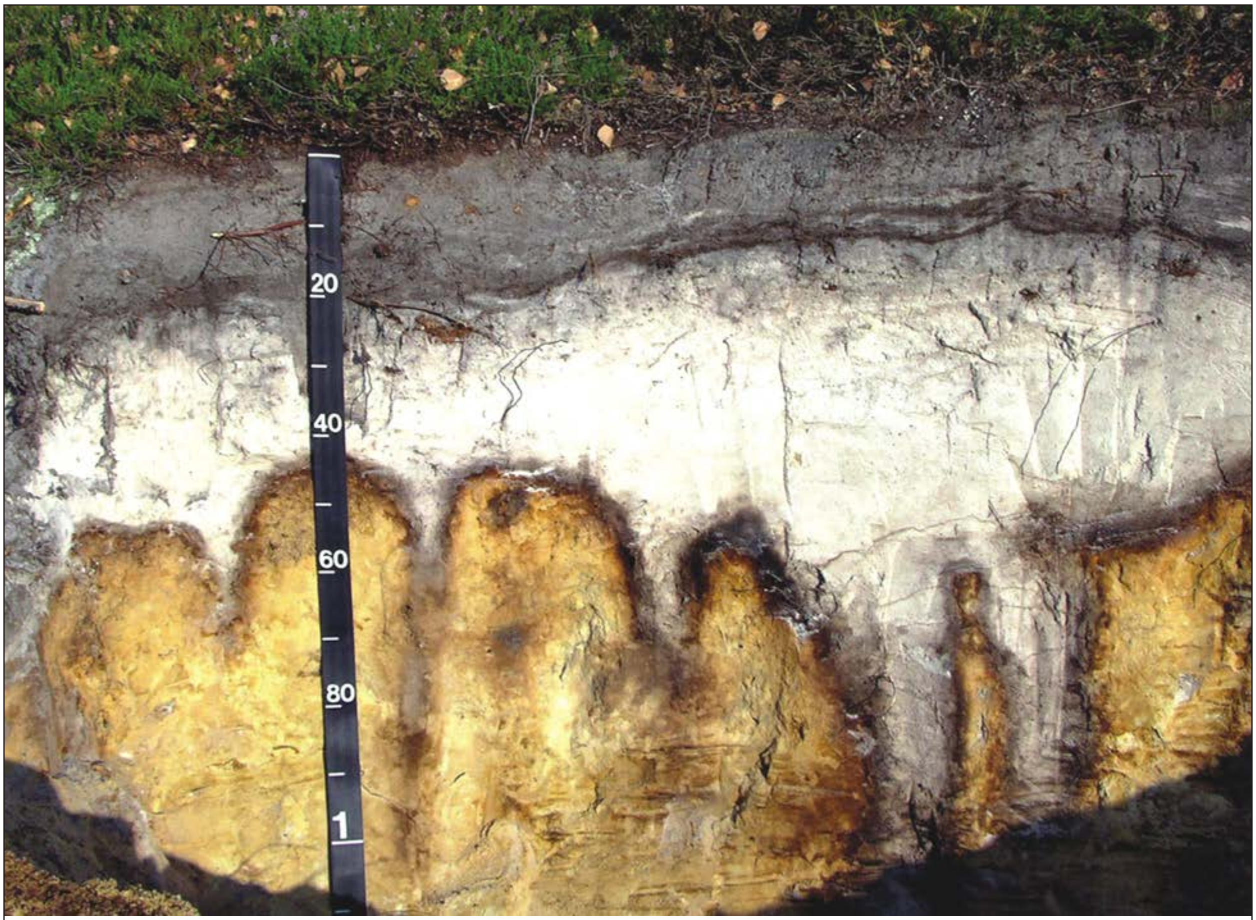

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Effect of Different Rates of Nitrogen and Phosphorus on Yield and Yield Components of Potato (*Solanum tuberosum* L.) at Masha District, Southwestern Ethiopia

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ABSTRACT

An experiment was conducted at Masha District, Southwestern Ethiopia to investigate the effect of nitrogen and phosphorus rates on yield and yield components of potato. Four rates of nitrogen (0, 55, 110, 165 kg ha^{-1}) and four rates of phosphorus (0, 20, 40, 60 kg ha^{-1}) were combined in 4×4 factorial arrangement in randomized complete block design with three replications. Data collected on growth and yield parameters were analyzed using SAS 9.2 computer software. Application of 165 kg N ha^{-1} significantly increased days to flowering by 6 days, days to physiological maturity by 13 days, above ground biomass by 36%, underground biomass by 29.79%, total tuber yield by 60.33%, marketable tuber number by 56.36% and total tuber number by 31.7% and average tuber weight by 22.43%. However, N did not influence days to emergency, unmarketable tuber yield and unmarketable tuber number. Application of P significantly increased days to flowering by 3 days, above ground and underground biomass by 8.78% and 61.4% respectively and marketable tuber number by 19.72%. The interaction effect of 165 kg of N and 60 kg P increased marketable tuber yield (36 t ha^{-1}) by 122% as compared to control (16.2 t ha^{-1}). The result of this study verified that yield and yield components of potato are influenced by nitrogen and phosphorus rates. From this study, it can be concluded that the higher rates of nitrogen (165 kg ha^{-1}) and phosphorus (60 kg ha^{-1}) can be used for optimum production of potato variety Jalene in the study area Masha, Southwestern Ethiopia.

Key words: Growth parameters, nitrogen, phosphorous, Jalene potato variety, yield parameters

INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and genus *Solanum* (Thompson and Kelly, 1972). It is native to South America (Eskin and Michael, 1989). It has been introduced to Ethiopia in 1859 by a German Botanist called Schimper (Berga *et al.*, 1994b). For many years in Ethiopia, potato production was limited to only homesteads, as a garden crop. World annual production of potato is about 330 million metric tons with area coverage of 18,651,838 ha. In Africa total production of potato is about 17,625,680 tons with total area coverage of 1,765,617 ha. In Ethiopia total production is around 572,333 tons on area coverage of 69784 ha.

It is one of the major world food crops in its ability to produce high food per unit area per unit time (FAOSTAT, 2010). Ethiopia is endowed with suitable climatic and edaphic conditions for potato production. However, land acreage under potato production is estimated to be only about 69,784 ha and the national average yield is about 8.2 t ha^{-1}, which is very low as compared to the world's average production of 17.67 t ha^{-1} (FAOSTAT, 2010). Potato requires a variety of plant nutrients for growth and development. Nitrogen, phosphorus and potassium are the most important among the elements that are essential to potato. Low soil fertility is one of the most important constraints limiting potato production in Eastern Africa and hence accelerated and sustainable agricultural intensification is required for suitable potato production (Muriithi and Irungu, 2004). Fertility of most Ethiopian soils has already declined due to continuous cropping, abandoning of fallowing, reduced use of manure and crop rotation. The use of animal manure and crop residues for fuel and erosion coupled with low inherent fertility are among the main causes for decreasing soil fertility (Taye *et al*., 1996; Tilahune *et al*., 2007). In Ethiopia, national yield and variety trials data over several locations on different crop species clearly indicated that soil nutrient stress is the most significant factor controlling crop yield (Tamirie, 1989). Farmers should tackle this problem through the application of both organic and inorganic fertilizes, which amend the soil environment. Nutrient and soil fertility management is also becoming more accepted by development and extension programs in SSA and most importantly, by smallholder farmers (Place *et al*., 2003). It has been reported that nitrogen and phosphorus are deficient in most Ethiopian soils and thus application of these fertilizers has significantly increased yield of the crop (Tekalign *et al*., 2001). Nitrogen and phosphorus fertilizers application have shown good yield responses, for different crops across different locations indicating low nitrogen and phosphorus status of the soils (Berga *et al*., 1994a; Yohannes, 1994). This situation would become more critical in potato production in view of the fact that the potato crop one of the heavy feeders of plant nutrients (Powon, 2005). Inconsistent recommendations have been reported by different researchers at different location. According to Bereke (1988), application of 150/66 kg ha^{-1} of N/P_2O_5 under rain-fed condition resulted in a yield advantage of 32% over the unfertilized control. Getu (1998) found that the optimum fertilizer rates for potatoes were 87 kg N and 46 kg P_2O_5 on clay soil of Haramaya. According to Mulubrhan (2004), the application of 165 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1} is needed for optimum potato production on vertisols of Mekelle area. Zelalem *et al*. (2009) found in their study conducted on response of potato to different fertilizer levels under rain fed highland situation at Deber Berhan area and 207 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1} gave optimum tuber yield. Soils in Southwestern Ethiopia are low in soil organic matter, Cation Exchange Capacity and are high in acidity. The low level of soil organic matter combined with poor land coverage have resulted in poor soil structure, limited rooting depth and susceptibility to accelerated erosion (Wakene, 2001). Without considering the fertility status of the soil and the type of crop cultivar, blanket national recommendation of 165 kg urea and 195 kg DAP ha^{-1} is being used in Sheka Zone since there is limited information on soil fertility studies for potato production in the area (Taye, 1998). Fertilizer practices in the region have been mainly based on the experience of other regions. Therefore, investigating the response of potato for nitrogen and phosphorus fertilizers under this specific agro-ecology is required to come up with relevant nitrogen and phosphorus recommendation for Masha district in Southwestern Ethiopia.

MATERIALS AND METHODS

Description of the study area: The experiment was conducted at Masha District in Southwestern Ethiopia during 2010/2011 main cropping season. The area is located 677 km

Southwest of Addis Ababa at 7°44'N latitude 35°29'E longitude and 7.733°N latitudes and altitude of 2223 m.a.s.l., the optimum range for the growth of Jalene potato variety. The site is with an average annual rainfall of 1800-2200 mm with bimodal distribution, annual mean temperature of 15-27°C (Bedru, 2007). The soils of the area are Acrisols (Berhane and Sahelmemedhin, 2003). Acrisols are characterized by high Kaolinitic clays, low cation exchange capacity, low base saturation and low pH values. This may be due to hot climate and high rainfall that result in intensive leaching. These soils are deep, well drained and reddish brown when moist and dark red when dry (Berhane and Sahelmemedhin, 2003).

Experimental treatments, design and procedures: Jalene potato variety obtained from Holeta Agricultural Research Center was used for this experiment. It is one of the potential potato cultivars for Masha district in Southwestern Ethiopia. It is being cultivated widely and has been accepted by farmers due to its high yielding ability, consumers' preference, wider adaptation, better cooking ability and relatively resistance to late blight compared to local and other improved potato varieties growing in the area. Four levels of nitrogen: 0, 55, 110 and 165 kg and four levels of phosphorus: 0, 20, 40 and 60 kg per ha were combined in 4×4 factorial arrangements in randomized complete block design with three replications. All management practices, such as weeding, insect pest and diseases control were applied as per the general recommendations for potato (Gebremedhin *et al*., 2008). The experimental field was divided into three blocks each containing 16 plots and a plot size of 9 m^2 (3 m length×3 m width) was used. A distance of 0.75 m was maintained between the plots within a block and 1 m distance was maintained between blocks and 75 cm row spacing was uniformly used and medium sized and well sprouted potato tubers were planted. The entire rate of phosphorus and half the rate of nitrogen was applied at the time of planting and the remaining half of nitrogen was applied 45 days after planting. Urea (46% N) and triple super phosphate, TSP (46% P_2O_5) fertilizers were used as sources of nitrogen and phosphorus.

Data collection and analysis: Data collected on growth parameters such as days to 50% flowering and maturity, plant heights, shoot and root dry weight and yield parameters such as total and marketable tuber number, total and marketable tuber yields (t ha^{-1}) and average tuber weight were checked for normality and subjected to analysis of variance using SAS Version 9.2 statistical software (SAS., 2008). Treatment means were compared using LSD value at 5% significant level (Montgomery, 2005).

RESULTS AND DISCUSSION

Effect of nitrogen and phosphorus rates on growth parameters: The effect of both nitrogen and phosphorous rates were found highly significant ($p<0.001$) on all growth parameters studied including days to 50% maturity, shoot and root dry weight except days to 50% flowering which was highly significantly ($p<0.01$) affected by rates of nitrogen and significantly ($p<0.05$) affected by rates of phosphorus.

Days to 50% flowering: Application of 165 kg N ha^{-1} delayed the time required to reach 50% flowering by 7 days (Fig. 1). This is because high N levels promoted excessive vegetative growth and delayed flowering. This result in coherent with the findings of Lauer (1986), Frezgi (2007) and Zelalem *et al*. (2009) who reported excessive vegetative growth and delayed flowering due to high nitrogen levels.

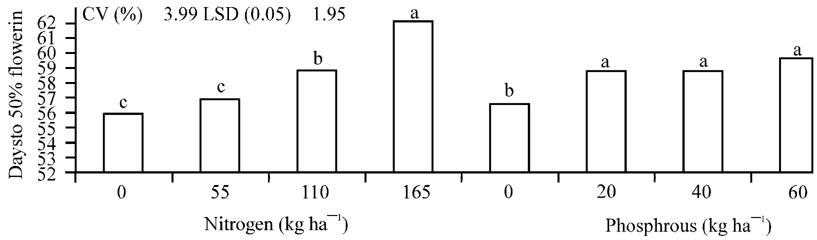

Fig. 1: Means for number of days to 50% flowering of potato as influenced by nitrogen and phosphorus rates. Means for number of days to 50% flowering of potato followed by different letters differ significantly at $p<0.05$ as established by LSD test

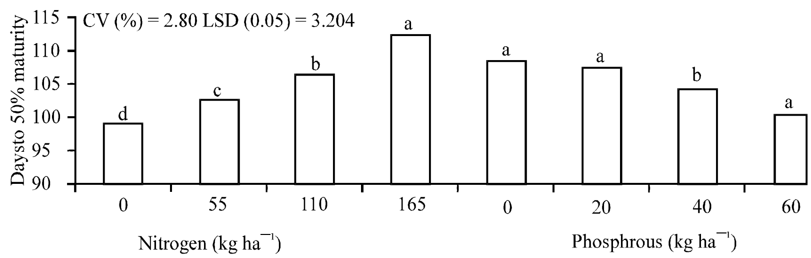

Fig. 2: Means for number of days to 50% maturity of potato as influenced by nitrogen and phosphorus rates. Means for number of days to 50% maturity of potato followed by different letters differ significantly at $p<0.05$ as established by LSD test

Similarly increased phosphorus application from 0-60 kg P ha^{-1} prolonged the days to 50% flowering by 3 days from 56-59 (Fig. 1). This result is in agreement with the findings of Harris (1978) and Mulubrhan (2004) who confirmed that phosphorus application had been found to prolong days required to 50% flowering.

Days to 50% maturity: Increasing the application rate of nitrogen from zero to 165 kg N ha^{-1} delayed days to 50% maturity from 99-112 by 13 days (14%) (Fig. 2). This is due to the fact that increased level of nitrogen increased the leaf area which in turn increased the amount of solar radiation intercepted and consequently, increased days to physiological maturity.

Therefore, a crop with more nitrogen will mature later in the season than a crop with less nitrogen because later growth is related to excessive haulm development whereas early tuber growth to less abundant haulm growth (Beukema and van der Zaag, 1990; Mulubrhan, 2004). On the other hand, increased rate of phosphorus application reduced the days to 50% maturity (Fig. 2). This might be due to the role of phosphorus in accelerating the physiological maturity of potato. The observation of the present investigation supports the earlier studies on the effect of phosphorus on days to maturity (Kleinkopf *et al.*, 1987; Mulubrhan, 2004) where phosphorus was reported to be related with shortening maturity of potato.

Shoot dry weight: Application of 165 kg N ha^{-1} increased shoot dry weight from 52.75-72.25 by 19.5 g per hill. This increase in shoot dry weight is 37% as compared to control treatment (Table 1, 2).

Table 1: Effect of nitrogen and phosphorus rates on shoot and root dry weight of potato

Treatments	Shoot dry weight (g $hill^{-1}$)	Root dry weight (g $hill^{-1}$)
Nitrogen (kg ha^{-1})		
0	52.75^{d}	8.90^{c}
55	58.33^{c}	9.97^{bc}
110	65.00^{b}	11.43^{ba}
165	72.25^{a}	11.56^{a}
Phosphorus (kg ha^{-1})		
0	59.67^{b}	7.59^{c}
20	61.25^{ba}	10.37^{b}
40	63.00^{ba}	11.70^{a}
60	64.92^{a}	12.21^{a}
LSD (p<0.05)	2.785	1.541
CV (%)	5.370	17.640

Means followed by different letters per column differ significantly at p<0.05 as established by LSD test

Table 2: Mean squares for potato growth parameters and harvest

	Mean squares					
Source of variation	df	DF	DM	pH	SDW	RDW
Block	2	2.79	20.27	06.90	8031.06	171.37
Nitrogen	3	95.82**	384.7**	496.27**	837.91**	19.48**
Phosphorus	3	30.37*	158.3**	201.09*	61.36**	51.88**
Nitrogen×Phosphorus	9	02.79^{ns}	15.33^{ns}	21.37^{*}	02.90^{ns}	01.08^{ns}
Error		05.47	03.36	02.83	11.16	03.41
SE±		02.34	03.36	01.37	03.34	01.84
CV		04.00	03.20	04.48	05.37	17.64

SDW: Shoot dry weight, RDW: Root dry weight, DM: Dry weight, *Significant,**Highly significant, ns: Non significant, Df: Degree of freedom

This is due to the fact that, increased concentration of nitrogen fertilizer can increase the nitrogen uptake and this increase has a positive effect on chlorophyll concentration, photosynthetic rate, leaf expansion, total number of leaves and dry matter accumulation. Consequently nitrogen fertilizer plays an important role in canopy development especially on the shoot dry matter (Najm *et al*., 2010). As the rate of phosphorus application increased from 0-60 kg P/ha, the shoot dry weight of potato increased from 59.67-64.91 g per hill and the increased application rate of phosphorus increased shoot biomass by 8.78 (Table 1, 2). The result of the current investigation is in conformity with the finding of Zelalem *et al*. (2009) who concluded that N and P fertilization significantly influenced shoot dry weight of potato.

Root dry weight: With application of 165 kg N ha^{-1} the highest root dry weight (11.56 g $hill^{-1}$) was obtained compared to the control treatment with the lowest root dry weight of 8.90 g $hill^{-1}$ (Table 1, 2). This could be due to the effect of nitrogen that stimulated the growth and development of roots. In similar manner FAO (2000) reported that good supply of nitrogen to the plant stimulates root growth and development as well as uptake of other nutrients. Regarding phosphorus the maximum root dry weight (12.2 g $hill^{-1}$) was registered from plants that were fertilized with phosphorus at rate of 60 kg P ha^{-1} and this value was statistically at par with the application of 40 kg P ha^{-1} but the lowest root dry weight (7.58 g $hill^{-1}$) was recorded from plots

Table 3: Effect of nitrogen and phosphorus rates on total and marketable tuber number, total tuber yield and average tuber weight of potato

Treatments	Total tuber No./hill	Marketable tuber No./hill	Total tuber yield (t ha^{-1})	Average tuber weight (g)
Nitrogen (kg ha^{-1})				
0	9.77^{d}	5.68^{c}	23.75^{d}	54.48^{c}
55	10.70^{c}	6.80^{b}	30.17^{c}	63.00^{b}
110	11.20^{b}	7.13^{b}	34.64^{b}	67.54^{ab}
165	12.19^{a}	8.88^{a}	38.08^{a}	70.23^{a}
Phosphorus (kg ha^{-1})				
0	10.67^{c}	6.44^{b}	27.10^{c}	56.8^{c}
20	10.82^{bc}	6.58^{b}	28.83^{c}	59.68^{c}
40	11.15^{ab}	7.76^{a}	33.11^{b}	65.93^{b}
60	11.55^{a}	7.71^{a}	37.56^{a}	72.85^{a}
LSD (5%)	0.456	0.523	1.270	5.499
CV (%)	4.95	8.80	10.32	10.33

Means followed by different letters per column differ significantly at p<0.05 as established by LSD test

Table 4: Mean squares for potato yield parameters

		Mean squares				
Source of variation	Df	Marketable tuber No./hill	Total tuber No./hill	Marketable tuber yield (t ha^{-1})	Total tuber yield (t ha^{-1})	Average tuber weight (g)
Block	2	1.00	0.92	7.86	0.05	29.31
Nitrogen	3	21.15**	13.17**	334.54**	459.51**	571.44**
Phosphorus	3	6.03**	1.80*	291.62**	264.29**	609.69**
Nitrogen×Phosphorus	9	0.46^{ns}	0.37^{ns}	15.84*	20.11^{ns}	52.62^{ns}
Error	30	0.4	0.3	6.16	10.69	43.50
SE±		0.63	0.54	2.48	3.27	6.59
CV (%)		8.80	4.95	9.66	10.33	10.33

*Significant, **Highly significant, ns: Non significant, Df: Degree of freedom

that received no phosphorus application. This might be application of higher rate of phosphorus enhanced the development of roots particularly lateral and fibrous rootlets. Similarly Brady and Weil (2002) reported that P is required in large quantities in young cells, such as root tips, where metabolism is high and cell division and development of root is rapid. The current finding is in agreement Zelalem *et al*. (2009) confirmed that higher level of N and P fertilization significantly influenced root dry weight of potato.

Effect of nitrogen and phosphorus rates on yield parameters: The effect of both nitrogen and phosphorous rate was found highly significant (p<0.001) on yield parameters such as marketable tuber number and total tuber yield and significant (p<0.05) on average tuber weight except total tuber number which was highly significantly (p<0.01) affected by rate of nitrogen and significantly (p<0.05) affected by rate of phosphorus (Table 3, 4).

Total tuber number: Increasing the application of nitrogen increased total tuber number per hill from 9.78-12.2 (Table 3, 4). This can be attributed to increased vegetative growth of the potato plant. The current result is in consistent with the work of many researchers (Reddy, 1968; Herlihy and Carroll, 1969; Sommerfeld and Knutson, 1965; Hanley *et al*., 1965; Mahmoodabad *et al*., 2010) who had reported that an increase in nitrogen application increases tuber number. In the present study, raising the rate of applied nitrogen from 0-165 kg ha^{-1} increased total tuber number by 31.7%. Similarly, increasing the level of applied phosphorus significantly increased total tuber number per hill from 10.68-11.55 (Table 3, 4). According to Sommerfeld and Knutson (1965) and Sparrow *et al.* (1992), the application of phosphorus increased the number of potato tubers set per unit. Application of phosphorus from 0-60 kg P ha^{-1} increases total tuber number by 8.19% as compared to control.

Marketable tuber number: Marketable tuber number increased with increased rate of nitrogen. Hence, increasing rate of nitrogen application from 0-165 kg N ha^{-1} increased marketable tuber number from 5.68-8.85/hill without affecting the unmarketable tuber number (Table 3). This could be probably due to the fact that marketable tuber number increases at higher nitrogen rate because nitrogen can trigger the vegetative growth development.

The increase in number of marketable tuber with increase in applied nitrogen was associated with decrease in the number of the small size tubers due to increase in the weight of individual tubers. This result is in line with the finding of Hanley *et al.* (1965) who confirmed that application of nitrogen increased the number of tubers produced per hill in a study conducted for three consecutive years. Application of nitrogen from 0-165 kg N ha^{-1} increased marketable tuber number by 56.36%. Similarly, increasing the level of applied phosphorus also increased marketable tuber number per hill from 6.44-7.76. However, there was no apparent difference between application of 40 and 60 kg P ha^{-1} (Table 3).

Total tuber yield: Increasing the application rates of nitrogen resulted in increasing the total tuber yield from 23.75 to 38 t ha^{-1} (Table 3). While, the highest yield was obtained at 165 kg N ha^{-1} but the lowest yield was obtained at zero nitrogen application. Increasing the application rates of nitrogen from 0 to 165 kg N ha^{-1} increased total tuber yield by 60.33%. Similar to the effect of increased nitrogen, increasing phosphorus application rate from 0-60 kg P ha^{-1} increased the total tuber yield from 27.1 to 37.6 t ha^{-1}. The highest total tuber yield (37.6 t ha^{-1}) was obtained at phosphorus application of 60 kg P ha^{-1} but the lowest yield (27.1 t ha^{-})^{1} was obtained at no phosphorus application (control treatment). This value is statistically similar with the application of 20 kg of phosphorus. Application of phosphorus from 0-60 kg P ha^{-1} increased total tuber yield by 38.6% as compared to the control treatment. Phosphorus application also increased significantly total tuber yield the increase in total tuber yield by phosphorus application was not sharp (Table 3). This show there is opportunity for additional gain in tuber yield through further application of more N and P fertilizers above 165 kg N ha^{-1} and 60 kg P ha^{-1}, respectively. This result is in line with the finding of Zelalem *et al.* (2009) and Mulubrhan (2004) who reported that application of nitrogen increased the total tuber yield.

Marketable tuber yield: The highest marketable tuber yield (35 t ha^{-1}) was recorded at 165 kg ha^{-1} nitrogen in combination with phosphorus at 60 kg ha^{-1} but the lowest marketable tuber yield (16.2 t ha^{-1}) was obtained from the combination of zero levels of nitrogen and phosphorus. Nitrogen showed significant differences in marketable tuber yield under the same phosphorus level (Fig. 3), indicating that the effect of different levels of phosphorus on marketable tuber yield is dependent on the levels of nitrogen. This may be due to the positive interaction and complementary effect between nitrogen and phosphorus in affecting and increasing the marketable

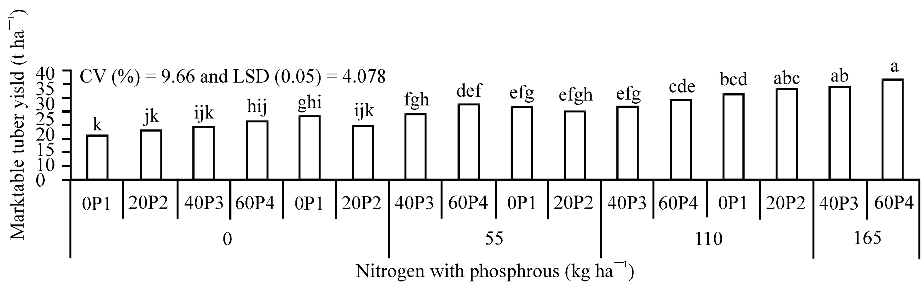

Fig. 3: Means for marketable tuber yield of potato per hectare as influenced by the interaction between nitrogen and phosphorus rates. Means for marketable tuber yield followed by different letters differ significantly at $p<0.05$ as established by LSD test

tuber yield of potato in the study area. Similarly FAO (2000) reported without phosphorus application, nitrogen efficiency declined thereby indicating interaction between these nutrients.

Average tuber weight: The highest average weight of tubers (70.23 g) was found in the treatment that received 165 kg N ha^{-1} and this value was statistically similar with application of 110 kg N ha^{-1} and the lowest average weight of tubers (54.47 g) was obtained in the treatments that received no nitrogen (Table 3). Increased application rate of nitrogen from 0-165 kg N ha^{-1} increased average tuber weight by 22.43% as compared to the control. Likewise increasing application of phosphorus increased average tuber weight and showed a consistent increasing trend with increasing dose of phosphorus fertilizer rate. Increasing the phosphorus application rate from 0 to 60 kg P ha^{-1} increased the average tuber weight by 22.49% as compared with the control.

CONCLUSION

Several factors limiting crop yields have been reported by many workers and the current investigation showed that the effect of both nitrogen and phosphorous rates were found highly significant on all growth parameters studied including days to 50% maturity, shoot and root dry weight except days to 50% flowering which was highly significantly affected by rates of nitrogen and significantly affected by rates of phosphorus. The longest days to 50% flowering was achieved with the application of (165 kg N ha^{-1}), which had a similar effect with application of (60 kg P ha^{-1}). Similarly delay in maturity from treatments of plants with 165 kg N ha^{-1} while, with phosphorus the delay in maturity of plants was due to absence of phosphorus application (0 kg ha^{-1}). The highest shoot and root dry weight of potato was obtained at 165 kg ha^{-1} nitrogen and 60 kg ha^{-1} of phosphors. The effect of both nitrogen and phosphorous rate was found highly significant on yield parameters such as marketable tuber number and total tuber yield and significant on average tuber weight except total tuber number which was highly significantly affected by rate of nitrogen and significantly affected by rate of phosphorus. Considering of the yield of potato, the highest marketable tuber yield was obtained from the combined application of (165 kg N ha^{-1}) with (60 kg P ha^{-1}). In conclusion, the result of this study showed that different nitrogen and phosphorus rates and their interaction have sound and promising impact on growth and marketable tuber yield of potato. Therefore, on the basis of the results of the present study, it is indicative that potato can grow well in the Masha area and farmers can benefit more by using 165 kg ha^{-1} of nitrogen in combination with 60 kg ha^{-1} phosphors.

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