Influence of Mineral Nitrogen and Potassium Fertilizers on Ware and Seed Potato Production on Alluvial Soil in Eastern Ethiopia

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Abstract: Potato (*Solanum tuberosum* L.) is an important food security and cash crop in Ethiopia. However, the yield of the crop is low in the country due to a number of factors among which poor soil fertility management is a major one. Therefore, a field experiment was conducted on the main campus of Haramaya University in the 2009/10 cropping season to elucidate the effect of mineral nitrogen and potassium fertilizers on growth and tuber production of the crop. The treatments consisted of five rates of nitrogen (0, 50,100,150, and 200 kg N ha^{-1}) and three rates of potassium (0, 100, and 200 kg K_2O ha^{-1}). The experiment was laid out as a randomized complete block design in a factorial arrangement and replicated three times per treatment. The results of the experiment revealed that nitrogen had significant main effects on all parameters except tuber specific gravity whilst potassium did not influence any of the parameters studied. The maximum marketable ware potato tuber yield (21.4 t ha^{-1}) was obtained in response to the application of 100 kg N ha^{-1}. However, the highest yield (12.7 t ha^{-1}) and number (5.2 tubers $hill^{-1}$) of medium-sized tubers, which are appropriate for planting as seed, were attained at the rate of 200 kg N ha^{-1}. Thus, it could be concluded that the rate of nitrogen fertilizer required to enhance seed tuber production was found to be higher than that required to optimize ware potato production, and potassium application was not necessary to produce the crop.

Keywords: Soil properties; *Solanum Tuberosum* L.; Tuber number; Tuber Size Distribution; Tuber Yield

1. Introduction

Potato (*Solanum tuberosum* L.) is important for household food security and income generation for smallholder farmers in Ethiopia (Gildemacher *et al*., 2009; Abebe *et al*., 2010). However, the annual production of the crop in the country is low (about 525,657 t) (FAOSTAT, 2010). The national average yield of the crop in the country ranges only between 8 to 10 t ha^{-1} (Haverkort *et al*., 2012). There are several causes for the low yield of the crop in the country among which depleting soil fertility, poor agronomic practices, and diseases and pests are the main ones (Gildemacher *et al*., 2009).

A non-site-specific generic (blanket) recommendation of 111 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1} [(165 kg urea and 195 kg diammonium phosphate (DAP) ha^{-1}] has been promoted for potato production in Ethiopia for a long time (EIAR, 2004). There are also no any site-specific mineral and organic fertilizer recommendations to optimize the yield of the crop. Consequently, like most smallholder farmers in other sub-Saharan African countries, farmers in Ethiopia use low rates of fertilizers for producing crops possibly due to prohibitively high prices (Bekunda *et al*., 2010). They also apply low amounts of organic fertilizers owing to competing needs such as the use of cow dung and crop residues as a source of energy for cooking, construction, animal feed etc (Morris *et al*., 2007; Wogi *et al*., 2015). The application of low rates of fertilizers in sub-Saharan Africa may also be attributed to lack of knowledge as to which kinds and rates of fertilizers are recommended for the specific crops, soils, and agro-climatic conditions (Vlek, 1990).

Gildemacher *et al.* (2009) reported that the amounts of FYM, nitrogen, and phosphorus applied to the potato crop by smallholder potato farmers in the central highlands of Ethiopia averaged only 3.0 t ha^{-1}, 30.6 kg N ha^{-1}, and 33.4 kg P (76 kg P_2O_5) ha^{-1}, respectively. This indicates that potatoes are grown in the country under sub-optimal rates of nitrogen and phosphorus application. Therefore, nutrient deficiencies are very common in potato production in the country due to application of no or low rates of fertilizers including manure by potato farmers (Gildemacher *et al*., 2009; Haverkort *et al*., 2012).

Potato is a heavy feeder of potassium, nitrogen, and phosphorus. Potassium and nitrogen are found in the largest amounts in a potato plant, followed by Calcium (Ca) and Magnesium (Mg) (Westermann, 2005). On the other hand, the low root nutrient uptake efficiency of the crop (Perrenoud, 1983; Dechassa *et al*., 2003) may exacerbate the problem of nutrient deficiencies in potato production. Therefore, ample application of fertilizers containing the major plant nutrients (N, P, and K) is required to obtain sufficient yield of the crop. Nitrogen and phosphorus are deficient in most areas of Ethiopia (Murphy, 1968). Research done on fertilizer requirements of potato on major soils of Eastern Hararghe Zone revealed significant effects of nitrogen and phosphorus on the yield of the crop. Beyene (1998) reported that application of 87 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1} was required for optimum yield of the

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potato crop on black soil in Haramaya district in eastern Ethiopia. Zelalem *et al.* (2009) reported that application of 138 kg N and 46 kg P_2O_5 ha^{-1} was necessary for obtaining optimum yield of potato on black soil of Debre Berhan in central Ethiopia. Balanced nutrient application is also important in crop production. For example, without application of phosphate and potassium, the yield response to increasing levels of nitrogen is smaller than when adequate amounts of P and K were applied (Mengel *et al.*, 2001).

The other major constraint to increased potato production is lack of good quality seed tubers. Agronomic practices of a seed potato crop are different from those of ware potatoes. Seed tuber production should be aimed at a high rate of multiplication, high yield of seed-sized tubers, and maintenance of healthy seed tubers that have optimum physiological quality (Lung'aho *et al.*, 2007).

Since potato is propagated vegetatively mostly using seed tubers, the quantity of planting material (tubers) required to plant a unit area of land is important. Therefore, it is not only the total tuber yield that matters in seed tuber production but also the size as well as the number of tubers produced. Small tubers have fewer eyes and produce only a few stems and larger tubers whilst large tubers have many eyes and produce a number of stems that would produce too many tubers, which may grow under stiffer competition for growth factors and become too small and unmarketable for use as either ware or seed potato. Besides, large tubers are too bulky and uneconomical to use as seed or to transport. Therefore, the best seed tubers are the ones that are medium-sized (39-75 g) (Lung'aho *et al.*, 2007). Fertilizer application may affect tuber size distribution of potato (Rosen and Bierman, 2008), and may influence ware as well as seed tuber production.

This study was, therefore, initiated with the objective of elucidating the effect of applying mineral nitrogen and potassium fertilizers on ware and seed potato production.

2. Materials and Methods

2.1. Description of the Experimental Site

The experiment was conducted at the crop research field on the main campus of Haramaya University. The site is located at 9°24'N latitude and 42°03'E longitude. The altitude of the site is 2006 meters above sea level. The site has a bimodal rainfall distribution and is representative of a sub-humid mid altitude agro-climatic zone. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October and accounts for about 45% of the total rainfall (Belay *et al.*, 1998). The mean annual rainfall and temperature are 760 mm and 17°C, respectively. However, during this cropping season, the mean monthly maximum and minimum temperatures and rainfall at the experimental area (July to November) were 23.72°C, 10.6°C, and 105.46 mm, respectively. Thus, the rainfall was particularly low during this period. During the previous cropping season, wheat was grown at the site. The trial was conducted under rain-fed condition. The soil of the experimental site is an alluvial deposit with sandy loam texture.

2.2. Materials Used in the Experiment

Plan Material

A potato variety named Badhasa was used as a planting material. The variety was released by Haramaya University in 2001, and is being grown as one of the improved potato varieties in eastern Ethiopia. It is a variety that requires about 90 to 100 days to mature.

Fertilizer Material

Urea (CO ($[NH_2]_2$) (46% N) and potassium sulphate (K_2SO_4) (52% K_2O) were used as sources of nitrogen and potassium, respectively. Tri-superphosphate ($CaH_2PO_4)_2$, which constitutes 46% P_2O_5, was used as a source of phosphate.

2.3. Treatments, Experimental Design, and Procedures

The treatments consisted of five rates of nitrogen (0, 50, 100, 150, and 200 kg N ha^{-1}) and three rates of potassium (0, 100, and 200 kg K_2O ha^{-1}). The experiment was laid out as randomized complete block design in a factorial arrangement and replicated three times per treatment. The size of a plot was 4.5 m x 3.6 m (16.2 m^2). A distance of 1 m between plots and 2 m between blocks was kept.

On 23 July 2010, uniform and medium-sized (39-75 g) tubers of the test variety with sprout lengths of 1.5 to 2.5 cm (Lung'aho *et al.,* 2007) were planted on ridges with inter-and intra-row spacing of 75 cm and 30 cm, respectively. Plants in the border row at each side of a plot and one plant at the end of each row were left out from data recording to avoid edge effects. The entire rates of potassium and 1/3rd of the rate of nitrogen fertilizer were applied at the time of planting in the form of potassium sulphate (52% K_2O) and urea (46%N), respectively, according to the specified treatments. The remaining N fertilizer was applied in two equal splits 38 days after planting and at the start of flowering of the plant. Phosphorus was applied uniformly to all plots as triple super phosphate at the rate of 46% kg P_2O_5 at the time of planting.

All the recommended cultural practices were followed to raise the crop. Harvesting was done at physiological maturity. However, before harvesting, the haulms of the potato plants were mowed 15 days earlier to toughen the tuber periderm so as to pre-empt the likelihood of bruising and skinning during harvesting. For determining certain yield components and growth parameters plant samples were taken randomly from the middle rows. To determine tuber yield, the entire plants were harvested from the middle rows on 23 December 2010.

2.4. Soil Sampling and Analysis

Soil samples were taken randomly in a W-shaped pattern from the entire experimental field. The samples were composited and replicated three times for determining physico-chemical properties.

The soil was air-dried and sieved through a 2 mm sieve. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Page, 1982). Texture of the soil was determined by the sedimentation method. Organic carbon was determined by the method of Walkley and Black (1934). Total nitrogen was determined using the Kjeldhal method (Jackson, 1975). Available phosphorus was determined by extraction with 0.5 M $NaHCO_3$ according to the methods of Olsen *et al.* (1954). Exchangeable potassium was extracted with 1 N ammonium acetate according to Hesse (1971) and determined using a flame photometer. Sulphur content of the extract was measured by the turbidmetric method as described by Okalebo *et al.* (2002) using a spectrophotometer.

2.5.Data Collection and Measurement

Data on total biomass were determined from 10 plants randomly sampled from each plot just at physiological maturity. Shoot dry mass was determined by oven-drying the fresh shoot biomass at 65 ^{0}C to a constant weight. Harvest index was determined as the ratio of fresh tuber mass to the fresh biomass yield at physiological maturity. Specific gravity of tubers (g cm^{-3}) was determined by the weight in air /weight in water method (Kleinkopf *et al.*, 1987). Seed tuber categories were identified as small (< 39 g); medium (39-75 g); and large (>75 g) (Lung'aho *et al.*, 2007). A healthy tuber weighing more than 20 g was considered marketable while rotten, diseased, insect-attacked, shrivelled, and deformed tubers and those having undersized tubers (less than 20 g) were categorized as unmarketable. Total tuber yields and numbers were recorded as the sum of marketable and unmarketable tuber yields and numbers, respectively. Medium-sized potato tubers (39-75 g) were categorized as seed tubers. To determine the tuber dry matter content (%), five potato tubers were randomly selected from each plot, chopped into small 1-2 cm cubes, mixed thoroughly, and two fresh sub-samples each weighing 200 g were weighed. Each sub-sample was placed in a paper bag and put in an oven until a constant dry weight was attained at 70^{o}C. Each sub-sample was immediately weighed and the mean recorded as dry weight. Percent dry matter content for each sub-sample was calculated based on the formula described by Bonierbale *et al.* (2006).

$$\text{Dry matter (\%)} = \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100$$

2.6. Data Analysis

The data were subjected to analysis of variance using SAS statistical software (SAS, 2002) version 9.1. All significant pairs of treatment means were compared using the Least Significant Difference (LSD) test at 5% level of significance.

3. Results and Discussion

3.1. Physico-Chemical Properties of the Experimental Soil

The results of the soil analysis before planting are shown in Table 1. The textural analysis showed that the soil is sandy loam. The cation exchange capacity (CEC) of the soil is high according to the rating of Landon (1991). Therefore, there could be no limitation to the growth of the potato crop in terms of this soil chemical property. The pH of the experimental soil is moderately alkaline according to the rating of Murphy (1968) and that of Tekalign Tadese (1991). Potatoes can grow under a wide range of soil pH varying from neutral to alkaline reaction (Jadhav and Kadam, 1998; Fageria, 2011). However, the optimum soil pH for growing the crop ranges from 5.0 – 6.5 (Brown and McLean, 1984), which varies from very strongly acidic to slightly acidic reaction. This shows that the study site is stressful for potato growth due to the high soil pH. High soil pH has unfavourable effect on availability of nutrients such as phosphorus, which becomes precipitated in the form of calcium and magnesium phosphates (Holford, 1997). Alkaline soils also favour potato skin diseases such as common scab (*Streptomyces scabies*) (Jadhav and Kadam, 1998). Therefore, both potato yield and quality are likely to be negatively affected by the moderate alkalinity of the soil in the study area.

The organic carbon content of the soil is low according to the rating of Tekalign Tadese (1991), who categorized soil organic carbon contents of below 0.5, 0.5-1.5, 1.5-3.0, and >3.0% as very low, low, medium, and high, in the order mentioned here. Murphy (1968) categorized total soil nitrogen contents of below 0.10, 0.10-0.15, 0.15-0.25, and >0.25% as low, medium, high, and very high, respectively and Tekalign Tadese (1991) similarly categorized total soil nitrogen contents of below 0.05, 0.05-0.12, 0.12-0.25, and >0.25% as low, medium, high, and very high. Accordingly, the total nitrogen content of the experimental soil is medium. This shows that the soil is moderate in supplying nitrogen through mineralization during the cropping season for uptake by crops (Murage *et al.*, 2000). This signifies that external application of nitrogen and organic fertilizer is important for enhancing the fertility of the soil and yield of the crop. The available phosphorus content of the soil is high in accordance with the rating of Cottenie (1980) and Holford and Cullis (1985), who categorized available Olsen phosphorus contents of below 5, 5-10, 10-17, 17-25, and > 25 mg kg $soil^{-1}$ as very low, low, medium, high, and very high in the order listed here. This shows that application of phosphorus fertilizer is not required as a regular fertilizer practice but just to replace offtake of the nutrient in the harvested potato crop (DEFRA, 2009). Landon (1991), FAO (2006), and Hazelton and Murphy (2007) categorized exchangeable soil potassium contents of 0 - 02, 0.2 - 0.3. 0.3 - 0.7, 0.7 - 2.0, and > 2.0 $cmol_c$ kg $soil^{-1}$ as very low, low, medium, high, and very high. In accordance to these categories, the exchangeable potassium content of the experimental soil is almost in the high category. This means that potassium fertilizer is not be required at least in the short-term. However, in the long term, mineral and/or organic fertilizers containing potassium may be required due to possible depletion as a result of continuous cropping (Sarkar, 2014). According to the rating of Bashour (2007), sulphate sulphur ranging from 0 -10, 10-20, 20-35, 35-45, and > 45 mg kg $soil^{-1}$ is very low, low, medium, high, and very high, respectively, for availability to plants. Therefore, sulphate sulphur content of the experimental soil is high. Thus, there seems to be no requirement for application of sulphur from an external source.

Table 1. Mean values of the physico-chemical properties of the experimental soil on the campus of Haramaya University, Ethiopia.

pH_{-water}	CEC	Total N	OC	SO_4-S	Exchangeable K	Available P	Soil texture		
	($cmol_c$ kg $soil^{-1}$)	(%)	(%)	(mg kg $soil^{-1}$)	($cmol_c$ kg $soil^{-1}$)	(mg kg $soil^{-1}$)	Clay (%)	Silt (%)	Sand (%)
8.0	27.0	0.11	1.15	35.2	0.65	18.2	17.44	19.64	69.92

CEC = Cation exchange capacity; OC = Organic carbon; K = Potassium; N = Nitrogen; P = Phosphorus.

3.2. Effect of Nitrogen and Potassium on Total Biomass

The main effect of nitrogen significantly influenced total dry biomass yield of the crop, but not its harvest index (Table 2). However, potassium application did not affect these parameters. The increase in total biomass yield continued up to the highest level of N (200 kg N ha^{-1}) which was higher than the biomass yield obtained from plants in the control treatment by about 31%. This result is in conformity with the findings of Millard and Marshall (1986) who reported a significant increment in canopy dry matter yield of potato in response to increased nitrogen application. On the other hand, neither the main effect of nitrogen nor that of potassium had a significant influence on harvest index. Consistent with this result, Zelalem *et al.* (2009) also reported that nitrogen had no significant influence on harvest index of potato.

Table 2. Main effects of nitrogen and potassium on total biomass and harvest index of potato at Haramaya University during the 2009/10 cropping season.

Treatment	Parameter	
	Total Biomass (g $hill^{-1}$)	Harvest index
Nitrogen (kg N ha^{-1})		
0	658.72^{c}	0.78
50	683.89^{bc}	0.77
100	745.33^{b}	0.79
150	701.44^{bc}	0.78
200	864.07^{a}	0.78
F-test	***	ns
Potassium (kg K_2O ha^{-1})		
0	719.71	0.78
100	724.29	0.79
200	748.07	0.77
F-test	ns	ns
CV(%)	10.90	4.43

*Means sharing the same letter within a column are not significantly different at 5% level of significance; *** = significant at 0.001 probability level; ns = non-significant at 5% probability level; CV= coefficient of variation.*

3.3. Effect of Nitrogen and Potassium on Tuber Yields

Both the total and marketable tuber yields increased significantly ($P < 0.01$) in response to the increase in the rate of nitrogen application. However, both yields did not increase in response to increasing the rate of nitrogen beyond 100 kg ha^{-1} (Table 3). The total and marketable tuber yields of plants treated with 100 kg N ha^{-1} exceeded the total and marketable tuber yields of plants not supplied with nitrogen by about 33 and 26%, respectively. These increments were 19 and 35%, respectively, over plants treated with 50 kg N ha^{-1}. Corroborating these results, Mulubrhan (2005) and Zelalem (2009) reported highly significant increases in total tuber yield in response to increased levels of nitrogen application.

Both the total and marketable tuber numbers increased significantly (P < 0.05) with the increase in the rate of nitrogen application. However, similar to the tuber yields, the increase in the tuber number in response to the increase in the rate of nitrogen application occurred only up to 100 kg N ha^{-1}. Thus, increasing the rate of nitrogen application from nil and 50 kg N ha^{-1} to 100 kg N ha^{-1} increased total tuber number by about 26 and 12%, respectively. Similarly, increasing the rate of nitrogen application from nil and 50 kg N ha^{-1} to 100 kg N ha^{-1} increased marketable tuber number by about 92 and 30%, respectively. In agreement with this finding, Sharifi (2005) reported a significant increase in tuber numbers in response increased rates of nitrogen application. Similarly, Jenkins and Mahamood (2003) observed that the number of tubers varied considerably as a result of N fertilization, and doubled when the rate of nitrogen was increased to higher levels. Consistent with the results of this study, Zelalem *et al.* (2009) also reported that total tuber yield was strongly associated with average tuber weight and total tuber number signifying that the increase in both tuber number and size substantially contributed to increased tuber yields. Concordant with this result, Kanzikwera *et al.* (2001) also reported that the number of tubers per plant and mean fresh tuber weight increased as a result of nitrogen application. In contrast, however, there are reports demonstrating the absence of strong relationship between rates of nitrogen application and tuber number in potato (Sharma and Arora, 1987).

The lack of response of the potato crop to the increased application of nitrogen from nil to 150 and 200 kg N ha^{-1} in terms of tuber production implies that higher rates of nitrogen than required by the plant may lead to growth of more shoot at the expense of tubers (Sommerfeld and Knutson, 1965). This result indicates that increasing N fertilizer more than 100 kg N ha^{-1} would be wasteful for ware potato production

Table 3. Main effects of nitrogen and potassium on potato tuber yield and number at Haramaya University during the 2009/10 cropping season.

Treatment	Parameter					
	Total tuber Yield (t ha^{-1})	Total tuber (No. plant^{-1})	Marketable tuber yield (t ha^{-1})	Marketable tuber (No .plant^{-1})	Unmarketable tuber yield (t ha^{-1})	Unmarketable tuber (No. plant^{-1})
Nitogen (kg N ha^{-1})						
0	17.60^{c}	9.75^{b}	14.08^{b}	3.96^{b}	3.52^{a}	5.79^{a}
50	19.80^{bc}	10.96^{b}	15.84^{b}	5.86^{b}	3.96^{a}	5.10^{ab}
100	23.48^{a}	12.25^{a}	21.35^{a}	7.61^{a}	2.13^{b}	4.64^{b}
150	22.64^{ab}	11.52^{a}	20.48^{a}	7.30^{a}	2.16^{b}	4.22^{b}
200	21.98^{ab}	11.98^{a}	19.78^{a}	7.02^{ab}	2.20^{b}	4.96^{b}
F-test	**	*	**	*	*	*
Potassium (kg K_2O ha^{-1})						
0	20.33	10.87	15.99	6.23	4.34	4.64
100	21.13	10.82	16.60	6.27	4.53	4.55
200	21.87	11.42	16.89	6.06	4.98	5.36
F-test	ns	ns	ns	ns	ns	ns
CV(%)	16.74	9.26	21.27	23.26	29.94	18.84

*Means sharing the same letter within a column are not significantly different at 5% level of significance; ** = significant at 0.01 probability level; * = significant at 0.05 probability level; ns = non-significant at 5% probability level; CV= coefficient of variation; No. = number.*

The increase in the marketable tuber weight and number in response to the increased application of nitrogen could be attributed to the effect of the nutrient on enhancing leaf growth and leaf surface area. This would enhance the interception of photosynthetically active radiation by the leaves for production of carbohydrate, which would ultimately be partitioned to tubers. In line with this argument, Wilcox and Hoff (1970) reported that the positive effect of N fertilizer on potato growth and yield was rooted in its impact on promoting the number of tubers produced per plant, the average weight of tubers, and the establishment of optimum leaf area index and leaf area duration. In the present study, increasing the rate of nitrogen beyond 100 kg N ha^{-1} did not result in significant increases in total and marketable tuber yields. Reduction in yield due to supra-optimal N application could be ascribed to the phenomenon that extra N application often stimulates shoot growth at the expense of tuber initiation and bulking (Sommerfeld and Knutson, 1965). In agreement with this suggestion, Krauss and Marschner

(1971) reported that a larger and continuous supply of nitrogen to potatoes delays or even prevents tuberization.

In contrast to the total and unmarketable tuber yields and numbers, however, increasing the rate of nitrogen application decreased unmarketable tuber yields and numbers significantly ($P < 0.01$) (Table 3). However, the significant decrease occurred only up to 100 kg N ha^{-1}. Thus, from 100 kg N ha^{-1} onwards, the unmarketable tuber yields and numbers were all lower and in statistical parity. The higher unmarketable tuber yields and numbers at nil and 50 kg N ha^{-1} may be attributed to nitrogen deficiency, which often leads to poor growth and photosynthesis for accumulation of sufficient starch for tuber bulking.

Although unmarketable tubers may be controlled more importantly through manipulating other factors such as disease and insect-pest incidence, in this study, harvesting practice, etc. rather than mineral nutrition (Berga *et al.* 1994), nitrogen deficiency may have contributed to the development of at least very small tubers due to scarcity of photoassimilates for tuber enlargement and bulking.Thus, N deficiency may have enhanced the unmarketable tuber numbers and yield at the lowest and marginal levels of N supply. Therefore, it could be suggested that marketability of potato tubers could be improved through enhanced nitrogen application as well as disease and pest control.

In the present study, applying 100 kg N ha^{-1} resulted in optimum total tuber yield, marketable tuber yield, total tuber number, and marketable tuber number. Conversely, the markedly low unmarketable tuber yield and number obtained at 100 kg N ha^{-1} signify the superiority of this level of nitrogen for the production of optimum fresh potato tuber yield. The vigorous response of potato yield to nitrogen application could be attributed to the low native soil N, which is associated with the very low content of organic carbon and total nitrogen (Landon, 1991; Murage *et al*., 2000). Under low organic carbon content of the soil, there is little nitrogen that may become available to plants in the form of nitrate or ammonium through mineralization during the growing season. In addition, nitrogen is lost through leaching during wet seasons and its deficiency would become severe (Mengel *et al.* 2001).

Potassium had no significant effect on any of the above-mentioned tuber characteristics (Tables 2, 3, 4, 5). It had also no significant interaction effect with nitrogen. Lack of response of potato to potassium application in terms of the aforementioned tuber characteristics is consistent also with the results of Mulubrhan (2005) who found a non-significant influence of the nutrient on potato tuber yields and yield components on pellic Vertisols of Mekelle in northern Ethiopia.

The average value of exchangeable potassium of the experimental soil just before conducting the experiment was found to be 0.65 $cmol_c$ kg $soil^{-1}$, which is equivalent to about 255 mg kg soil-1. This level of exchangeable potassium in the soil is sufficiently available for uptake by plants (FAO, 2006; Hazelton and Murphy, 2007) and may have led to the lack of response from the potato crop to the external application of the nutrient. This may also confirm the earlier report of Murphy (1968) which indicates that most soils in eastern Ethiopia have sufficient levels of available potassium for crop production.

3.4. Effect of Nitrogen and Potassium on Tuber Size Distribution

Yield of small-sized tubers decreased in response to increasing the rate of nitrogen application (Table 4). The results revealed a significantly lower yield of small-sized tubers at 200 kg N ha^{-1} than at 0, 50, and 100 kg N ha^{-1}.For example, the yield of small-sized tubers obtained from plants in the control treatment exceeded the yield obtained at the highest rate of N by about 35%.

Increasing the rate of nitrogen application also affected the number of small-sized tubers although the trend of increase or decrease in response to application of the fertilizer was not consistent. The smallest numbers of small-sized tubers were obtained at nil and 200 kg N ha^{-1}. For example, the number of small-sized tubers obtained at 50 kg N ha^{-1} was significantly higher than the number obtained at 200 kg N ha^{-1} by about 34.85%. The significant reduction in the number of small-sized tubers at the highest level of N supply may have evidently occurred at the expense of production of increased number and yield of large-sized tubers.

The yield and number of medium-sized tubers were significantly higher at 200 kg N ha^{-1} than at the other nitrogen rates. The increments in yield and number of medium-sized tubers in response to increasing the fertilizer from nil to at 200 kg N ha^{-1} amounted to 58% and 76%, respectively.

In line with the present results, Mulubrhan (2005) reported that higher rates of nitrogen (165 kg ha^{-1}) produced a significantly higher number of medium-sized tubers than the other tuber size categories.

Thus, the results of this study have revealed that cultivating potato by applying 200 kg N ha^{-1} on the experimental soil would yield a quantity of seed potato tubers that could plant over half more area of land (53%) than the quantity obtained at 100 kg N ha^{-1}.

The number and yield of large-sized tubers increased highly significantly ($P < 0.01$) at 100 and 150 kg N ha^{-1}, but decreased at the highest rate of nitrogen supply (200 kg N ha^{-1}) (Table 4). The increments in the yield of large-sized tubers at 100 and 150 kg N ha^{-1} were 101% and 119%, respectively, compared to the yields of large-sized tubers attained in the control treatment. Concurrent with this result, Rosen and Bierman (2008) reported that increased rates of phosphorus application significantly decreased the proportion of large and medium-sized tubers whilst increasing the proportion of small-sized tubers.In contrast to this result, however, Reddy and Rao (1968) and Sharma and Arora (1987) reported that increased application of nitrogen and potassium increased the proportion of medium and large-sized tubers. Similarly, Sharma and Arora (1987) observed decreased number of small (less than 25 g), increased number of medium (25-75 g) and large (above 75 g) grade tubers with increase in the rate of nitrogen application from 0 to 250 kg N ha^{-1}.

Emergence, seedling vigour, subsequent plant growth and final yield are affected by seed tuber size. Although all sizes of seed potatoes can grow into a crop, seed growers should only plant tubers ranging from 39 to 75 g. Such tuber sizes produce optimum stem number (25-30 m^{-2}) since they have optimum number of eyes and lead to high yield. Since basic seed tubers are sold on a weight basis, planting large tubers (> 75 g) is usually expensive as more of them are required to plant a unit area. In addition, large tubers are also bulky to transport and handle during planting. On the other hand, small tubers have small number of buds and give rise to small number of stems resulting in lower vigour and yields. Therefore, potato seed producers should aim at producing medium-sized tubers (Lung'aho *et al.*, 2007). In this experiment, the highest number of medium-sized tubers was obtained at 200 kg N ha^{-1}. Therefore, for the purpose of seed tuber production, the rate of N fertilizer application should be about twice as much as the rate required for ware potato production. It can, thus, be suggested that production of seed potato or ware potato could be optimized by manipulating the rate of nitrogen application.

Table 4. Main effects of nitrogen and potassium on tuber size distribution at Haramaya University during the 2009/10 cropping season.

Treatment	Tuber size categories					
	Small tuber yield (t ha^{-1})	Small tuber No. $hill^{-1}$	Medium tuber yield (t ha^{-1})	Medium tuber (No. $hill^{-1}$)	Large tuber yield (t ha^{-1})	Large tuber (No. $hill^{-1}$)
Nitrogen (kg N ha^{-1})						
0	6.24^{ab}	6.20^{bc}	8.03^{d}	2.96^{d}	3.33^{c}	0.59^{c}
50	7.56^{a}	7.39^{a}	8.64^{cd}	2.98^{cd}	3.60^{c}	0.59^{bc}
100	6.07^{ab}	6.56^{ab}	10.72^{b}	3.40^{bc}	6.69^{ab}	2.29^{a}
150	5.76^{bc}	6.54^{ab}	9.60^{bc}	3.55^{b}	7.28^{a}	1.43^{a}
200	4.62^{c}	5.48^{c}	12.69^{a}	5.20^{a}	4.67^{bc}	1.30^{b}
F-test	*	*	***	***	.**	**
Potassium (kg K_2O ha^{-1})						
0	6.32	6.49	9.73	3.40	4.28	0.98
100	5.97	6.23	10.21	3.69	4.95	0.90
200	6.54	6.62	9.90	3.78	5.43	1.02
F-test	ns	ns	ns	ns	ns	..ns
CV(%)	23.32	14.95	17.94	16.54	25.26	29.83

** = significant at 0.05 probability level;** = significant at 0.01 probability level; *** = significant at 0.001 probability level; ns = not significant at 5% probability level. Means sharing the same letter within a column are notsignificantly different at 5% level of significance; CV= coefficient of variation; No. = number.*

3.5. Tuber Dry Matter Content and Specific Gravity

Tuber dry matter content was significantly lower in plots treated with 100 kg N ha^{-1}than the plots receiving other N application rates. The decrease in tuber dry matter yield (Table 5) at this level of N supply is consistent with the high total tuber yield and numbers obtained at 100 kg N ha^{-1}(Table 2). This could be attributed to the higher tissue water content of tubers growing optimally when nitrogen is sufficiently available. In agreement with this finding, Maier *et al.* (1994), found reduction in dry matter content when nitrogen and potassium rates were increased.

Table 5. Main effects of nitrogen and potassium on dry matter yield and specific gravity of potato tubers at Haramaya University during the 2009/10 cropping season.

Treatment	Tuber quality parameter	
	Dry matter content (%)	Specific gravity (gcm^{-3})
Nitrogen (kg N ha^{-1})		
0	25.02[a]	1.088
50	25.18[a]	1.091
100	24.25[b]	1.087
150	25.62[a]	1.086
200	25.25[a]	1.088
F-test	*	ns
Potassium (kg K_2O ha^{-1})		
0	25.18	1.086
100	24.72	1.090
200	25.28	1.087
F-test	ns	ns
CV(%)	3.52	0.74

** = significant at 0.05 probability level; ns = not significant at 5% probability level. Means sharing the same letter within a column are not significantly different at 5% level of significance; CV = coefficient of variation.*

On the other hand, potassium had no significant effect on tuber dry matter production (Table 5). Similarly, Patricia and Bansal (1999), Kanzikwera *et al.* (2001), and Mulubrhan (2005) demonstrated that application of potassium had no significant effect on tuber dry matter yield. The absence of change or decrease in tuber dry matter production in response to increased supply of potassium, which might result in luxury consumption of the nutrient, could be ascribed to accumulation of high water in the cells, which may dilute the dry matter yield (Maier *et al.*, 1994).In this study, application of both nitrogen and potassium fertilizers had no effect on the specific gravity of potato tubers.

4. Conclusion

The results of this experiment have revealed that increasing the rate of nitrogen fertilizer application increased the yield and most yield components of the crop. However, potassium did not affect the yield and yield components of the crop. Moderate rate of nitrogen supply (100 kg N ha^{-1}) resulted in optimum total and marketable tuber yields. However, medium-sized tubers (39-75 g), which are the appropriate-sized tubers for use as planting material, were produced in a significantly larger numbers and quantity at the highest rate of nitrogen supply (200 kg N ha^{-1}). This implies that enhanced production of seed potato tubers requires higher rates of nitrogen fertilizer application than production of ware potato. The results of this study have also revealed that application of potassium fertilizer is not required for potato production in the study area since the soil contains sufficiently available quantities of the nutrient for uptake by the plant. Therefore, for potato seed tuber production, farmers in the study area should apply higher rates of nitrogen fertilizer than the rate required for ware potato production. Furthermore, application of mineral potassium fertilizer is not required for potato production in the study area at least on a short-term basis. However, to make a conclusive recommendation, the results of this study should be confirmed by conducting similar research over locations and growing seasons in the region.

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