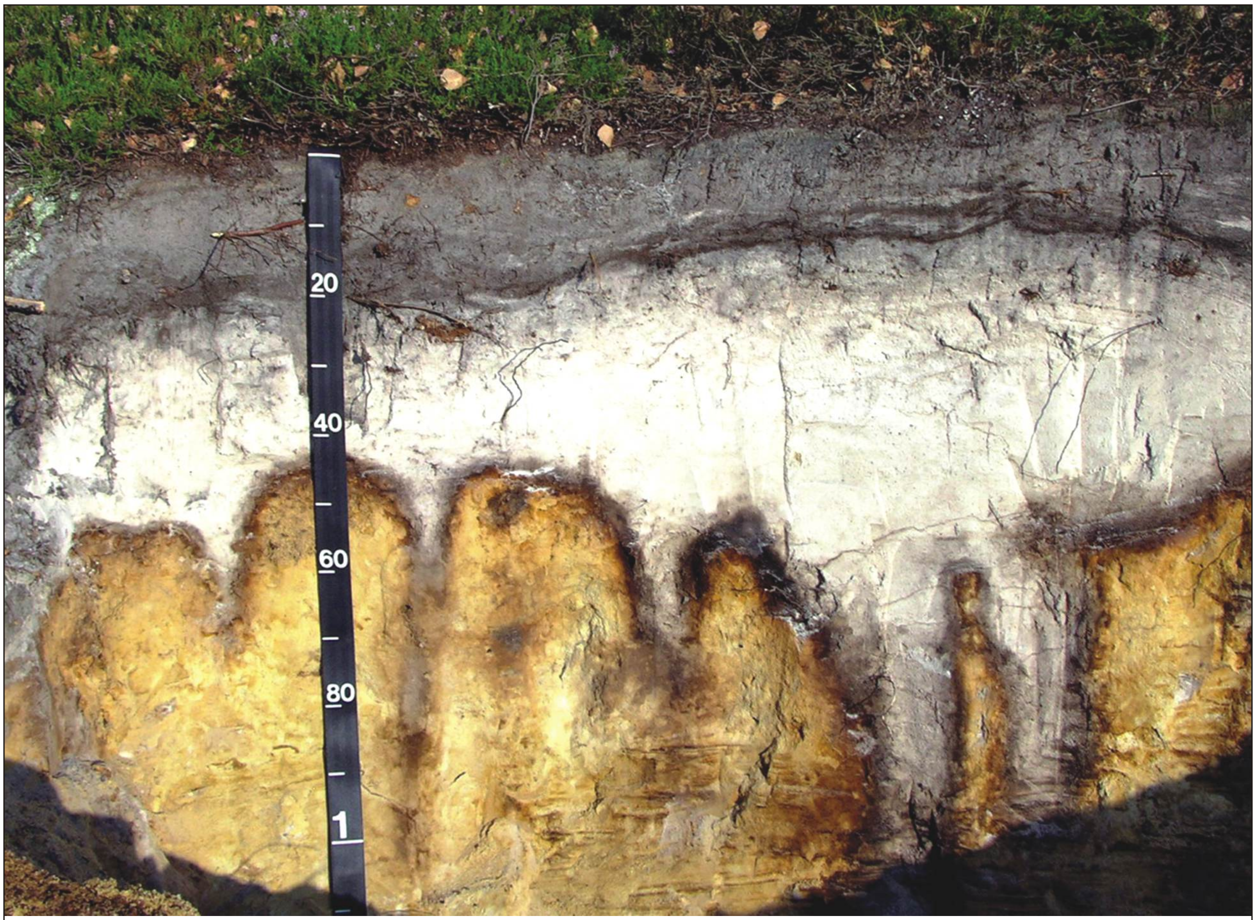

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Research Article
Influence of Nitrogen Rate on Nitrogen use Efficiency and Quality of Potato (*Solanum tuberosum* L.) Varieties at Debre Berhan, Central Highlands of Ethiopia

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Abstract

Background and Objective: Potato is an important crop grown by many smallholder farmers in the central part of Ethiopia. However, the productivity of the crop is low which is mainly attributed to poor soil fertility and improper application of fertilizers. Thus, this field experiment was conducted to study influence of nitrogen rate on nitrogen use efficiency and quality of potato (*Solanum tuberosum* L.) varieties at Debre Berhan, Central Highlands of Ethiopia. **Material and Methods:** Factorial experiment of six nitrogen rates (0, 46, 92, 138, 184 and 230 kg N ha^{-1}) and two varieties (Gera and Gudene) were arranged in randomized complete block design scheme with three replications. The collected data were subjected to ANOVA using SAS-GLM procedure. **Results:** The total N uptake and concentration in above ground part were raised by two and three folds, respectively with application of 230 kg N ha^{-1} that had increased N concentration in tuber by 57.17% and soils after harvest by 20.87% as compared to the control. Generally, the highest values of total dry matter, above ground biomass, total plant dry matter and medium size tubers were found at the 184 kg N ha^{-1} rate. However, the maximum amounts of agronomic and physiological N efficiencies were recorded at 46 kg N ha^{-1} that had the highest percent of apparent N recovery and N harvest index. **Conclusion:** The finding of this study had revealed that N had significant impact on production of quality potato tubers and nitrogen use efficiency. Generally, 184 kg N ha^{-1} showed the highest dry matter accumulation with good apparent nitrogen recovery and agronomic nitrogen use efficiency, beyond which there were poor efficiency and non-significant difference.

Key words: Nitrogen use efficiency, nitrogen harvest index, apparent nitrogen recovery, physiological efficiency, agronomic efficiency

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most important food crop next to maize, rice and wheat[1] and because of ability to give high yield of quality product per unit input within short growth period than major cereal crops like maize, it is the one among potentially food securing crop[2]. Potato is more enrich with important vitamins like thiamine, riboflavin, niacin and vitamin C than rice, maize and wheat. Besides, it is antispasmodic, mild anodyne, digestive remedy, diuretic and emollient[3].

Nitrogen, an essential constituent of metabolically active compounds such as amino acids, protein, enzymes, co-enzymes and some non-protein compounds, is the most important growth and yield limiting nutrient in potato production[4]. Over 40 years, the application of N-containing mineral fertilizers is increased by 7.4 folds while overall yield doing by 2.4 times implying that Nitrogen Use Efficiency (NUE) is very low in agricultural production[5]. Generally, establishing optimum nitrogen rates and application schedule for potato is a difficult task. For instance, late application until tuber initiation decreases economical yield due to poor tuber set[6] and/or excessive early-season application during tuber bulking delays tuberization by seven to ten days and reduces tuber yield[7]. Moreover, excessive N application during tuber initiation promotes vegetative growth and delays tuber maturity by prolonging the vegetative stage[8].

Ethiopia has the highest potential for potato production (about 70% of suitable arable land). But, the average yield is below 10 t ha^{-1}[9] which is lower than the 40 and 17.4 ha^{-1} for countries in North America and Europe, respectively[10]. Low soil fertility, the lack of improved varieties, poor crop management practices, diseases, poor research-extension linkage, poor seed system, use of inferior quality seed tubers of unknown origin and inappropriate storage structure are among the key factors contributing to this low yield[9].

As forwarded by Berga *et al.*[11] 165 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1} are still under use for potato production throughout our country. Basically for having better growth and yield of potato production on nitosols and vertisols of north Shewa zone (Debre Berhan), about 110 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1} were recommended[12]. However, these and other recommendations are not doing well due to genetic potential/responses of varieties in use, micro-climate and edaphic factors, market of the input and product, etc. Besides, there is a research gap in determining the NUE of potato tubers produced at the area. Thus, in view of the above facts, this research was conducted to determine the nitrogen use efficiency and quality of potato varieties in response to rates of nitrogen at Debre Berhan (Central Highlands of Ethiopia).

MATERIALS AND METHOD

Experimental treatment, design and statistical analysis: The experiment was conducted during the main growing season of 2015/16 on the Agricultural Experiment Site of Debre Berhan University which is found at about 125 km from the capital city Addis Ababa. The area is situated at 09°35'45'' to 09°36'45'' North latitude and from 39°29'40'' to 39°31'30'' East longitude. The treatment group had 2 potato cultivars namely Gudene and Gera that were tested for their response to six different rates of nitrogen (0, 69, 92, 138, 184 and 230 kg ha^{-1}). It was a factorial experiment at which the treatments were arranged in Randomized Complete Block Design (RCBD) with three replications.

All the collected data were subjected to a two way analysis of variance (ANOVA) using SAS GLM procedure[13]. The significance between mean values was checked by Tukey test at 5% probability level ($p \leq 0.05$).

Planting and field management: The crop was grown under rain fed condition using medium sized and well-sprouted potato tubers. The plot size was 3.75×2.45 m with five rows spaced by 75 cm each having seven plants at gap of 35 cm. The plots and blocks were separated by 1 m gap. Uniform dose of 70.5 kg ha^{-1} triple supper phosphate was applied at planting[12]. Nitrogen was applied as urea (46% N) at a distance of 10 cm away from the plant by splitting mode (half dose at planting and the remaining half at 45 days after planting)[14]. Two times earthing-up were done at 25 and 55 days after planting. Agronomic practices (weeding, cultivation and ridging) were done as per advice of horticulture division, Debre Berhan Agricultural Research Center.

Determination of soil physico-chemical properties: A composite soil sample was prepared from systematically collected ten sub samples using an auger from the top (0-30 cm depth) part of the experimental field for pre planting analysis. After harvesting another soil samples were collected from each plot of the three replications and mixed accordingly for total N analysis. Before their physical and chemical analysis, all the collected soil samples were air dried on plastic tray, ground and sieved through a 2 mm mesh sieve.

Particle size (soil texture) was determined by using hydrometer method of Bouyoucos[15]. Organic carbon was analyzed using the standard laboratory procedure according to Walkley and Black[16]. The soil pH was determined in 1:2.5 (weight/volume) soil to water dilution ratio using a glass electrode attached to digital pH meter[17] and the total N was determined by wet oxidation procedure of the Kjeldahl method[18]. The soil Cation Exchange Capacity (CEC) was determined by ammonium acetate method. Available phosphorus was tested using Olsen and Dean method[19].

Determination of potato tuber quality and nitrogen use efficiency: Tuber dry matter (%) was estimated by the weight ratio of tuber dry matter and fresh yield. Tuber size (%) was made on the bases of tuber weight at the market. Mean that, tubers below 45 g have categorized as small, 45-75 g as medium and above 75 g as large size. Tuber specific gravity was determined by weighing the tubers in air and under water method[20]:

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air-Weight in water}} \quad (1)$$

For determination total N in plant tissue using the micro-kjeldahl digestion methods[18], the tubers and haulms were chopped separately into pieces and dried at 65°C until a constant weight was obtained then after were ground and sieved[21].

Parameters like agronomic efficiency, physiological efficiency, apparent recovery, N harvest index and N use efficiency were calculated as follows using the formula of Mengel and Kirkby[22], Dobermann[23] and Fageria *et al.*[24]:

$$\text{Potato N uptake} = \text{N uptake by haulm} + \text{N uptake by tuber} \quad (2)$$

$$\text{N Harvest Index (NHI)} = \frac{\text{Nitrogen uptake in tuber}}{\text{Nitrogen uptake in tuber and haulm}} \quad (3)$$

$$\text{Agronomic Efficiency (AE)} = \frac{\text{TYf - TYU}}{\text{Na}} \quad (4)$$

where, TYf is the tuber yield of the fertilized plot, TYu is the tuber yield of the unfertilized plot and Na is the quantity of N applied:

$$\text{Physiological Efficiency (PE)} = \frac{\text{BYf - BYu}}{\text{Nf - Nu}} \quad (5)$$

where, BYf is the biological yield (tuber plus haulm) of the fertilized plot, BYu is the biological yield of the unfertilized plot, Nf is the N uptake of the fertilized plot and Nu is the N uptake of the unfertilized plot.

$$\text{Apparent N Recovery (ANR)} = \frac{\text{Nf - Nu}}{\text{Nu}} \quad (6)$$

where, Nf is the N uptake (tuber plus haulm) of the fertilized plot, Nu is the N uptake (tuber plus haulm) of the unfertilized plot and Na is the quantity of nutrient applied:

$$\text{Utilization Efficiency (EU)} = \text{ANR} \times \text{PE} \quad (7)$$

RESULTS AND DISCUSSION

Soil analysis before planting: The composite sample was analyzed and the mean physic-chemical characteristics are given in Table 1. The soil textural class was found as clay loam with moderate (25-40%) content of sand, silt and clay particles[25]. The pH value of the soil was found under moderately acidic (5.6-6.0) range[26].

The amount of Organic Matter (OM) in the soil was described as moderate (1.70-3.0%) rate[27]. Soils enrich with OM are characterized by sustainable crop productivity due to health soil processes[28]. The detected total N was under medium (0.12-0.25%) range[29]. The C: N ratio of the soil was under good (8-15) range[30]. The amount of available phosphorus in the soil was believed as moderate (10-17 ppm)[31]. Generally, the availability and adsorption of P in the soil is determined by physic-chemical properties like nature and amount of clay, level of OM, pH and reaction time, ion exchange and soil temperature[32].

Calcium was the dominant exchangeable base (20.81 cmol(+) kg^{-1}) than Mg (3.58 cmol(+) kg^{-1}), Na (0.02 cmol(+) kg^{-1}) and K (0.73 cmol(+) kg^{-1}) (Table 1). According to Metson[33], the CEC, PBS, exchangeable Na, exchangeable K, exchangeable Ca and exchangeable Mg were under high (25-40 cmol(+) kg^{-1}), very high (>80%), low (0.1-0.3 cmol(+) kg^{-1}), high (0.7-2.0 cmol(+) kg^{-1}), very high (>20 cmol(+) kg^{-1}) and high (3.0-8.0 cmol(+) kg^{-1}) ranges, respectively.

Tuber quality and nitrogen use efficiency of potato: The dry matter content of tuber, above ground parts and total plant dry matter were significantly ($p<0.05$) affected by different

Table 1: Pre planting soil physico-chemical properties of the experimental site

Parameters	Values
Clay: Silt: Sand (%)	39: 32: 29
Texture class	Clay loam
pH (1:2.5 soil to water)	5.8
Organic matter (%)	1.90
Total N (%)	0.17
C:N ratio	11
Available P (ppm)	13.28
CEC (cmol(+) kg^{-1})	27.45
Base saturation (%)	92
Exchangeable bases (cmol(+) kg^{-1})	
Sodium	0.02
Potassium	0.73
Calcium	20.81
Magnesium	3.58

CEC: Cation exchange capacity

Table 2: Effects of N and variety on above ground and tuber biomass accumulation, tuber specific gravity and tuber sizes

Factors	Treatments	Tuber dry matter (g per hill)	Above ground biomass (g per hill)	Total plant dry matter (g per hill)	Tuber specific gravity (g m^{-3})	Small size (%)	Medium size (%)	Large size (%)
N rate (kg ha^{-1})	0	182.67^{e}	18.17^{e}	197.83^{e}	1.094^{a}	28.15^{a}	64.30^{b}	7.55^{b}
	46	239.50^{d}	23.33^{d}	262.84^{d}	1.090^{ab}	14.94^{b}	72.85^{a}	12.21^{ab}
	92	271.83^{c}	26.67^{c}	298.50^{c}	1.087^{ab}	14.26^{b}	71.69^{a}	14.05^{a}
	138	303.00^{b}	31.66^{b}	334.67^{b}	1.086^{ab}	13.82^{b}	71.42^{a}	14.76^{a}
	184	359.33^{a}	39.33^{a}	398.67^{a}	1.085^{ab}	9.66^{b}	75.51^{a}	14.83^{a}
	230	358.67^{a}	37.33^{a}	397.00^{a}	1.066^{b}	9.22^{b}	74.53^{a}	16.26^{a}
LSD		21.98	2.19	21.06	0.015	6.20	5.89	6.13
Variety								
Gudene		288.67^{a}	30.00^{a}	317.03^{a}	1.0086^{a}	14.12^{a}	73.20^{a}	12.67^{a}
Gera		283.00^{a}	28.83^{a}	311.67^{a}	1.083^{a}	15.88^{a}	70.24^{b}	13.87^{a}
LSD		8.45	0.84	8.09	0.009	2.40	2.26	2.35
CV		4.28	4.14	3.72	1.32	23.16	4.57	25.68

LSD: Least significant difference, CV: Coefficient of variance, treatment means of the main effect within a column followed by the same letter are not significantly different ($p>0.05$) while the different letters are significantly different ($p<0.05$)

rates of N (Table 2). But, there was no remarkable difference between varieties and their interaction with the different levels of N. The highest dry matter content was obtained from 184 and 230 kg N ha^{-1} while the lowest from the control. The results indicated that increasing in N level up to 184 kg N ha^{-1} increased dry matter of potato but beyond this didn't show any increment. These findings are in line with Alam *et al.*[34], found decided that tuber yield per unit area was increased with increasing N fertilizer up to suitable level. When the N level gone beyond 184 kg N ha^{-1}, vegetative parts of the plant was found significantly higher which might be a reason for reduction of tuber formation through hampering translocation of photo assimilate to the storage organs. Because, excessive levels of N can affect tuber growth, yield and quality by shortening tuber bulking period, reducing specific gravity and delaying maturity[35].

Results of ANOVA indicated that specific gravity was significantly affected by the different rate of N ($p<0.05$). But, it was not affected by cultivars and their interaction with the different levels of N (Table 2). In accordance to the current results, several researchers reported that as N rate increased the specific gravity was decreased[36]; that might affect the internal quality of potato tuber (starch and total solids contents, mealiness, etc)[20].

Results revealed that significantly ($p<0.05$) the highest value of small size and lowest value of medium size potato tubers were recorded in the unfertilized plot (control) and with increasing N there was an increasing trend in tuber sizes (Table 2). Similarly, significantly the lowest value of large size potato tubers was recorded in control plot than all other treatments except 46 kg N ha^{-1} rate. This finding is similar with Kolodziejczyk[37] who reveled that dose of nitrogen at 180 kg ha^{-1} can increase the amount of marketable tubers than lower levels. Except the medium sizes of tuber, the large and small sizes tuber records were not shown significant variation ($p>0.05$) between varieties. Generally, highest amount of medium size potato tuber was shown in Gudene than Gera variety. In line with these findings, Saluzzo *et al.*[38], has revealed that positive effect of N on root dry weight increase in sweet potato can be attributed to more interception of photosynthetically active radiation, higher dry matter accumulation and partitioning to tuber portion of more medium and large sizes. Besides, N fertilization and cultivar features may directly influence the number and size of potato tuber[35,36].

The tuber N uptake was significantly ($p<0.05$) affected by the different rate of N 5% probability level. But, the ANOVA indicated that N uptake by the two cultivars had not shown significant variation. Likewise there was no remarkable difference due to interaction effect of the variety and different levels of N fertilizer (Table 3). The highest and lowest tuber N uptakes were recorded at the maximum (230 kg N ha^{-1}) and lower (0 kg N ha^{-1}/control) which had statistically similar value with the 184 and 46 kg N ha^{-1} levels, respectively. Because, the amount of nutrient uptake increases by application of more fertilizer levels[39] and there is a significant effect ($p<0.05$) of nitrogen rates on tuber nitrogen content[40]. However, these results were in contrast to the finding of Shunka *et al.*[41], who obtained lowest uptake form an increased N rate (133 kg ha^{-1}) than the lowest (87 kg ha^{-1}).

Results of ANOVA indicated that the total plant N uptake was significantly ($p<0.05$) affected by different rate of N but not by the varieties and it was not significantly ($p>0.05$) affected by the interaction of varieties and different rate of N. Moreover, the above ground N uptake was statistically similar in both varieties and their interaction with different level of

Table 3: Effects of N and variety on tuber and above ground N concentrations, total plant N uptake and total soil N after harvest

Factors	Treatments	Tuber N concentration (%)	Above ground N concentration (%)	Total plant N uptake	Total soil N after harvest (%)
N rate (kg ha^{-1})	0	0.84^{e}	0.96^{e}	1.60^{e}	0.23^{c}
	46	1.03^{d}	1.46^{d}	2.5^{d}	0.243^{c}
	92	1.14^{c}	1.95^{c}	3.08^{c}	0.246^{c}
	138	1.23^{b}	2.45^{bc}	3.5b^{c}	0.250^{bc}
	184	1.27^{ab}	2.78a^{b}	3.75^{b}	0.266^{ab}
	230	1.32^{a}	2.95^{a}	4.27^{a}	0.278^{a}
LSD		0.076	0.47	0.48	0.018
Variety					
Gera		1.13^{a}	1.90^{a}	3.20a	0.258^{a}
Gudene		1.14^{a}	2.06^{a}	3.03a	0.250^{b}
LSD		0.03	0.18	0.18	0.007
CV		3.37	13.30	8.86	3.99

LSD: Least significant difference, CV: Coefficient of variance, Treatment means of the main effect within a column followed by the same letter are not significantly different (p>0.05) while the different letters are significantly different (p<0.05)

Table 4: Effects of N and variety agronomic N efficiency, physiological N efficiency, apparent N recovery and N harvest index

Factors	Treatments	AE (kg tuber/kg N applied)	PE (kg tuber/kg N applied)	ANR (%)	NUE (%)	NHI (%)
N rate (kg ha^{-1})	0	-	-	-	-	0.53^{a}
	46	162.58^{a}	62.11^{a}	0.86^{a}	56.01^{a}	0.42^{b}
	92	146.21^{ab}	52.30^{ab}	0.72^{ab}	37.81^{ab}	0.37^{bc}
	138	142.69^{ab}	50.16^{ab}	0.61^{ab}	25.89^{b}	0.35^{cd}
	184	134.98^{ab}	47.18^{b}	0.52^{ab}	22.81^{b}	0.34^{cd}
	230	101.71^{b}	42.72^{b}	0.51^{b}	24.23^{b}	0.31^{d}
LSD	45.94	14.81	0.24	15.21	0.06	
Variety						
Gera		133.93^{a}	49.11^{a}	0.61^{b}	30.03^{a}	0.39^{a}
Gudene		141.34^{a}	52.68^{a}	0.76^{a}	39.95^{a}	0.38^{a}
LSD		20.18	5.19	0.104	7.08	0.02
CV		19.11	16.67	20.99	26.38	8.86

LSD: Least significant difference, CV: Coefficient of variance, AE: Agronomic N efficiency, PE: Physiological N efficiency, ANR: Agronomic N recovery, NUE: N use efficiency, NHI: N harvest index, Treatment means of the main effect within a column followed by the same letter are not significantly different (p>0.05) while the different letters are significantly different (p<0.05)

N p>0.05). But, significant (p<0.05) variations was shown among the different levels of N treatments (Table 3) and it was analogous to the work of Gagnon *et al.*[42], who verified that as the level of N fertilizer increased so does the concentration in above ground N concentration. This might be due to the fact that vegetative parts of the plant was increased due to the highest dose of N which consequently results in higher take up of the nutrient in the soil.

Significantly different total soil N after harvest was recorded due to the variation in variety and levels of N (p>0.05). But their interaction effects was not shown statistically different total soil N (p>0.05). The ANOVA results indicated that variety Gera had shown higher total soil N than Gudene (Table 3). Similarly, the highest soil N left over was recorded from the plots treated with higher N than the low and control treatments and statistically similar total soil N was recorded on the plots of 184 and 230 kg N ha^{-1} but there was no statistical difference among all the treatments. Similar finding was reported by Gagnon *et al.*[42], as an increased level of N has found in the soil after harvest due to excessive application of N containing fertilizer beyond the plant use.

Different rate of N significantly (p<0.05) influenced the agronomic N efficiency of potato. But, the varieties and their interaction effects with different rate of N were not significantly (p>0.05) influenced the agronomic N efficiency. As shown Table 4, the lowest agronomic efficiency was shown in the high rate of applied N (230 kg N ha^{-1}) and it was statistically similar with 184 kg N ha^{-1}. Normally, there was no statistical difference of agronomic efficiency among the rate of 92, 138 and 184 kg N ha^{-1} that were significantly lower than the 46 kg N ha^{-1}. Several researchers had obtained reduced agronomic N efficiency as application of N increase[35,36]. In order to get high agronomic N use efficiency, the yield increment per unit nitrogen applied should be high due to reduced nitrogen losses and increased uptake of nitrogen[43].

Application of different N level had significant (p<0.05) effect on physiological N efficiency of potato varieties. However, variation in physiological N efficiency of the varieties was statistically in par (p>0.05). The interaction effects of varieties and different N rate had shown non-significant (p>0.05) variation (Table 4). The highest physiological N efficiency was for 46 kg N ha^{-1} and an increase in N rate from

92-230 kg N ha^{-1} had not shown any difference in physiological N efficiency. In harmony to this, the finding of Jamaati-e-Somarin *et al.*[35], also indicated a reduced physiological efficiency as application of N fertilizer increased.

Results revealed that significant effects of the variety (p<0.05) and N rate (p<0.05) on apparent N recovery. As shown in Table 4, effect of different rate of N was influenced apparent N recovery of potato but not the varieties and their interaction effects. The lowest apparent N recovery was shown in 230 kg N ha^{-1} rate which was statistically similar with all the other treatments except the 46 kg N ha^{-1}. Likewise, there was no statistical difference recorded in apparent N recovery between 46 and 92 kg N ha^{-1} rate. Similar finding had reported that decreasing N rate from 500-125 kg N ha^{-1} was significantly (p<0.05) increased in N recovery[35].

According to Fageria *et al.*[44], N harvest index is very useful in measuring nutrient partitioning in crop plants, which provides an indication of how efficiently the plant utilized acquired N for economic production. Results of ANOVA indicated that different rate of N was significantly (p<0.05) influenced N harvest index of the plants. Conversely, the varieties and their interaction with rates of N was not shown any significant (p>0.05) variation in N harvest index (Table 4). The highest N harvest index was found in the control treatment followed by 46 and 92 kg N ha^{-1}. But, the lowest value of N harvest index was recorded at the 230 kg N ha^{-1} that had statistically similar value with the 184 and 138 kg N ha^{-1} rates. In agreement to results of Jan *et al.*[45], who reported unfertilized plots had higher N harvest index than fertilized plots.

The effects of different N rate were significantly (p<0.05) influenced N use efficiency but varieties and their interaction effects with N rate did not influence the N use efficiency. The highest percentage of utilization efficiency was recorded from 46 kg N ha^{-1} (Table 4). Plants treated with 92, 138, 184 and 230 kg N ha^{-1} were not shown any significant variation in use efficiency. In accordance to Saravia *et al.*[46] and Jamaati-e-Somarin *et al.*[35], a maximum Nitrogen Use Efficiency (NUE) was occurred at minimum N level. Because as the rate of N increases, there will be more vegetative growth which in turn reduce utilization efficiency by decreasing the root to shoot ratio of the plant[47].

CONCLUSION

This experiment revealed that potato varieties had different responses of tuber quality and nitrogen use efficiency to rates of N at which the 184 kg N ha^{-1} had shown highest dry matter, above ground biomass and medium size potato. Besides, this rate had closer tuber specific density, agronomic nitrogen use efficiency and apparent N recovery with other lower N rate treatments. So that, it is reasonable to use 184 kg N ha^{-1} for ensuring profitable potato production in most parts of the central highlands of Ethiopia.

SIGNIFICANCE STATEMENT

This research discovers the unusual concerns of nitrogen nutrient rate on nitrogen use efficiency and quality of potato varieties at central highlands of Ethiopia that can be beneficial for both producers and consumers. The study will help the researchers to uncover the critical areas of soil fertility and plant nutrition (soil science and horticulture). Thus, a new theory on nitrogen use efficiency and quality of potato varieties due to application of nitrogen containing fertilizers may be found and practiced.

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