant height was measured using a ruler starting from the base of the main shoot to the apex at full blooming. Number of stems per hill was recorded as the average stem count of five hills per plot at flowering stage. Only stems arising from the mother tuber were considered for measurement. Days to physiological maturity was noted when the leaves of 75% of the plants in each plot was turned to yellowish color. Tuber number and yield were measured taking an average of 12 hills per plot. Healthy tubers with diameter > 3.5mm was considered as marketable , while rotten, diseased, insect attacked, deformed tuber and those having < 3.5 mm in diameter was categorized as unmarketable as described by (AL-Moshileh & Errebi, 2005). The average tuber fresh weight was recorded by dividing the total fresh weight of tubers per plot by the total number of fresh tubers.

Pre planting soil samples were randomly collected from the experimental site at 0-30cm depth with auger and a composite soil sample prepared. Soil samples were also collected from each plot at the same depth after harvest and each sample prepared for analysis. The collected samples were air dried ground and sieved to pass through a 2-mm sieve for soil physical and chemical analysis. Tuber specific gravity was measured using the weight in air and weight in water method (Kleinkopf et al., 1987) .Starch content was calculated based on the Van Scheele equation. To determine, dry matter N.P and K content of tubers from five randomly selected plants per plot were taken at harvest washed, chopped and mixed. The sample was weighed while fresh and late dried in an oven at 80 ^{0}C for 72 hours and reweighted. It was calculated as the ratio between dry and fresh mass expressed as a percentage. Furthermore the dried sample ground and sieved then N,P and K content of the tuber was determined .Fertilizer use efficiency (FUE) of PK was calculated by subtracting tuber yield in control from tuber yield with fertilizer then dividing the result to fertilizer applied and expressed as kg yield/kg PK as described by Jansson (1998)

Uptake of a nutrient element by the potato tuber was obtained at harvest by multiplying dry weight of potato tuber (kg/ha) by a given nutrient (NPK) concentrations within each. Then, the N, P and K uptake of tubers was determined

2.5 Statistical Data analysis

All crop data were tested their normality and subjected to General analysis of variance using Gen Stat version 13th edition. Whenever the treatment was significant Tukey test were used for mean separation between and/or among treatments. Simple linear correlations between parameters were computed when applicable to estimate the relationship between yield and yield components as affected by phosphorus and potassium using Minitab soft ware 14th edition.

3. Results and discussion

3.1 Effect of P K fertilizer rates on growth parameters of potato

3.1.1 Days to flowering and maturity

The result have indicated that the main effect of phosphorus fertilization was significantly influenced the days to reach flowering and to attain physiological maturity in potato where as potassium fertilization not significantly affected (Tables 2.). Application of P at the rate of 89.7 kg P_2O_5 /ha delays flowering and maturity by 3 and 7 days respectively compared to unfertilized treatment. The interaction effect of P and K were significantly influenced the days physiological maturity but not for the days to flowering. A combined application of 112 Kg P_2O_5/ha and 150 Kg K_2O/ha delayed the days to flowering and maturity by 3 and 6, respectively in relative to the control. The lowest days to flowering and maturity was recorded in the control at both treatments and their interaction. In general the present study concludes that the main and interaction effect of PK fertilization prolonged the days to flowering and maturity. In agreement with this study, Zelalem et al (2009) who reported that application of P increased the days to reach flowering. In addition, Mulubrhan (2004) reported that P addition significantly prolonged the days to flowering as K has no significant effect on days either to flowering or maturity. Similarly, Ayalew and Beyene (2012) reported that potassium fertilization did not affect the time to reach emergence, flowering and physiological maturity

3.1.2 Plant height

Tables 3.1 and 3.2 shows that the main and their interaction affect of P and K fertilizers were not significantly influenced the plant height at maturity. The tallest plant height 72.13 and 72 cm were recorded due to the interaction effect P and K fertilizer rates at 112 Kg P_2O_5/ha, and 150 Kg K_2O/ha P and K respectively. Besides the interaction effect, the tallest plant height 71.28 cm and 70.17 was measured at P fertilizer rate of 89.7 Kg P_2O_5/ha and 150 Kg K_2O/ha alone respectively. The lowest plant height was obtained at the control compared to the fertilized treatments (Table 2). In general the tallest plant height was obtained at the fertilized, where as the shorter at the unfertilized once. Despite their significant in harmony with this study, Nikardi (2009), working on the response of potato source and method of application, reported that a significant increment in plant height of potato was observed due to K applications. Similarly, Al-Moshileh and Errebi (2004) reported that plant height was significantly affected by K fertilizer and the tallest plant was observed at the highest rate i.e. 450 Kg K_2SO_4 /ha .In addition, Asmaa and Magda (2010) found that the vegetative growth parameters, i.e. plant height and dry weight of leaves and shoots were gradually and significantly increased with increasing the level of potash fertilizer.

3.1.3 Plant biomass yield

Potato biomass yield was found to significantly influence by the main effect of P and K fertilizer rates, and by their interaction (Table 2). Fertilized potato was produced more biomass than the control. The highest total biomass yield (46.77t/ha) were obtained at the interaction rates of 89.7 Kg P_2O_5/ha and 100 Kg K_2O/ha P and K respectively. Positive and highly significant correlation was obtained with stem number (r=0.63***), tuber number (0.71***) and total tuber yield (r = 0.98***) indicating that the existence of close association between them. In addition the biomass was positively and significantly correlated to P (r=0.53**) and none significantly to K (r=0.20^{ns})

application (Table 6). This indicates that with increasing P and K levels the biomass was increased and more responsive to PK fertilizer. In conformity, Zelalem *et al* (2009) observed that aboveground and underground biomass yields of potato were significantly influenced by N and P fertilization. Moreover Eleiwa et al (2012) reported that application of NPK levels significantly increased the dry weight of potato.

3.2 Effect of P K fertilizer rates on yield components of potato

3.2.1 Stem number per hill

The main effect of P and K fertilization were statistically significant to increase the stem number per hill at early maturity but not their interaction. The highest stem number per hill 4.93 and 4.68 was obtained at the main effect of P and K application rates of 112 Kg P_2O_5/ha and 150 Kg K_2O /ha respectively. Moreover, owing to the interaction effect the highest number of stem per hill (5.43) was obtained from a combined PK at the rates of 112 Kg P_2O_5/ha and 150 Kg K_2O /ha P and K respectively and the lowest was observed at the control on both main and interaction effects (Table 3). The positive effect of P and K fertilizer on the stem number per hill was further strengthened by the positive and significant correlation observed with the applied P (r = 0.41***) and K (r=0.41*). In addition, positive and highly significant correlation was observed with the number of tuber per hill (r = 0.77***), marketable tuber yield (r= 0.56***) and total tuber yield (r= 0.60*) (Table 6). In agreement to this study, Ayalew and Beyen (2012) reported that stem number of potato was influenced by the application of K fertilizer and was positively correlated with the applied K but most of the K rates gave a lower stem number though the stem number neither decreased nor increased with increasing the rates of K application. In contrary, Zelalem et al (2009) reported that N, P fertilization and their interaction did not significantly influenced the number of stems initiate.

Table 2. Main effect of Phosphorus and potassium fertilizer rates on growth parameter, dry matter (DM) and specific gravity (S.G) of potato

Treatment	Days to flowering	Days to maturity	Plant height (cm)	Biomass yield (t/ha)	No. stems per plant	DM (%)	S.G
P_2O_5rates kg/ha							
0	58.58^b	90.33^c	65.68	34.01^c	3.51^d	28.22	1.067
67.3	61.17^a	96.08^b	68.47	37.32^b	4.02^c	27.77	1.071
89.7	61.25^a	97.33^a	71.28	40.0^a	4.44^b	27.56	1.072
112	60.75^a	98.00^a	70.44	39.55^a	4.93^a	27.43	1.068
LSD (5%)	1.029	0.835	ns	1.884	0.225	ns	ns
KO_2rates kg/ha							
0	60.67	95.08	66.63	32.82^c	3.97^b	28.89^a	1.072
50	59.83	95.17	69.26	36.88^b	4.01^b	28.01^b	1.071
100	60.58	95.42	69.82	40.72^a	4.24^b	27.07^c	1.068
150	60.67	96.08	70.17	40.47^a	4.68^a	27.01^c	1.07
LSD (5%)	1.029	ns	ns	1.884	0.225	0.82	ns
CV(%)	2	1	6.4	6.00	6.4	3.5	0.5

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = ns, and different letter are significant different at 5%, of probability level based on Tukey test

3.2.2 Tuber number per plant

The main effect of P and K fertilizer were significantly increased the number of tubers per plant, but not their interaction. The number of tubers per plant was increased significantly as the main effect of P and K application rate increased. Moreover, the highest number of tubers 9.5 and 9.3 were obtained at K and P respectively who had significantly different with other rates. The highest number of tubers per plant were recorded at 112 Kg P_2O_5/ha and 100 Kg K_2O/ha with respect P and K fertilizer application solely (Table 4). Despite their non significant influence due to the interaction effect of P and K , higher number of tubers per plant (10.1) was recorded at rates 89.7 Kg P_2O_5/ha of P and 100 Kg K_2O /ha of K . The number of tubers per plant increased due to applied P and K was statistically significant compared to the control and the first level, while between the last levels a non-significant difference was observed (Table 3). The total tuber number per plant for the overall treatment interaction effects showed an increasing trend even though the increment was statistically non-significant. In order to optimize the number of tubers that could be set by a potato is more influenced by the main effect of P and K fertilizer application than their interaction; thus, attention must be given to fixing the right P and K rate. The positive effect of P and K fertilizer on tuber number was further confirmed by the positive and significant correlation between tube number per plant and the applied P (r = 0.77***) and applied K (r= 0.41*). Positive and significant correlation values was also found between number of tubers and marketable yield (r=0.70***) and number of tubers and total tuber yield (r = 0.72***) (Table 6). In agreement with this study, Mulubrhan (2004), Zelalem *et al* (2009) who reported that application of N and P increased significantly total tuber number and

Eleiwa *et al* (2012) also reported that NPK application increased significantly the number of tubers per plant and tuber yield per plant.

3.2.3 Average Tuber weight

The main effect of P and K fertilizer rates had highly significantly ($p \leq 0.001$) whereas the interaction effect significantly ($p < 0.05$) affected average tuber weight. As the main effect of P and K fertilizer rate increased the average tuber weight increase (Table 3 & 4) .The significance of P and K application was observed between fertilizer rates and the control and among the rates. The highest average tuber weight (83.23gm) was obtained at rates of 112 Kg P_2O_5/ha and 150 Kg K_2O/ha P * K interaction effect (Table 4). Furthermore of average tuber weight 80.47 gm was recorded due to main effect of K at the rate of 150 Kg K_2O/ha where as the lowest was obtained at the control (Table 3). In line to this study, Jenkins and Mahmood (2003) reported that the average tuber weight was generally much greater when all the three nutrients were supplied at a higher level and the smallest weight was obtained when both N and K were deficient while P is being optimal. In addition, Panique *et al*. (1997) reported that the average tuber weight was increased in response to the application of K. The average tuber weight was positively and significantly correlated with the applied K (r = 0.40*) and applied P (r = 0.29*). The average tuber weight was also positively and significantly correlated to the total tuber yield (r=0.76***) and marketable yield(r=0.80***) (Table6). This indicated a closer relationship between the applied P and K with the average tuber weight and the yield advantage obtained due to P K application could be attributed to its effect on potato tuber weight increment.

3.2.4 Effect of PK fertilizer rates on specific gravity (S.G), dray matter content (DM (%), Starch content (%) of potato tuber

The main and interaction effect of P and K fertilizer rates was not significantly influenced the tuber specific gravity. Although application of P fertilizer alone non-significantly increased the specific gravity, but the increasing trend, which was not linear, followed to the rate of P application. Moreover as application of K fertilizer rate alone increase specific gravity decrease none significantly (Table 2). The lowest specific gravity was associated with control in relation to P and K fertilized treatments, where as the highest with PK treated treatments. The potato of the specific gravity in this study was ranged 1.067- 1.072 gm/$cm^{3,}$ this range indicates low specific gravity. This study agrees with (Khan *et al*, 2010) who reported that potatoes with low specific gravity are used for canning. However, potatoes with a very high specific gravity (1.10) may not be suitable for French fries because they become hard or biscuit like**.** Westermann *et al.* (1994a) also reported that the highest specific gravity was always associated with the lowest N and K application rates. Moreover, when the K application rate exceeds the recommended rate the specific gravity is decreased. Similarly Mulubrihan (2004) reported that there was a significant decrease in the specific gravity due to the application of potassium .In agreement with this study, K (r= have a negative and significant correlation with specific gravity. In contrary to this study Chapman *et al.* (1992) reported a higher specific gravity can found due to K application. Therefore, when quality is a requirement special consideration should be given to PK fertilizer rate application.

The main effect of K were significantly decreased the dry matter content of potato tube and there was a significant difference on dry matter content among the treatments due to interaction effect of PK fertilizer, where as the main effect of P not significantly affected it. With the increasing K rates from 0, to Kg 150 K_2O /ha the dry matter content of tubers decreased significantly from 28.89 to 27.01 %, but as P rate increases from 0 to 112 P_2O_5 kg /ha dry matter content decreased non significantly from 28.22 to 27.43% (Table 2) .The highest dry matter content (28.89 %) was recorded at control relative to K fertilizer application alone (Table2). Interaction effect of PK on dry matter content of potato tuber was decreased significantly from 28.9 % to 27.34% with increasing PK combination rates from the control to the highest rate. The study also found that the dry matter was negatively and not significantly correlated with the application of P ($r=-0.14^{ns}$) and negatively but significantly correlated with K (r= - 0.51*)(Table6). In agreement with this, Sparrow *et al*. (1992), Mulubrihan (2004) and Zelalem et al (2009) reported that there was a reduction in dry matter content of tubers due to increased P application. Maier *et al*. (1994) and Kanzikwera *et al.* (2001) also reported that reduction in dry matter content was observed when rate of potassium fertilizer increased. However, Patricia and Bansal (1999) reported that application of K had no effect on tuber dry matter content. In Contrary, Tawfik (2001) reported that potato while was fertilized by high K rate had a significantly higher dry matter.

The main effect of P, K and its interaction had no a significant influence on the starch content of potato tuber. The starch content of potato tuber was non- significantly and none linearly increasing with increasing the P rate alone. Moreover as the K rate increased the starch content of the tuber was decreased non linearly , however, the combination of PK rates increased the starch content of tuber increase inconsistent and non-significant .The highest (12.64%) starch content of tuber was obtained from the combined application 89.7kgP_2O_5/ha and 0 kgK_2O/ha . In agreement to this, Eleiwa *et al* (2012) reported that the chemical constituents of potato tubers like starch content was increased with increasing the NPK levels. In contrary, Eremee *et al* (2009) reported that fertilization of NPK reduced significantly the starch content of potato. According to Joudu (2003) the starch content of tubers was affected by a cultivation method, fertilization and storage conditions.

3.3 Effect of P K fertilizer rates on potatoes tuber yield

3.3.1 Total tuber yield

As shown in table 3 the main effect of P and K fertilizer application showed that there was a highly significant difference in total tuber yields and significant difference due to the their interaction effect (Table 3 &4) .As the application rate of P and K increase total tuber yield was increased significantly till the rate of P: 89.7 Kg P_2O_5/ha and K: 100 Kg K_2O/ha. The optimum tuber yield (41.84t/ha) was achieved due to the interaction effect of P and K at combined rates of 89.7 kg P_2O_5/ha and 100 Kg K_2O/ha (table 4). The total tuber yield was increased in response to the main and interaction effect of PK fertilizer application. With respect to the main effect the highest total tuber yield 36.17 t/ha and 36.08 were obtained at P rate of 89.7 Kg/ha P_2O_5 and K rate of 100 Kg/ha K_2O respectively (Table 3). A combined NPK fertilizer application produced a higher total tuber yield as compared to P and K fertilizer alone (Table 3 and 4). In this study, it was found that the total tuber yield was more responsive to PK fertilizer interaction compared to the main effect. In general it is the control where the lowest tuber yield was obtained compared the treatments, which they were treated with P K fertilizer (Table 3 &4). This study, also revealed positive and highly significant correlation between the total tuber yield and the applied P (r=0.54***) (Table6)

A significant increase in total tuber yield was due to the application of PK fertilizer, which seemed to prove that the soil, of Wukro is poorer in these nutrients. In harmony with this study, Zelalem *et al* (2009) and Mulubrihan (2004) reported that application of P significantly increased the tuber yield at Debre Berhan and Mekelle areas, respectively. Adhikari and Sharma (2004), Eremeev *et al* (2009) and Eleiwa *et al* (2012) also reported increasing the NPK levels significantly increased the tuber yield and the yield parameters of potato at harvest. The highest tuber yield was obtained from the application of K which is similar to the report by Tawfik (2001), Robert and Monnerto (2000) and Haile and Boke (2011). Similarly, Zameer *et al* (2010) was reported a significant higher tuber yield with K application rate at K_2O 150 Kg /ha than NP treatment. In addition Westermann *et al.* (1994a) also reported a significant increment in tuber yield due to K fertilizer only on the K responsive soils. Ayalew and Beyene (2012) and Mulubrihan (2004) reported that application of K had a yield advantage over the control even if the difference was insignificant.

Table 3. Main effect of P and K fertilizer rates on marketable, unmarketable and total yield of potato

Treatment	Number of tubers/plant	Average tuber weight (gm)	Marketable yield t/ha	unmarketable yield t/ha	Total (t/ha)
P_2O_5rates kg/ha					
0	8.5^{b}	69.91^{d}	27.46^{c}	3.00	30.34^{c}
67.3	8.5^{b}	73.57^{c}	29.47^{bc}	2.89	32.37^{bc}
89.7	9.2^{a}	78.84^{b}	32.94^{a}	3.48	36.17^{a}
112	9.3^{a}	75.94^{a}	30.07^{b}	4.47	34.54^{ab}
LSD(P<0.05)	0.55	2.106	1.661	ns	1.672
KO_2rates kg/ha					
O	8.1^{c}	70.95^{c}	25.84^{c}	3.01	28.73c
50	8.8^{bc}	70.33^{c}	29.74^{b}	3.14	32.96^{b}
100	9.5^{a}	76.52^{b}	32.78^{a}	3.64	36.08^{a}
150	9.2^{ab}	80.47^{a}	31.59^{ab}	4.05	35.64^{a}
LSD (p<0.05)	0.55	2.106	1.661	ns	1.672
CV(%)	7.5	3.4	6.6	44.8	6

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = ns, and different letter are significant different at 5%, of probability level based on Tukey test

3.3.2 Marketable tuber yield

The productivity of potato is measured in terms of marketable tuber yield. The main and interaction effect of P and K fertilization significantly affects the marketable tuber yield. There was also a significant difference in marketable tuber yield among the rates. The maximum marketable tuber yield (38.61 t/ha) was obtained due to the interaction effect of PK fertilizer at a combined rates of 89.7 Kg P_2O_5/ha and 100 Kg K_2O/ha P and K respectively (Table 4).In addition a higher marketable yield (32.94) and (32.78t/ha) were obtained at 89.7 kg P_2O_5/ha and 100 kg K_2O/ha rates, respectively due to the main effect of P and K fertilizer alone (Table 3). The correlation between the marketable tuber yield and the applied P ($r = 0.51^{***}$) and K ($r=0.19^{ns}$) were positive and significant with P but not significant with K. Besides positive and highly significant correlation was observed between the total tuber yield and marketable yield (r= 0.96***), marketable tuber yield and average tuber weight (r=0.80***).(Table6). In agreement to this Zelalem, *et al* (2009) reported that application of P significantly increased the marketable tuber yield**.** Similarly, Eremeev *et al* (2009) reported that the total yield of tubers as well as the proportion of marketable tubers increased significantly with the use of NPK. AL-Moshileh and Errebi (2004) indicated that marketable tuber yield was significantly improved with increasing the potassium level. Mulubrihan (2004) observed that application of P and K significantly increased marketable yield but K didn't.

Table 4. Interaction effects of P and K fertilizer rates on yield and yield components of potato tuber

Treatment P_2O_5*K_2O rates kg/ha	Average tuber weight (gm)	Marketable tuber yield (t/ha)	unmarketable tuber yield (t/ha	Total tuber (t/ha)
(0, 0)	67.83^{g}	22.37^{f}	2.95	25.32^{e}
(67.3,0)	67.23^{gf}	26.53^{def}	1.81	28.34^{de}
(89.7,0)	78.33^{bc}	27.48^{bcdef}	1.59	29.07^{cde}
(112,0)	70.4^{efg}	26.97^{cdef}	5.23	32.2^{bcd}
(0,50)	66.37^{fg}	25.69^{ef}	2.51	28.2^{ed}
(67.3,50)	68.87^{fg}	32.11^{bcd}	2.77	34.88^{bc}
(89.7,50)	75.5^{cd}	33.00^{abc}	2.95	35.95^{ab}
(112,50)	70.57^{efg}	28.17^{bcdef}	4.63	32.8^{bcd}
(0,100)	71.67^{def}	31.68^{bcde}	2.6	34.28^{bcd}
(67.3,100)	75.67^{cd}	28.81^{bcde}	3.3	32.11^{bcd}
(89.7,100)	79.17^{abc}	38.61^{a}	3.23	41.84^{a}
(112,100)	79.57^{abc}	32.01^{bcd}	4.1	36.11^{ab}
(0, 150)	73.77^{de}	30.12^{bcde}	3.44	33.56^{bcd}
(67.3,150)	82.5^{ab}	30.45^{bcde}	3.69	34.14^{bcd}
(89.7,150)	82.37^{ab}	32.67^{abc}	5.16	37.83^{ab}
(112,150)	83.23^{a}	33.11^{ab}	3.94	37.05^{ab}
LSD ($p<0.05$)	4.211	3.321	ns	3.344
CV(%)	3.4	6.6	44.8	6

Means of the same interaction effect within a column followed by the same letter are not significantly different at 5% of probability level = ns, and different letter are significant different at 5%, of probability level based on Tukey test

3.3.3 Unmarketable tuber yield

The study revealed that the main and interaction effect of PK were not significant affected the unmarketable tuber yield (table 3 &4). In harmony with this finding, Zelalem *et al* (2009) and Mulubrhan (2004) observed a non significant influence of P application on un marketable yield.

3.4 Effect of PK fertilizer rates on Nutrient use efficiency and Uptake

Fertilizer use efficiency (FUE) was significantly influenced due to the main effect of K and PK interaction but not with the main effect of P. Comparing the main effects the highest FUE (67.04 kg/kg) was obtained due to the main effect of K at the rate of K: 100Kg K_2O/ha (Table 5). The highest FUE (89.63kg/kg) was obtained due to interaction effect of P*K at the rate of P: 0 Kg P_2O_5/ha and K: 100 K_2O kg/ha. As the fertilizer rate of K increase FUE of potato increase significantly none consistently with the level of rate. Moreover FUE of potato increase none significantly as the level of P increase (Table5). There was a positive and significant correlation between FUE and the marketable tuber yield (r= 0.23*) (Table 5). In agreement to this study, Raza *et al* (2005) reported that optimum dose of PK in potato gave higher FUE as compared to half or double doses. In general the result found in this study was not clear, so it need farther research on the effect of PK on FUE. Total uptake of PK by potato tuber was significantly affected by both the main and interaction effect P and K fertilizer application but not uptake of N (Table 5). At the rate of P: 112kg/ha P_2O_5 the highest NP K uptake was recorded over the other treatments of PK and control with respect to the main effect. As P and K fertilizer rate increase the uptake of NPK increase (Table5). Furthermore, due to the interaction effect, the highest P tuber uptake was obtained due to the effect of PK fertilizer application at the rate of 87.3 Kg P_2O_5/ha and 50 kg K_2O and the highest uptake of K was obtained at the rate of 112 Kg P_2O_5/ha and 150 Kg K_2O/ha . In agreement to this study, Jenkins and Mahmood (2003) reported that the deficiency of an essential nutrient hinders the uptake of a well supplied. According to Abd El-Latif *et al* (2011), the extent of yield increase considerably dependent up on the uptake of N, P and K.

P and K concentration in potato tuber were significantly influenced due to the main effect of P and K fertilizer respectively but not P and K concentration due to fertilizer K and P respectively (Table5). There was a significant difference among the treatments in K (%) concentration due to the interaction effect of P and K fertilizer but not P and N concentration. The P and K concentration of the tubers increased with increasing the P and K levels. This indicated that there was difference in the nutrient concentration in tubers with the application of PK. In line to this, Zameer *et al* (2010) reported that the application of K increased the N, P and K concentrations in potato tuber. Similarly, Eleiwa *et al* (2012) reported that a higher content of N, P, and K in shoots and tubers were obtained by applying the highest NPK level.

Table 5. The main Effect of P and K fertilizer on fertilizer use efficiency, NPK uptake and concentration on tuber

Treatment	FUE	NPK Uptake of tuber kg/ha			NPK Concentration (%)		
		N	P	K	N	P	K
P_2O_5rates kg/ha							
0	50.56	8.2	17.19^{b}	17.64^{a}	0.22	0.125^{b}	12.54
67.3	51.99	10.9	10.17^{c}	24.45^{a}	0.21	0.122^{b}	12.34
89.7	64.28	20.1	24.22^{a}	33.33^{b}	0.21	0.145^{a}	12.56
112	50.82	20.7	28.91^{a}	35.35^{b}	0.23	0.147^{a}	13.20
LSD (P<0.05)	ns	ns	6.24	6.623	ns	0.010	ns
KO_2rates kg/ha							
O	37.03^{a}	13.2	14.28^{b}	21.61^{b}	0.21	0.122^{c}	11.74^{b}
50	65.38^{b}	15.6	18.08^{b}	29.97^{a}	0.21	0.131^{bc}	12.70^{a}
100	67.04^{b}	13.2	19.72^{b}	26.56^{ab}	0.22	0.138^{ab}	12.73^{a}
150	48.12^{a}	18	28.41^{a}	32.35^{a}	0.23	0.148^{a}	13.47^{a}
LSD (P<0.05(	15.198	ns	6.24	6.623	ns	0.010	0.875
CV(%)	33.5	62.0	37.2	28.7	17.5	8.5	8.3

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level = ns, and different letter are significant different at 5%, of probability level based on Tukey test

3.5 Effects of PK application on selected post harvest soil chemical properties

Analysis of the post harvest soil samples collected at the depth of 0 – 30 cm revealed that there was a significant difference among the treatments in soil pH, EC and CEC after harvest due to the main effect of P and K fertilizer. The interaction effect of P*K fertilizer affects significantly to CEC but not pH and EC. As the rate of P and K increase the pH value decreases significantly. In both fertilizers the value of pH is higher at the low level rate of fertilizer.

There were a significant difference among the treatments in available P and K after harvest in the soil due to the main effect of P and K fertilizer respectively. Available P and K was significantly influenced by the interaction effect of P*K fertilizer. Mg^{+2}, Ca^{+2}, Na^{+} and K^{+} were not significantly difference among the main and interaction effect treatments of PK fertilizer rates after harvest . With increasing the rates of application P and K fertilizer the soil EC was increased irrespective to the level. The post harvest soil pH and EC were higher than the pre-harvested, which justified that application of P and K increased soil pH and EC. Increasing the application of P and K fertilizer rates in the form of P_2O_5 Kg /ha and K_2O kg/ha increased the soil available PK, which indicated that application of PK increased soil fertility status or available P and K. The observed increment in soil available PK in response to the increased application of PK fertilizer could be explained by the fact that some of the applied PK in the soil has not been utilized by the plant and hence remained in the soil. In agreement to the present study, Salim *et al* (2009) reported that additional rates of NPK fertilization had a significant effect on soil N, P and K remained in the three soil layers after potato harvesting and application of NPK fertilizer as a combined form of increased the available soil N, P and K more than a single nutrient

Table 6. Correlation between the yield and yield components of potato

	P	K	TTY	TMY	NSPH	NTPP	AVTW	SG
Potassium(K)	0.0^{ns}							
Total tuber yield (TTY)	0.54***	0.14^{ns}						
Total Marketable Yield (TMY)	0.51***	0.19^{ns}	0.96***					
Number of stem per hill (NSPH)	0.41***	0.41*	0.60^{***}	0.56***				
Number of tuber per plant (NTPP)	0.77***	0.29*	0.72^{***}	0.70***	0.77***			
Average tuber weight(ATVTW)	0.29*	0.40*	0.76***	0.80***	0.41^{ns}	0.42^{*}		
Specific gravity (SG)	0.09^{ns}	-0.29^{*}	0.33^{**}	0.28^{ns}	-0.05^{ns}	-0.05^{ns}	-0.22^{ns}	
Nutrient use efficiency (FUE)	0.36*	-0.15^{ns}	0.23^{ns}	0.23*	0.25*	0.38^{**}	0.30^{*}	0.07^{ns}

Non significant (ns) at P < 0.05, Significant (*) at P< 0.05, highly significant (**) 0.01≤ P>0.001 and highly significant (***) P≤ 0.001

4. Conclusion and recommendation

It can be concluded that growth parameters, yield and yield components of potato were responded positively to PK fertilizers either applied as sole or in combination. The average tuber weight, marketable and total tuber yield was significantly affected by P and K fertilizer levels and their interaction. The highest tuber yield, average tuber weight, number of tubers per plant and number of stem per hill were obtained from application of a combined PK fertilizer at the rate of P:89.7 Kg P2O5/ha and K:100 Kg K_2O/ha. The effect of PK fertilizer on NPK uptake was dependent on the total tuber yield obtained. P application at the rate of 89.7 Kg P_2O_5/ha solely showed the highest fertilizer use efficiency compared to K alone and PK combination levels. Soil chemical properties such as CEC, EC, pH, Ca^{+2}, Mg^{+2}, and K^+ were positively affected by increased application of PK either solely or in combination. The optimum tuber yield and net income were obtained from the combined application of PK at the rate of 89.7 Kg P_2O_5/ha and 100 Kg K_2O/ha. Hence it is recommended that farmers should apply a combination of P and K at the rates of 89.7 Kg P_2O_5/ha and 100 kg K_2O/ha P and K respectively with 110 Kg N/ha to attain optimum tuber yield and yield component of potato in the study area and other similar areas..

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