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Influence of phosphorus and potassium fertilizers on growth and yield of potato (*Solanum tuberosum* L.) at Assosa, Benishangul Gumuz Regional State, Western Ethiopia

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Potato is one of the most important food security and cash crops in Ethiopia. It is constrained by poor soil fertility. A field experiment was conducted at Assosa Agricultural Research Centre to investigate the effect of phosphorus and potassium fertilizers on growth performance and yield of potato. The experiment was laid out as a randomized complete block design (RCBD) in 4×6 factorial arrangement of potassium (0, 100, 200 and 300 kg K_2O ha^{-1}) and phosphorus (0, 46, 92, 138, 184 and 230 kg P_2O_5 ha^{-1}) in three replicates. A potato variety, Gudanie (CIP-386423-13) was used. Analysis of the data revealed that the interaction effect of both phosphorus and potassium did not influence the phenotypic, growth parameters and tuber yields of potato, but their main effect is significant influence on days to 50% flowering, physiological maturity, plant height, marketable and total tuber yields, leaf area, above and underground dry biomasses. Optimum above and underground dry biomass (232.11 and 494.74 Mg* ha^{-1}), marketable (23.94 kg K_2O ha^{-1}) and total tuber (29.56 kg K_2O ha^{-1}) yields were attained at 200 kg K_2O ha^{-1}; for phosphorus, optimum marketable tuber (23.30 Mg ha^{-1}), total tuber (28.83 Mg ha^{-1}), and yield of above ground and underground dry matter (218.48 and 479.60 Mg ha^{-1}) were attained at 138 kg P_2O_5 ha^{-1}. The lowest yield obtained from above ground and underground dry matter, marketable and total tuber in both fertilizers were recorded at zero level.

Key words: Fertilizer rate, phenotypic parameter, plant height, biomass, tuber yield.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important food and cash crop in Eastern and Central Ethiopia. The food potential of the potato crop has been indicated in literature as being a cheap source of human diet. Potato produces 74.5% more food energy per unit area than wheat and 58% more than rice. Also it produces 54% more protein per acre than wheat and 77% more than rice (Thornton and Sieczka, 1980). It has relatively high carbohydrate and quality protein, and low fat content (FAO, 1980; Dean, 1994). Due to its shallow root system

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and short crop duration, the nutrient requirement of potato for growth and development is very high, especially due to its coarse roots and sparse root hairs, making potato inefficient in the uptake of phosphorus (Perrenoud, 1993; Nigussie-Dechassa et al., 2003). Unfortunately, P is one of the least accessible nutrients in most soil especially under tropical conditions where low P availability is a big challenge to agricultural production (Kochian et al., 2004). Phosphorus is present to some extent in all soils and unlike nitrogen it is held tightly by soil particles and therefore it is not easily leached from the soil (Carroll and Reiley*,* 2011).

On the other hand, uptake of fertilizer nutrients (NPK) by potato per unit area and time is quite high due to fast rate of early growth and tuber bulking (Singh, 1999). Potato is less efficient user of potassium than other crops (Trehan and Claassen, 2000). A potato crop of average yield in the tropics may remove 50-80 kg N ha^{-1}, 20-30 kg P_2O_5 ha^{-1} and 80-100 kg K_2O ha^{-1} from the soil (Sikka, 1982). The fertilizer use efficiency of K in potato ranges between 50 and 60% (Bansal and Trehan, 2011).

Many researchers reported that phosphorus application affects crop growth by increasing radiation interception (over the whole season) or by increasing light use efficiency (Plenet et al., 2000). Plants grown under low P level develop lower plant biomass due to either limited light interception or the amount of absorbed photosynthetically active radiation (PAR) (Colomb et al., 1995) to a less efficient conversion of the intercepted radiation (Plenet et al., 2000). The reduced total leaf area could be due to both reduced number of leaves and smaller individual leaf size. A decrease in number of leaves in P deficient plants can be ascribed to reduced leaf initiation and activity of the shoot meristems (Chiera et al., 2002). On the other hand, the reduced individual leaf size can be due to reduced cell division rate (Assuero et al., 2004) or reduced epidermal cell expansion (Radin and Eidenbock, 1984), which ultimately affect leaf expansion rate. Colomb et al. (2000) observed significantly lower final leave number in non-P treated plants than in P treated ones, which ultimately affected total plant leaf area. Likewise, many researchers reported that potassium application caused a significant increase in vegetative growth (Li-Xiu and Liu-Ya, 2003; Pauletti and Menarim, 2004). The vegetative growth gradually and significantly increased by increasing level of potassium application (Asmaa and Hafez, 2010).

Moreover, 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 (Getu, 1998; IAR, 2000). The P adsorption and fixation is influenced by soil pH, clay type and content, as well as the amount of iron and aluminium oxides (Mesifin, 1998). There is a claim that potassium is least deficient in Ethiopian soils and that the soils have good potassium supplying power (Tsedale, 1983, Tekalign and Haque, 1988). However, this claim may not apply to acidic soils (Brich, 1969; Atanasiu, 1970). The highly weathered soils have low exchangeable potassium (below 0.3 milliequivalents per 100 g of soil) (Murphy, 1963; Mesfin, 1998). Results from analysis of soils of Assosa Research Agricultural Center (AsARC) indicated very low available P and exchangeable potassium (0.85 ppm and 0.157 milliequivalents per 100 g, respectively). These values are very low according to Landon (1991) and Mengel and Kirkby (2001). In general, the soils in the south-western and western Ethiopia are acidic due to the high precipitation that leads to lose of basic cations by leaching (Mesfin, 1998). Thus, contrary to the general belief that most soils of Ethiopia are rich in potassium, this nutrient is likely limited in acidic soils due to high rate of leaching (Mengel and Kirkby, 2001).

Hence, in view of the fact that Ethiopian soils are poor in fertility and have problem of low soil pH, phosphorus fixation, and N and K leaching, and realizing the importance of fertilizers in potato production, the use of inorganic and organic fertilizers in potato production for optimum yield and quality tuber production is vital. This research is, therefore, aimed at investigating the effect of different rates of inorganic phosphorus and potassium fertilizers on the phenology, growth and yield of potato under Assosa condition.

MATERIALS AND METHODS

Experimental site

The experiment was carried out in the Benishangul Gumuz Region of Ethiopia at Assosa Agricultural Research Center, which is located at latitude of 10°02' N, longitude of 34°34' E and an altitude of about 1553 m above sea level. The area has a mean annual rainfall of 1100 mm. It has a warm humid climate with mean maximum and minimum annual temperatures of 32 and 17°C, respectively (AsARC, 2011). The soil of the area is Nitosol, which is characteristically reddish to brown in colour. It is acidic having a pH of 5.1 and silty in texture with contents of 49% silt, 17% sand, and 34% clay. The soil has organic matter content of 4.86%, and total nitrogen, available phosphorus and exchangeable potassium contents of 0.068%, 8.52 mg kg^{-1} soil and 0.136 cmol kg^{-1} soils, respectively, at 0-30 cm soil depth.

Experimental materials

Planting material

The potato variety called 'Gudanie' (CIP-386423-13) was used as a planting material which has wide-range environmental adaptation in Ethiopia. It requires up to 120 days for physiological maturity and considered moderately resistant to the late blight disease (Woldegiorgis et al., 2008).

Fertilizer material

Triple superphosphate (TSP) (46% P_2O_5) and potassium chloride (KCl) (60% K_2O) were used as sources of phosphorus and potash, respectively. Urea ($CO[NH_2]_2$) (46% N) was used as a source of nitrogen.

Treatments and experimental design

The treatments consisted of four levels of potassium (0, 100, 200 and 300 kg K_2O ha^{-1}), and six levels of phosphorus (0, 46, 92, 138, 184 and 230 kg P_2O_5 ha^{-1}). The basis for these levels was the pre-testing of the soil nutrient which was low in available phosphorus (8.52 ppm) and very low in exchangeable potassium (0.12 cmol kg^{-1} soil) according to Mengel and Kirkby (2001). The experiment was laid out as a randomized complete block design (RCBD) in a 4 × 6 factorial arrangement and replicated three times. There were 24 treatment combinations, which were assigned to each plot randomly. The total number of plots was 72 and each plot had a gross area of 11.25 m^2 with 3 m length and 3.75 m width. Each plot contained five rows of potato plants, with each row accommodating 10 plants per row with a total population of 50 plants per plot at the spacing of 0.75 m and 0.30 m between rows and plants, respectively. The spacing between plots and adjacent blocks was 1 m and 2 m, respectively.

Experimental procedures

Land preparation

The land was prepared in May to June 2011 using a tractor and human labour. Ridges on which to plant the tubers were constructed manually.

Planting

Medium-sized (40 to 60 g) and sufficiently sprouted potato tubers (with 2 to 3 cm long sprouts) were planted on ridges at the specified spacing on 08 July, 2011.

Fertilizer application

Application of phosphorus and potash fertilizers at the specified rates was done by banding the granules of the two fertilizers at the depth of 5 to 10 cm below and around the seed tuber at planting. All phosphorus was applied at planting while potash was applied in two splits [1/2 at emergence and 1/2 at mid-stage of the plant (at about 40 days after planting)] because of the problem of leaching caused by high rainfall. Nitrogen at the blanket recommended rate of 92 kg N ha^{-1} was applied to all plots equally in the form of urea in three splits [1/4th at planting, 1/2 at mid-stage of the plant (at about 40 days after planting), and 1/4th at the initiation of tubers (at the start of flowering)].

Other cultural practices

Weeds were controlled by hoeing. Earthing-up was done as required to prevent exposure of tubers to direct sunlight, to promote tuber bulking and to ease harvesting. Mancozeb ($C_8H_{12}MnN_4S_8Zn$), active ingredient of maneb and metiram (USEPA, 2005), was sprayed at the rate of 50 g per 20 L of water to control late blight disease.

Data collection

Data were recorded on different phenotypic and growth characteristics as well as yield of potato.

Crop phenotype

Days to 50% flowering was referred to the time required to attain 50% of the plant to flower while days to 50% physiological maturity was referred to the time required by the plant to reach the stage of growth when 50% of the vines started senescing. This was done when haulms (vines) of 50% of the plant population became yellow or the leaves senesced according to IBPGR descriptor list (IBPRG, 1977).

Plant growth parameters

Plant height (cm)

Plant height (cm) is the height from the base to the apex of the plant. It was determined by measuring the height of 20 randomly selected plants using a ruler from the central three rows at flowering.

Leaf area index (LAI)

Leaf area index (LAI) was obtained by dividing the value of the leaf area by the area of the land occupied by the plant using the following formula (Diwaker and Oswalt, 1992):

$$\text{Leaf area index (LAI)} = \frac{LA_m \text{ x } N}{A}$$

Where; LA_m = mean leaf area of the plant (cm^2); A = the area (cm^2) occupied by one plant in the cropping area; and N = number of leaves on the plant. To determine the total leaf area (cm^2), five plants (hills) from plot was randomly selected, tagged, and the leaf length (LL) (cm) of the individual plants at 20 days intervals measured. Individual leaf area (LA) of the potato plants (cm^2) was estimated from individual leaf length using the following formula developed by Firman and Allen (1989):

$$\log_{10}{}^{(LA)} = 2.06 \times \log_{10}{}^{(LL)} - 0.458$$

Total dry biomass (Mg ha^{-1})

Total dry biomass (Mg ha^{-1}) was referred to the dry weight of leaves, stems, roots, stolons, and tubers. It was determined from 10 randomly taken plants from the central rows just before senescence (at physiological maturity). Samples of dry weights were taken after air-drying and oven-drying the samples at 65°C till constant weight is obtained (CIP, 1984).

Tuber dry matter content (%)

Five fresh tubers were randomly selected from each plot and weighed. The tubers were then sliced and dried in an oven at 65°C until a constant weight was obtained and the dry weight was recorded. The dry matter percent was calculated according to the following formula (Williams and Woodbury, 1968):

$$\text{Dry matter (\%)} = \frac{\text{Wieght after drying (g)}}{\text{Initial weight (g)}} \text{ x } 100$$

Yield parameters

Marketable tuber yield (kg ha^{-1}) was the weight of tubers which are free from diseases, insect pests, and greater than or equal to 25 g

Table 1. Mean squares of potato phenology, growth parameters and yield components as influenced by phosphorus, potassium and their interaction.

Variable		**P**	**K**	**P x K**
Degree of freedom (d.f)		5	3	15
Phenological parameter	Days to 50% flowering	4.6**	71.2**	1.0^{Ns}
	Days to 50% physiological maturity	28.5**	566.9**	3.4^{Ns}
Growth parameter	Plant height (cm)	386.10**	941.83**	74.66^{Ns}
	Leaf area index	2.51Ns	25.90**	2.87^{Ns}
	Above ground dry biomass (Mg ha^{-1})	723.65*	26843.41**	1179.08^{Ns}
	Underground dry biomass (Mg ha^{-1})	21415.76*	108768.76**	11313.30^{Ns}
	Total dry biomass (Mg ha^{-1})	27381.16*	243102.38**	17602.55^{Ns}
Tuber yields	Marketable (Mg ha^{-1})	53.89**	166.37**	15.09^{Ns}
	Total (Mg ha^{-1})	60.94**	230.19**	19.36^{Ns}

**, *: Significant differences at 1 and 5% level of significance, respectively; Ns = non-significant at 5% level of significance; P = phosphorus (P_2O_5); K = potassium (K_2O).

in weight was recorded. Unmarketable tuber yield (kg ha^{-1}) includes the weight of tubers that are diseased and/or rotten and small-sized (less than 25 g in weight) were recorded. Total tuber yield (kg ha^{-1}) is the sum of tuber yield weights of marketable and unmarketable tubers.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) according to the Generalized Linear Model (GLM) of SAS version 9.0 (SAS Institute, 2004). Significant differences between treatment means were separated using the least significance difference (LSD) test at 5% significance level.

RESULTS

Influence of P and K on Phenological parameters

The analysis of variance for P and K interactive effect was non-significant while the main effect of phosphorus and potassium fertilizers showed highly significant difference ($P < 0.01$) on days to flowering and maturity (Tables 1 and 2). Increasing phosphorus application from nil to 92 kg P_2O_5 ha^{-1} prolonged the days required by the potato plants to attain 50% flowering by about 2.7%. Increasing the phosphate supply further to 184 and 230 kg P_2O_5 ha^{-1} further prolonged the days required by the potato plants to attain 50% flowering to about 2.9 and 3.3%, respectively, as compared to plants grown in the control treatment (Table 2). However, plants grown at the phosphate supply of 92 and 138 kg P_2O_5 ha^{-1} had values of days to 50% flowering that were in statistical parity (Table 2). Similarly, application of phosphorus fertilizer prolonged the time required by the potato crop to reach physiological maturity (Table 2). Thus, compared to plants that received no phosphorus fertilizer, plants that received phosphorus at the maximum rate of 230 kg ha^{-1} required about three more days (about 3%) to attain 50% physiological maturity. Even if 230 kg ha^{-1} delayed the 50% flowering to 3 days, the treatments that received beyond 46 kg ha^{-1} did not show statistical significant.

Application of potassium fertilizer linearly and highly significantly prolonged the days required to reach 50% flowering and physiological maturity. The days to 50% flowering was delayed by about 9% when the rate of potassium was increased from nil to 300 kg K_2O ha^{-1}. Similarly, the days for 50% physiological maturity were delayed by about 13.89% (about 14 days) in response to increasing the rate of potassium from nil to 300 kg K_2O ha^{-1} (Table 2).

Influence of P and K on growth parameters

Plant height

Phosphorus and potassium did not interact to influence plant height; however, it responded highly significantly (*P < 0.01*) to the main effects of phosphorus and potassium application rates (Tables 1 and 3). Plants grown in the control treatment were highly significantly shorter than plants grown at the rates of ≥ 92 kg P_2O_5 ha^{-1}. Increasing the rate of phosphorus from nil to $^{-}$to 92, 138, 184 and 230 kg P_2O_5 ha^{-1} resulted in highly significant increases in plant height (Table 3). However, the heights of plants grown in plots supplied with only 46 kg P_2O_5 ha^{-1} were in statistical parity with the heights of plants in the control treatment. Similarly, the plant height of potato was highly affected by the main effect of potassium application (Table 1); however, the application of potassium fertilizer above the rate 100 kg K_2O ha^{-1} did not respond statistically to plant height parameter (Table 3).

Table 2. Phenological parameters of potato as affected by phosphorus and potassium fertilizers application.

Treatment	Days to 50% flowering	Days to 50% physiological maturity
P_2O_5 (kg ha^{-1})		
0	52.3^{c}	99.0^{e}
46	53.1^{bc}	99.8^{de}
92	53.7^{ab}	100.6^{cd}
138	53.7^{ab}	101.3^{bc}
184	54.0^{a}	102.0^{ab}
230	53.8^{ab}	103.3^{a}
F-test	**	**
LSD (5%)	0.9	1.3
K_2O (kg ha^{-1})		
0	51.2^{d}	94.3^{d}
100	52.6^{c}	99.1^{c}
200	54.3^{b}	103.2^{b}
300	55.7^{a}	107.4^{a}
F-test	**	**
LSD (5%)	0.7	1.03
CV (%)	2.69	1.52

Means followed by the same letter within a column are not significantly different at 5% level of significance; ** = significant at P < 0.01 probability level; LSD = Least significant difference; CV = Coefficient of variation.

Table 3. Growth parameters of potato as influenced by phosphorus and potassium application at Assosa.

Treatment	Plant height (cm)	Leaf area index	Aboveground dry biomass (Mg ha^{-1})	Underground dry biomass (Mg ha^{-1})	Total dry biomass (Mg ha^{-1})
P_2O_5 (kg ha^{-1})					
0	56.56^{d}	3.80	162.77^{b}	346.41^{b}	509.18^{b}
46	61.04^{cd}	3.75	169.03^{b}	431.84^{ab}	600.87^{ab}
92	67.14^{ab}	3.67	177.18^{ab}	425.92^{ab}	603.09^{ab}
138	71.91^{a}	3.75	218.48^{a}	479.60^{a}	698.08^{a}
184	65.87^{bc}	3.92	212.90^{a}	477.18^{a}	690.08^{a}
230	69.66^{ab}	3.83	211.50^{a}	485.32^{a}	696.82^{a}
F-test	**	Ns	*	*	*
LSD (5%)	5.95	0.61	41.495	84.466	115
K_2O (kg ha^{-1})					
0	54.65^{b}	4.77^{c}	89.34^{c}	330.06^{c}	419.39^{c}
100	67.44^{a}	6.41^{b}	186.71^{b}	423.46^{b}	610.17^{b}
200	69.12^{a}	7.09^{ab}	232.11^{a}	494.74^{a}	726.86^{a}
300	70.25^{a}	7.48^{a}	259.75^{a}	515.91^{a}	775.66^{a}
F-test	**	**	**	**	**
LSD (5%)	4.87	0.84	33.88	68.97	93.90
CV (%)	11.07	19.44	22.72	25.34	22.93

Means of the same main effect followed by the same letter or with no superscript letter within a column are not significantly different at 5% level of significance; ** = significant at P < 0.01 probability level; * = significant at P < 0.05 probability level; Ns = non-significant at P < 0.05 probability level; LSD = Least significant difference; and CV = Coefficient of variation.

Leaf area index (LAI)

The analysis of variance of the influence of phosphorus and potassium on leaf area index (LAI) is shown in Table 1. Application of potassium highly significantly (P < 0.01) influenced LAI of potato while phosphorus fertilization and its interaction with potassium did not affect this parameter. Increasing potassium fertilization from nil to 100 kg increased leaf area index of the crop by about 34%. Further increased to 100 and 200 kg K_2O ha^{-1} increased the leaf area by about 49 and 57% as compared to that of the control. However, the leaf area index recorded at 100 and 200 kg K_2O ha^{-1} as well as that recorded at 200 and 300 kg K_2O ha^{-1} were in statistical parity (Table 3).

Dry biomass

The two nutrients did not interact to influence the dry aboveground biomass, underground as well as total biological dry mass of potato. However, the main effect of both phosphorus and potassium significantly ($P < 0.05$) and highly significantly ($P < 0.01$) affected all the aforementioned three parameters, respectively (Tables 1 and 3). Increasing the rate of phosphorus from 0 to 46 or 92 kg P_2O_5 ha^{-1} did not significantly change the aboveground dry biomass yield. However, when the rate of phosphate was further increased to 138 kg P_2O_5 ha^{-1}, the above ground dry biomass yield increased by about 34% but it did not respond to phosphorus fertilizer application beyond this level (Table 3). In case of underground dry biomass yield of potato, inconsistence increment of yield of dry biomass appeared as the application of phosphorus increases. All levels of phosphorus except the control had no statistically significance response on these parameters (Table 3). While in case of the influence of potassium, increasing the rate of potassium resulted in significantly increased aboveground, underground as well as total dry biomass yield of the crop even more vigorously than the increases recorded in response to phosphorus application. All treatments that received potassium fertilizer gave a significant better above-and underground biomass as well as total biomass compared to the control treatment; however, there was no significant biomass yield in treatments that received 200 and 300 kg K_2O ha^{-1}.

Influence of P and K on marketable and total tuber yields

The interaction of the phosphorus and potassium nutrients did not influence both marketable and total tuber yields. However, phosphorus highly significantly affected marketable and total tuber yields (Tables 1 and 4). Both marketable and total tuber yields obtained in the control treatment were highly significantly lower than those received rates of $\geq$ 46 kg P_2O_5 ha^{-1}, but the tuber yields did not respond statistically up to the level of 184 kg P_2O_5 ha^{-1}. Similarly, the main effect of potash significantly influenced marketable, as well as total tuber yields of potato (Tables 1 and 4). The lowest marketable and total tuber yields were also obtained from the control treatment of potassium. However, the application of potassium rate 100 and 200 kg K_2O ha^{-1} did not respond statistically to marketable tuber yield. Likewise, application beyond 200 kg K_2O ha^{-1} did not increase marketable and total tuber yields statistically (Table 4).

DISCUSSION

Influence of P and K on phenological parameters

Plants that received phosphorus prolonged the 50% flowering and physiological maturity of about 3%, as compared to plants that did not receive phosphorus fertilizer (Table 4). The longer duration required for flowering and maturity in response to the increased rates of phosphorus application could be ascribed to beneficial effect of phosphate fertilizer on growth which could be explained in terms of enhanced early canopy growth and increased radiation interception for photosynthesis (Jenkins and Ali, 1999). On the other hand, it might be the synergetic effect of phosphorus and potassium with the nitrogen uptake which enhanced the vegetative stage and hence, delayed flowering and maturity since its uptake was enhanced as the uptake of these nutrients increased. The result of this study is consistent with that of Zelalem et al. (2009) who observed that phosphorus fertilization significantly prolonged days required for flowering and to attain physiological maturity in potato. The observations of the current investigation, however, are in contrast to those of Kleinkopf et al. (1987) and Armstrong (1999) where phosphorus nutrient was reported to be associated with shortening maturity.

Application of potassium fertilizer linearly and highly significantly prolonged the days required to reach 50% flowering and physiological maturity. The longer duration required for maturity in response to the increased rates of potassium application could be ascribed to favourable growth conditions and less interplant competition at higher levels of potassium which may have prolonged the developmental stage for higher starch accumulation and partitioning to the tubers. This result coincides with that of Harris (1978) who noted that potassium application prolonged the leaf area duration and, thus the days required to reach physiological maturity.

Influence of P and K on growth parameters

Plant height

The result showed that potato plants grown at the rates of $\geq$ 92 kg P_2O_5 ha^{-1} had statistically longer height than the control. Increasing the rate of phosphorus from nil to 92, 138, 184, and 230 kg P_2O_5 ha^{-1} resulted in highly significant increases in plant height by about 19, 27, 16,

Table 4. Tuber yield parameters and harvest index of potato as influenced by phosphorus and potassium application at Assosa during the main cropping season in 2011.

Treatment	Marketable tuber yield (Mg ha^{-1})	Total tuber yield (Mg ha^{-1})
P_2O_5 (kg ha^{-1})		
0	18.83^{c}	23.32^{c}
46	22.51^{b}	26.63^{b}
92	21.70^{b}	26.31^{b}
138	23.30^{ab}	28.83^{ab}
184	23.00^{ab}	27.16^{ab}
230	25.24^{a}	29.80^{a}
F-test	**	**
LSD (5%)	2.36	2.65
K_2O (kg ha^{-1})		
0	18.17^{c}	22.06^{c}
100	22.47^{b}	26.71^{b}
200	23.94^{ab}	29.56^{a}
300	25.14^{a}	29.70^{a}
F-test	**	**
LSD (5%)	1.93	2.17
CV (%)	12.82	11.95

Means of the same main effect followed by the same letter within a column are not significantly different at 5% level of significance, DMRT test; ** = significant at $P < 0.01$ probability level; * = significant at $P < 0.05$ probability level; Ns = non-significant at $P < 0.05$ probability level; LSD = Least significant difference; CV = Coefficient of variation.

and 23%, respectively (Table 3). Similarly, the heights of plants grown in plots supplied with only 46 kg P_2O_5 ha^{-1} were in statistical parity with the heights of plants in the control treatment. This might indicate that phosphorus was still sub-optimal for growth of the plants to full height at this rate. However, the rates of phosphorus over 92 kg P_2O_5 ha^{-1} showed statistically parity in response to plant height. This indicates that the rate of phosphorus for growth of the potato plants to optimum height was 92 kg P_2O_5 ha^{-1}. The present finding agrees with that of Grewal et al. (1991) who reported that potato plant heights were positively related to phosphorus fertilizer applications in phosphorus deficient soils.

Similarly, application of potassium significantly enhanced the height of potato plant. When the rate of potash was increased from nil to 100 kg K_2O ha^{-1}, the plant height was increased by about 23%. However beyond the rate of 100 kg K_2O ha^{-1}, plant height was non-significantly affected (Table 3). This shows that potassium also contributes to increased cell division and elongation whereby it results in higher canopy development. This suggestion is in line with that of Marschner (1995) who reported that potassium results in enhanced cellular growth and development. The result of the present investigation is consistent with the findings of Asmaa and Hafez (2010) who noted that application of higher rates of potassium resulted in higher plant height of potato. In addition, Khandakhar et al. (2004) reported that application of potassium significantly increased plant height.

Leaf area index

The higher leaf area index obtained in response to increased potassium application could be attributed to enhanced growth of vegetative plant parts due to the simulative effect of the increased supply of the nutrient on assimilate synthesis and meristematic growth of tissues, which may have resulted in more number of leaves and higher leaf area indices. The leaf area index value obtained in this study is inconsistent with the suggestion of Marschner (1995) who stated that leaf area index of potato for optimum yield ranges between three and six. The results obtained from this study are in accord with those of Al-Moshileh et al. (2005) who reported that potassium is important for plant growth partly due to its effect on LAI and consequently light interception and dry matter production. The higher nutrient uptake right from early stage of crop growth was one of the reasons for improved vegetative growth at higher levels of potassium supply. However, some reports revealed that leaf area index was affected also by phosphorus (Yong-fu et al., 2006).

Dry biomass

Increasing the rate of phosphate from 0 to 46, and 92 kg

P_2O_5 ha^{-1} did not affect total dry biomass yield of the crop. However, increasing the rate of the nutrient from nil to 138 kg P_2O_5 ha^{-1} increased this parameter by about 37% (Table 3). Total dry biomass yield did not increase significantly beyond this level of the supply of the nutrient.The increase in dry matter production of the plant in response to phosphorus application could be attributed to increased radiation interception (over the whole season) or increased light use efficiency, and hence, increased canopy growth and increased water conductance of the plant that enhanced photoassimilation and production of dry matter. The results obtained in this experiment are in accord with that of Ali and Anjum (2004) who reported that increased phosphorus supply increased dry matter production in plants. Similarly, Soltanpour and Cole (1978) found that application of phosphorus fertilizers increased leaf, stem and tuber growth rates and, consequently dry matter and yields. Consistent with the results of this study, Ali and Anjum (2004) reported that higher rates of phosphorus application resulted in increased total dry weight and there was some evidence from ground cover scores that leaf senescence occurred earlier at higher phosphorus rates. Similarly, Zelalem et al. (2009) also reported that above and underground biomass yields increased significantly in response to the application of phosphorus fertilization. This may be attributed to enhanced interception of radiation and enhanced leaf expansion and photosynthesis especially during the early phase of growth.

Increasing the rate of potassium resulted in significantly increased aboveground, underground as well as total dry biomass yield of the crop even more vigorously than the increases recorded in response to phosphorus application. As increasing the rate of potash from 0 to 100 kg K_2O ha^{-1}, already significantly increased aboveground, underground, and total dry biomass yields by about 109, 28 and 45%, in the order cited. Similarly, increasing the rate of the nutrient from 100 to 200 kg K_2O ha^{-1} significantly further increased the aboveground, underground, and total dry biomass yields of the crop by about 24, 17, and 19%, respectively. Beyond this level of potash supply, no significant increases in all three parameters were recorded (Table 3). The increase in biological dry masses in response to the increased levels of potassium might be attributed to the fact that the nutrient enhanced growth of more vegetative parts including plant height, branches, total leaf area and production of more tubers through promoting enzymatic activities and enhancing the translocation of assimilates and protein synthesis as described by Devlin and Witham (1986). These results obtained in this study are in accord with those reported by Asmaa and Hafez (2010) who noted that a higher application of potassium resulted in higher biomass production in potato. Potassium increases leaf expansion particularly at early stages of growth, extends leaf area duration by delaying leaf shedding near maturity. It increases both the rate and duration of tuber bulking. Its application activates a carbohydrate metabolism and proteins and assists in the translocation of carbohydrates from leaves to tubers (Imas and Bansal, 1999).

Influence of P and K on marketable and total tuber yields

Increasing phosphorus application from nil to 46 kg P_2O_5 ha^{-1} significantly increased marketable tuber yield by about 20%. Increasing the rate of phosphorus further from 46 to 92, 138, and 184 kg P_2O_5 ha^{-1} did not affect marketable tuber yield. However, when the rate of phosphate was increased from 0 to 230 kg P_2O_5 ha^{-1}, marketable tuber yield increased by about 34%. Similarly, increasing the rate of phosphorus from nil to 46 kg P_2O_5 ha^{-1} significantly increased total tuber yield by about 14%. Increasing the rate of the nutrient from 46 to 92, 138, and 184 kg P_2O_5 ha^{-1} did not affect total tuber yield. However, when the rate was increased from 0 to 230 kg P_2O_5 ha^{-1}, total tuber yield increased by about 28%. In general, the result revealed that optimum marketable as well as total tuber yields were attained at 138 kg P_2O_5 ha^{-1} (Table 4). The marketable and total tuber yields increased in response to the application of phosphorus fertilizer possibly due to increased radiation interception and increased conversion efficiency. Corroborating this result, Zameer et al. (2010) showed significant increases in potato tuber yields in response to increased phosphorus application due to increased radiation interception rather than increased conversion efficiency. This is also in line with what Allison et al. (2001) suggested that the increased ground cover and radiation interception observed was the mechanism through which phosphorus fertilizer increased potato tuber yields.

Similarly, increasing the rate of potassium from 0 to 100 kg K_2O ha^{-1} increased marketable and total tuber yields by about 24 and 21%, respectively. Besides, further increasing the rate of the nutrient from 100 to 200 K_2O ha^{-1} increased both tuber yields by about 7 and 11%, respectively. Increasing the rate of the mineral fertilizer from 200 to 300 kg K_2O ha^{-1} did not change marketable and total tuber yields. In general, the amount of mineral potassium fertilizer that optimized marketable and total tuber yields amounted to 200 kg K_2O ha^{-1} (Table 4). The results of this study are corroborated by those of Al-Moshileh et al. (2005) who reported that marketable tuber yield increased significantly in response to increased potassium application rates. Besides, Khandakhar et al. (2004) and Asmaa and Hafez (2010) reported significant increments in yield due to potassium application. However, Mulubrhan (2004) and Zelalem et al. (2009) found that there was no significant increment in marketable as well as total tuber yields of potato in response to increasing the rate of potassium.

Conclusion

Both phosphorus and potassium affected the phonological parameters (days to flowering and days to maturity). The application of 184 kg P_2O_5 ha^{-1}, and 230 kg P_2O_5 ha^{-1} prolonged days to 50% flowering (by about 3%), and physiological maturity (by about 4%), respectively, as compared to the control while application of potassium at 300 kg K_2O ha^{-1} delayed the days required to reach 50% flowering by about 9% and physiological maturity by 13% (about 13 days) as compared to the days required by plants grown in the control treatment to reach the same stage of growth. However, phosphorus and potassium did not interact to influence these phenological parameters.

All growth parameters, plant height, leaf area index and biological dry mass were highly significantly affected by the main effect of potassium. The optimum plant height (67.44 cm) was recorded at the level of 100 kg K_2O ha^{-1}, leaf area (7.09), and above ground (232.12 Mg ha^{-1}), underground (494.74 Mg ha^{-1}) and total (726.86 Mg ha^{-1}) dry biomasses at the level of 200 kg K_2O ha^{-1}. Similarly, the main effect of phosphorus significantly influenced the plant height and the mentioned dry biomasses of potato. However, the main effect of phosphorus did not affect leaf area. Generally, the optimum plant height (67.14 cm), and above (218.48 Mg ha^{-1}), underground (479.60 Mg ha^{-1}) and total (698.08 Mg ha^{-1}) dry biomasses were recorded at the level of 138 kg P_2O_5 ha^{-1}. Moreover, phosphorus and potassium did not interact to affect these growth parameters.

Application of both of these fertilizers also highly significantly influenced the marketable and total tuber yields and their application beyond 138 kg P_2O_5 ha^{-1} and 200 kg K_2O ha^{-1} had non-significant increment on tuber yield. Generally, in response to phosphorus, the optimum marketable (23.30 Mg ha^{-1}) and total tuber (28.83 Mg ha^{-1}) yields were attained at the level of 138 kg P_2O_5 ha^{-1} while in case of potassium the optimum marketable (23.94 Mg ha^{-1}) and total tuber (29.56 Mg ha^{-1}) yields were attained at the application of 200 kg K_2O ha^{-1}.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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