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Response of Potato Varieties to Nitrogen Fertilizer Rates in Debark District, Northwestern Ethiopia

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ABSTRACT

Potato (*Solanum tuberosum* L.) is one of the most important vegetable crops in the highlands of Ethiopia. However, its productivity is very low mainly due to soil infertility, lack of site-specific fertilizer recommendation and appropriate varieties**.** Therefore, a study was conducted in 2019 under irrigation to evaluate the response of improved potato varieties to different rates of nitrogen fertilizer rates. The treatments comprised of four nitrogen rates (0, 55, 110 and 165 kg ha^{-1}) and three potato varieties (Belete, Gudene and Local), which were laid in a randomized complete block design with three replications. The analysis of variance revealed that the main effects of nitrogen rates and varieties significantly influenced the tested growth, yield and yield related traits of potato. The maximum marketable tuber yield (30.70 t ha^{-1}) was recorded from application of 110 kg nitrogen ha^{-1}, which increased tuber yields by 86% as compared to unfertilized plots. Among the tested varieties, Belete produced the highest marketable yield (29.8 t ha^{-1}) with a yield advantage of 71% compared to the local variety. The partial budget analysis result showed that application of nitrogen 110 kg nitrogen ha^{-1}for Belete variety gave the highest profit (205787ETB ha^{-1}) with acceptable marginal rate of return (485%). From the present result, it can be concluded that optimum yield and high profit can be obtained by applying110 kg nitrogen ha^{-1} for Belete variety.

Keywords: Benefit, Fertilizer, Nitrogen, Potato, Variety, Yield.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the main source of income and food security in developing countries (Gebru et al., 2017). It contains about 79% water, 18% starch as good source of energy, 2% protein and 1% vitamin including vitamin C, minerals including calcium and magnesium and many trace elements (Zewide et al., 2016). Potato is one of the most widely cultivated vegetable crops in the highlands of Ethiopia. Among root and tuber crops, potato ranks first in volume production and consumption in the country (Food and Agriculture Organization, 2017). It is grown mainly in central, eastern, north-western, and southern parts of the country. Amhara is the second largest potato producing region with 30% of total production area due to the availability of suitable ecological areas in East Gojjam, West Gojjam, South Gondar, North Gondar, Awi and North Wollo (Central Statistical Agency, 2017). About 14% of potato production in Amhara Region is obtained from North Gondar Zone. The main potato growing areas in North Gondar are Debark, Dabat, Wogera, Chilga, Janamora and Beyeda districts (Central Statistical Agency, 2017).

Despite its wider production and importance, the average national yield of potato is 13.92 t ha^{-1} (Central Statistical Agency, 2018), which is very low. Though the average productivity of potato in Amhara Region (15.3 t ha^{-1}) and in North Gondar zone (14 t ha^{-1}) is higher than the national average yield (Central Statistical Agency, 2017), it is still very low compared to the world average productivity of 20.11 t ha^{-1} (Food and Agriculture Organization, 2017) and its potential yield (47 t ha^{-1}) (Ministry of Agriculture and Rural Development, 2009). The major production problems that contribute for low yield of potato includes low soil fertility, inadequate application of fertilizers, diseases, pests, and lack of good quality seed (Gebru et al., 2017). Among the production

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factors low soil fertility is the most important one for low productivity of crops including potato.

Various research results have showed that application of nitrogen and using of improved varieties significantly increased the yield of potato in Ethiopia. The rates of nitrogen, however, vary from location to location. For instance, Getie et al. (2015) and Zewide et al. (2012) observed the highest tuber yield at nitrogen rate of 110 and 165 kg nitrogen ha^{-1}, respectively. Research findings also showed that the highest marketable yields were obtained from improved varieties such as Belete and Gudene (Alemayehu & Jemberie, 2018; Amdie et al., 2017; Gebreselassie et al., 2016). These results indicate that site specific nitrogen fertilizer application rate and adaptable varieties are needed to maximize potato crop production in each area. However, there is not enough research information on response of improved potato varieties to different rates of nitrogen fertilizer. Therefore, the study was conducted to evaluate the response of improved potato varieties to different nitrogen fertilizer rates.

MATERIALS AND METHODS

Description of the experimental site:

The experiment was conducted under irrigation during 2019 at Mekara Kebele in Debark district, Western Ethiopia. The site is located at 13º 19'N latitude 37º 92' E longitudes and altitude of 2885 m.a.s.l with the help of GPS. The minimum and maximum temperature of the study area is 3.7ºC and 23.1ºC, respectively and it receives mean annual rainfall of 1231 mm (average long-term data). The textural class of the soil is clay (40%clay, 32% silt and 28% sand). It was non saline (0.12 dS/m) and moderately acidic (pH of 5.94) based on the category of Roy & Motsara (2008). The soil contained medium total nitrogen (0.21%), medium available phosphorus (9.9 mg kg^{-1}), moderate exchangeable potassium (0.62 Cmol kg^{-1}), high organic carbon (2.44%) and organic matter (4.21%), very high cation exchange capacity (60 $meq100g^{-1}$) based on the rating of Havlin et al. (1999), Olsen et al. (1954), Metson (1961) and Landon (1991), respectively (Table 1).

Table1: Physical and chemical properties of the experimental soil.

Soil properties	Value
Soil chemical properties	
Total N (%)	0.21
Available P (mg kg^{-1})	9.90
Exchangeable K^+ ($Cmolkg^{-1}$)	0.62
Organic carbon (%)	2.44
Organic matter (%)	4.21
EC (dS/m)	0.12
CEC ($meq100g^{-1}$)	60.00
pH (1:2.5 H_2O)	5.94
Soil physical properties	
Clay (%)	40
Silt (%)	32
Sand (%)	28
Soil Texture	clay

Treatments and experimental design:

The experimental treatments consisted of factorial combinations offour levels of nitrogen rates (0, 55, 110 and 165 kg ha^{-1}) and three varieties (Belete, Gudene and local), laid out in randomized complete block design with three replications. A gross and net plot size was 9 m^2 (3 m x 3 m) and 3.6 m^2 (1.5 m x 2.4 m), respectively, with a spacing of 1 m between plots, and 1.5 m between blocks were used. Medium sized (30-50 g) and well sprouted potato tubers were planted at a spacing of 0.75 m between row and 0.3 m between plants. All management practices, such as ploughing, weeding and irrigation were applied as per the general recommendations for potato (Ministry of Agriculture and Natural Resources, 2017). The whole dose of TSP (90 kg $P_2O_5ha^{-1}$) was applied at planting to all plots uniformly. Half of Urea fertilizer for different nitrogen treated plots was applied at the time of planting and the remaining half was applied 45 days after planting. Irrigation water was applied every week at irrigation depth 30 mm using furrow irrigation method.

Soil sampling and analysis:

Before sowing, soil samples were collected using an auger from nine points in the experimental field from ploughing depth of 0-30 cm in a zigzag pattern. One composite sample was prepared, air dried, and grounded to pass through a 2 mm sieve to analyze soil texture, total nitrogen, available phosphorous, exchangeable potassium, organic carbon, soil pH, and cation exchange capacity. Soil pH was measured photometrically in the supernatant suspension of a 1:2.5 soils to water ratio by using a pH meter as described in Sertsu and Bekele (2000). Total nitrogen was determined according to Kjeldahl procedure with sulfuric acid (Jackson, 1958). Available phosphorus was determined by the Olsen method (Olsen et al., 1954). Exchangeable potassium and cation exchange capacity were determined by ammonium acetate methods. Organic carbon as determined following the wet oxidation method (Walkely & Black, 1954). Soil texture was determined using Bouyoucos Hydrometer method (Day, 1965) and then following the textural triangle.

Data collection:

Days to flowering and physiological maturity was recorded by counting the number of days elapsed from the time of planting up to the time when 50% of the plants in the plot flowered and to the time when the 90% helms in the plot dried. Plant height was measured from the base to the apex of the plant using tape meter at flowering stage. The number of tubers from five plant hills was counted and the average was recorded as tuber number per hill. Average tuber weight was determined by dividing the total fresh tuber weight of randomly sampled five plants. Tubers were harvested from each plot and categorized as marketable, unmarketable, and total tuber yields. Healthy tubers, having a size of more than 30 g were categorized as marketable tuber yield while under-sized (<30 g), diseased, cracked and rotten tubers were categorized as unmarketable tuber yield (Wakjira, 2017). The total tuber yield was calculated as the sum of both marketable and unmarketable tuber yields. Tuber yields were weighed and converted to tones per hectare.

Statistical analysis:

All the collected data were subjected to analysis of variance (ANOVA) using SAS version 9.4. Since ANOVA showed non-significant interaction effect and significant main effects of both factors, means of the main effects of nitrogen and varieties were compared using Least Significant Difference test at 5% significance level.

Partial budget analysis:

Partial budget analysis was done to determine the profitability of treatments as described by CIMMYT (1988). The current market prices of inputs at planting and outputs at harvest time were used for analysis on a hectare basis with Ethiopian birr (ETB). Costs for purchasing price (28 ETB kg^{-1}), transportation to the farm (0.20 ETB kg^{-1}) and for application (500 ETB ha^{-1}) of nitrogen, price of seed tuber (Belete and *Gudanie*= ETB 18 kg^{-1}each and local = ETB 10 kg^{-1}) was used to calculate total variable cost (TVC). Farm get selling price of potato at harvest (8 ETB kg^{-1}) was used to calculate gross benefit (GB). The yield was adjusted down by 10% due to management level variability between a researcher and a farmer (CIMMYT, 1988). Gross benefit was calculated as the product of the adjusted marketable yield (kg ha^{-1}) and sale prices (ETB 8.00 kg^{-1}). The net benefit was calculated by subtracting the total cost that varies from the gross benefit. All the treatments were arranged in ascending order of total variable cost. Dominance analysis was done to exclude the dominated treatments from computation of Marginal rate of return (MRR), which was calculated as percentage change in net benefit over change in total variable cost. Treatments that were not dominated, has the maximum net benefit and MRR greater than 100% was considered as the best economically profitable treatment.

RESULTS

Days to flowering and physiological maturity:

Phenological characteristics of potato were significantly (P<0.001) influenced by inorganic nitrogen and varieties, while their interaction effect was not significant (P>0.05). Increasing nitrogen rates from 0 to 165 kg ha^{-1}significantly delayed 50% flowering and 90% physiological maturity by 8.67 and 8.89 days, respectively. Regarding variety, the local variety flower and mature earlier than improved varieties. *Gudanie* took longer (54.75) days to reach 50% flowering and physiological maturity (98.55 days) compared to Belete variety (Table 2).

Plant height:

Plant height was very highly significantly (p<0.001) influenced by the main effects of nitrogen rate and cultivar. The tallest plant (69.35 cm) was recorded from plots treated with 165 kgN ha^{-1} and the shortest (56.37 cm) from the unfertilized one. Plant height was increased by 23% as nitrogen level increased from zero to165 kg nitrogen ha^{-1}. Among the varieties, the longest plant (68.68 cm) was observed from Belete, though it was statistically similar with Gudene (67.33 cm), while the shortest plant (53.87 cm) was recorded from local variety (Table 2).

Weight and number of tubers:

Number and weight of tubers were highly significantly (P<0.01) influenced by the main effects of nitrogen rate and variety, but not by their interaction. The maximum number of tubers per hill (14.17) and average weight (45.21g) of tubers were obtained from 165 kg nitrogen ha^{-1}althoughstatistically similar with 110 kg nitrogen ha^{-1}. The minimum numbers (7.46) and average

Table 2: Effect of nitrogen rate and variety on plant height (pH), days to 50% flowering (DTF) and maturity (DTM) of potato.

Treatments	DTF	DTM	PH (cm)
N rate (kg ha^{-1})			
0	53.66[c]	92.55[c]	56.37[b]
55	58.44[b]	95.55[bc]	60.13[b]
110	59.77[ab]	97.88[b]	67.32[a]
165	62.33[a]	101.44[a]	69.35[a]
LSD	3.22***	3.02***	3.82***
Variety			
Belete	58.00[b]	97.33[ab]	68.68[a]
Gudene	62.91[a]	98.5[a]	67.33[a]
Local	54.75[c]	94.75[b]	53.87[b]
LSD	2.79***	2.61*	3.31***
CV (%)	5.63	3.19	6.17

Means within a column with common letter are not significantly different; **= significant at p<0.01.

weight (7.46 g) of tuber was recorded from the unfertilized treatment. Weight and number of tubers significantly improved with increase in the nitrogen level from zero to 110 kg nitrogen ha^{-1}, beyond which the increments were not significant. As per the varieties, the maximum number of tubers per hill (12.24) and average weight of tuber (73.46g) were recorded from Belete variety. However, the minimum number (9.27) and weight (51.38 g) were obtained from the local variety, which was statistically similar with Gudene (Table 3).

Tuber yield:

Nitrogen rates and varieties had highly significant ($p<0.01$) effect on marketable, unmarketable, and total tuber yields, while their interaction effect was not significant. The maximum marketable (30.7 t ha^{-1}) and total (32.54 t ha^{-1}) tuber yields were obtained from application of 110 kg nitrogen ha^{-1}, while the minimum unmarketable yield (4.02 t ha^{-1}) was produced with the same rate. The minimum marketable (16.5 t ha^{-1}) and total (19.1t ha^{-1}) tuber yields were recorded from the unfertilized treatment, which produced the highest unmarketable yield (1.83 t ha^{-1}) (Table 3). Marketable yield was significantly improved as the nitrogen level increased from zero to 110 kg nitrogen ha^{-1}, but further increment of nitrogen rates to 165 kg ha^{-1} did not show significant improvement in marketable yield. Application of 110 nitrogen ha^{-1} increased tuber yields by 86% as compared to control. With respect to variety, the maximum marketable tuber yield was recorded from Belete variety (29.8 t ha^{-1}), followed by Gudene (24.3 t ha^{-1}) while the minimum yield (17.5 t ha^{-1}) was obtained from local variety (Table 3). Belete and Gudene had 71 and 27%more marketable yield advantage over the local variety, respectively.

Partial budget analysis:

Application of nitrogen fertilizer and improved potato varieties are more profitable than without nitrogen application and local variety. The highest net benefit (205787ETB ha^{-1}) was recorded from Belete variety at nitrogen application rate of110 kg $ha^{-1}$with marginal rate of return (485%) greater

Table 3: Effect of nitrogen rates and varieties on tuber yield and yield components of potato.

Treatments	Tuber number per hill	Average tuber weight (g)	Tuber Yield (t ha^{-1})		
			Marketable	Unmarketable	Total
N rate (kg ha^{-1})					
0	7.46^{c}	45.21^{c}	16.50^{b}	4.02^{a}	19.10^{b}
55	9.17^{b}	54.62^{b}	19.70^{b}	2.84^{b}	22.54^{b}
110	13.29^{a}	66.04^{a}	30.70^{a}	1.83^{c}	32.54^{a}
165	14.17^{a}	71.84^{a}	28.70^{a}	2.56^{b}	31.27^{a}
LSD	1.11**	*7.39***	*3.5***	*0.53***	*4.32***
Variety					
Belete	12.24^{a}	73.46^{a}	29.8^{a}	2.15^{b}	30.91^{a}
Gudene	11.57^{a}	53.44^{b}	24.3^{b}	2.47^{b}	26.82^{b}
Local	9.27^{b}	51.38^{b}	17.5^{c}	3.81^{a}	21.34^{c}
LSD	0.97**	*6.39***	*3***	*0.46***	*3.74***
CV (%)	10.34	12.71	15.00	19.4	16.76

Means within a column with common letter are not significantly different; **= significant at $p<0.01$.

Table 4: Partial budget analysis of all treatment interactions of N rate and varieties on potato.

Variety	N rate (Kg ha^{-1})	Un adj. MY (Kg ha^{-1})	Adj.MY (Kg ha^{-1})	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
Local	0	10740	9666	67662	20000	47662.0	_
Local	55	13770	12393	86751	21956.5	64794.5	875
Local	110	24140	21726	152082	23913	128169.0	3239
Local	165	21440	19296	135072	25869.5	109202.5	D
Belete	0	20070	18063	126441	36000	90441.0	D
Gudanie	0	18770	16893	118251	36000	82251.0	D
Belete	55	23000	20700	144900	37956.5	106943.5	D
Gudanie	55	22330	20093	140651	37956.5	102694.5	D
Belete	110	39000	35100	245700	39913	205787.0	485
Gudanie	110	29000	26100	182700	39913	142787.0	D
Belete	165	37330	33597	235179	41869.5	193309.5	D
Gudanie	165	27330	24597	172179	41869.5	130309.5	D

Where, Un.adj. MY = Unadjusted Marketable Tuber Yield, Adj. MY = Adjusted Marketable Tuber Yield, TVC = Total Variable Cost, GB = Gross Benefit, NB = Net Benefit, MRR = Marginal Rate of Return, D = Dominated Treatment.

than the minimum requirement (100%). The MRR of 485% indicates that the farmer can get an additional benefit of 4.85 ETB per unit cost incurred if the farmers apply 110 kg nitrogen ha^{-1} for Belete variety instead of applying 110kg nitrogen ha^{-1} on local variety (Table 4). Belete gave the higher net benefit than *Gudenie* with the same production cost. The result indicated that it is economically preferable to produce Belete variety at nitrogen application rate of 110 kg nitrogen ha^{-1}.

DISCUSSION

The results of the present study indicated that application of nitrogen prolonged days to flowering and maturity. This might be because availability of nitrogen enhances the photosynthetic activity and prolonged the vegetative growth of potato. In line with the current result, Alemayehu & Jemberie (2018) and Zelalem (2008) reported that application of nitrogen prolonged days to flowering and physiological maturity. There was also significant difference among varieties with respect to days to flowering and maturity. The local variety flower and matures earlier than improved varieties (Belete and Gudene). This could be due to the inherent traits of the varieties. Other research results in different areas of Ethiopia also showed that the local variety flowered and matured earlier than *Gudanie* and Belete varieties (Amdie et al., 2017; Alemayehu & Jemberie, 2018; Fenta et al., 2018).

The present finding indicated that increasing the application of nitrogen up to 165 kg ha^{-1} significantly increased plant height. This might be because nitrogen plays an important role in various physiological processes and consequently has positive effect on plant growth (Zewide et al., 2012; Rupa et al., 2013). The present finding agrees with that of Sanjana et al. (2014) who reported that increasing the rate of nitrogen up to 375 kg ha^{-1} increases the plant height of potato. There was also significant difference among varieties in the current study with respect to plant height. Improved varieties (Belete and Gudene) were taller than the local variety. This might be because of the genetic makeup of the varieties. The study in high lands of Guji zone also showed that Belete variety was taller than the local variety (Amdie et al.,2017). Similarly, a study conducted at Koga irrigation scheme showed that improved varieties (Belete and Gudene) were taller than the local variety (Alemayehu & Jemberie, 2018).

The maximum number and average weight of potato tuber were observed from the highest nitrogen rate (165kg nitrogen ha^{-1}). In line with the current result, Wakjira (2017) also obtained the highest tuber number $plant^{-1}$ from 150 kg nitrogen ha^{-1} and the lowest from the control. Similarly, Gebremariam et al. (2016) observed that increasing nitrogen from 0 to 56 kg ha^{-1} increased the average tuber weight. In the present, a greater number of tubers per hill and average tuber weight were observed from the improved varieties (Belete and Gudene) than the local variety. Similarly, Amdieet al. (2017) illustrated that Belete variety scored the highest average tuber number per hill, followed by Gudene. Alemayehu and Jemberie (2018) also found bigger tubers from Belete variety than Gudene. In contrast, Gashaw et al. (2018) studied in Eastern Amhara and observed the maximum tuber number $plant^{-1}$ from local variety compared to Belete, Gudene and *Bullue*. This indicates different varieties perform differently in different environmental locations.

The current result revealed that marketable yield of potato can be improved through increasing the application of nitrogen up to165 kg nitrogen ha^{-1}. This could be mainly because of the increase in number and average tuber of potato tuber with increasing level of nitrogen rates. Other research results from other areas of Ethiopia also showed the improvement of potato tuber yield due to application of nitrogen and improved varieties. For example, Getie et al. (2015) observed that application of high nitrogen rate (110 kg nitrogen ha^{-1}) helped to significantly improve marketable tuber yield. A study in eastern Amhara showed that application of nitrogen at the rate of 138 kg ha^{-1} with 23 kg ha^{-1} phosphorus gave the highest marketable yield (15.29 t ha^{-1}) (Sebnie et al., 2021). In the present also showed that improved varieties produced more marketable yield than the local variety. Research result obtained from different location of the country also revealed that maximum marketable tuber yield was obtained from improved varieties (Belete and Gudene*)* while the lowest yield from local variety (Gebreselassie et al., 2016; Amdie et al., 2017; Alemayehu & Jemberie, 2018). Shiferaw et al. (2017) also found 66, 64 and 53% more marketable tuber yield advantage from improved varies of *Gorobela*, Gudene and *Jalane*, respectively over local variety.

Application of 110 kg nitrogen ha^{-1} on Belete variety was the most profitable treatment as it gave the highest net benefit (205787 ETB ha^{-1}) was recorded from 110 kg nitrogen ha^{-1}. In line with the present finding, the study in eastern Amhara showed that application of nitrogen at the rate of 138 kg ha^{-1} with 23 kg ha^{-1} phosphorus resulted in the highest net benefit (164597 ETB) (Sebnie et al., 2021). Alemayehu and Jemberie (2018) also found the highest net benefit of potato from Belete variety supplied with nitrogen-phosphate fertilizer with sulphur fertilizer at the rate of 283.75 kg ha^{-1}followed by Gudene at the same fertilizer rate.

In conclusion, the present finding showed that growth, yield and yield related parameters of the tested potato varieties were highly significantly influenced by the main effects of nitrogen rates. The maximum marketable tuber yield (30.70 t ha^{-1}) was recorded by application of 110 kg nitrogen ha^{-1}, which gave 86% yields advantage as compared to unfertilized plots. Belete variety produced the highest marketable yield (29.8 t ha^{-1}) with a yield advantage of 71% compared to the local variety. The partial budget analysis result showed that application of 110 kg nitrogen ha^{-1} for Belete variety gave the maximum net benefit (205787 ETB ha^{-1}) with acceptable marginal rate of return (485%). From the present result, it can be concluded that optimum yield and high profit can be obtained by applying 110 kg nitrogen ha^{-1} for Belete variety.

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COMPETING INTERESTS

The authors have declared that they have no competing interest.

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