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Effect of nitrogen and potassium application rates on nitrogen use efficiency and tuber minerals content in central high lands of *Ethiopia*

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An experiment was conducted on a Nitisol of Holetta agricultural research and Jeldu Sub-center using three factors such as potato varieties (Belete, Jalenie and Gudanie), nitrogen rates (87, 110 and 133 kg/ha) and potassium oxide rates (0, 34.5, 69 and 103 kg/ha) that were arranged on randomized complete block design with three replications. The data were subjected to Proc GLM model of SAS software version 9.2. Higher tuber nitrogen content, uptake and utilization was obtained from Holetta location than Jeldu. Increasing nitrogen fertilizer from 87 to 133 kg/ha reduced the tuber nitrogen uptake and utilization efficiency by 75.56 and 75.49%, respectively. The interaction between variety and location also highly significantly affected tuber nitrogen content and nitrogen utilization efficiency. The interaction between nitrogen and variety affected tuber nitrogen in percent and protein content highly significantly. The highest tuber nitrogen and protein content was obtained from Belete and Gudenie varieties at a rate of 110 kg/ha nitrogen. From these results, it can be concluded that, the interaction between nitrogen and potassium rates did not affect significantly any parameter measured in this experiment, while nitrogen, varieties, interaction of location with variety showed significantly different nitrogen use efficiencies and tuber minerals content.

Key words: Gudenie, Belete, Jalene, potassium, nitrogen rates.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is temperate crop (Onder et al., 2005) that satisfactorily grows and yields well in cool and humid climates. It is a major food crop in many countries being grown from the tropics to the sub-polar. Among African countries, Ethiopia has possibly the greatest potential for potato production as 70% of its arable land mainly in highland areas with altitude greater than 1,500 m above sea level is considered suitable for potato (Yilma, 1991). As potato is a source of both food and income in the growing countries of the world, it can change greatly the food security ensuring capacity of countries as result of high productivity per unit area and time in relation to other crops. In addition, high prospects for growth of the market for fresh potatoes (Scott et al.,

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2000); make the commodity fundamental for rural development particularly in countries where food security is a major problem.

Soil fertility decline is one of the major environmental problems threatening the livelihoods of millions of farm households in rural Ethiopia (Mitiku et al., 2007). Stoorvogel et al. (1993) estimated that about 41 kg of N, 6 kg of P and 26 kg of K is lost per hectare per year from Ethiopian highlands which was valued in to $24 to 193 per ha per year (Ekossa et al., 2015). On top of this, approximately 41% of the total farmland of the country is acidic, of which nearly one-third faces the problem of aluminum toxicity (EATA, 2013). Strong soil acidity is associated with Al, H, iron (Fe), and manganese (Mn) toxicities to plant roots in the solution and corresponding deficiencies of the available phosphorus (P), molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium (K) (Jorge and Arrunda, 1997). The problem is exceptionally severe in the highlands of the country where the majority of the human and livestock population is concentrated (Teklu, 2005). Plants grown on acidic soils may be limited by deficiencies of N, P, K, Ca, Mg, or Mo; toxicity of Al or Mn; reduced nutrient cycling; and reduced uptake of nutrients by plant roots and inhibition of root growth (Marschner, 2011). Soil acidity adversely affects morphological, physiological and biochemical processes in plants and thus N uptake and use efficiency (Fageria and Baligar, 2005; Marschner, 2011). Plant nutrition is the practice of providing to the plant the right nutrient, in the right amount, in the right place, at the right time.

Potatoes productions require relatively high amounts of fertilizer (Munoz et al., 2005; Pack et al., 2006). Because of its shallow root system and short crop duration, the nutrient requirement of potato is very high (Dechassa and Schenk, 2004). Love et al. (2003) also described that, potato has shallow root system and relatively poor nutrient and water use efficiency. Depending on the soil type, variety, crop rotation, moisture supply and management practices a normal potato crop may remove an estimated 90 to 120 kg ha^{-1} of N, 13.8 to 25.8 kg ha^{-1} of P and 150 to 250 kg ha^{-1} of K from the soil (Sikka, 1982). As reported by Getu (1998), tubers account for more than 70% of the nutrient removed from the soil. N and K are found in largest amounts in a potato plant followed by Ca and Mg. Most of the phloem mobile nutrients will be in the tubers at harvest while the immobile nutrients will be in the residual vegetative portion of the plants (Westermann, 2005). The consequence of poor efficiency and high water/fertilizer rates requirement in potato is the potential for significant N acidification to soil as well as surface (Honisch et al., 2002) and groundwater (Madramootoo et al., 1992). Unless it is checked, the environmental pollution due to these effects is hazardous for future life sustenance. In potato production N is applied more frequently and in greater amounts than any other nutrient. An adequate amount of N increases root and shoot number and size of tubers. It is also the nutrient that most often limits yield (Tisdale et al., 1995), they reported that, N responses varies with the soil type, varieties, length of the growing season, organic manures, kind of fertilizers, time and method of application, moisture supply and nutrient interaction. Nitrogen and potassium rates determination for varieties relating with the nitrogen use efficiency is very important to alleviate these problems and maximize farm profit by declining resources wastage or cost of production, and increasing regulations to reduce environmental pollution (Powell et al., 2010). Low potassium nutrient availability is one of the limiting factors for plants growth which commonly found in acid soils including inceptisols (Amisnaipa et al., 2016).

Efficient use of available resources, especially water and nutrients, is one of the most important objectives in the sustainable management of cropping systems. Nitrogen use efficiency (NUE) in plants is a complex phenomenon that depends on a number of internal and external factors. According to Ravi et al. (2008), it basically depends on soil nitrogen availability, its uptake and assimilation, photosynthetic carbon and reluctant supply, carbon-nitrogen flux, nitrate signaling and regulation by light and hormones. Nitrogen use efficiency is a yield determining parameter that can be computed either by use of taken up nitrogen or utilized portion of nitrogen for formation of tubers. NUE can also be expressed based on apparent nitrogen recovery using physiological and agronomic parameters (Ravi et al., 2008). The most suitable way to estimate NUE depends on the crop, its harvest product and the processes involved in it.

Though potato has been under cultivation for 154 years in Ethiopia with high production potential, its national average yield is very low (7.9 t ha^{-1}) (Peter et al., 2009), compared to the world average (16.4 t ha^{-1}) (FAO, 2004). Among factors contributing to low average yield, poor agronomic practice and inefficient resource management are very important ones. Therefore, the present research was conducted in Holetta and Jeldu location to quantify and compare the nitrogen use efficiencies of three potato varieties (Jalenie, Gudenie and Belete) and also to determine the interaction effect of rates of nitrogen and potassium on nitrogen use efficiency (NUE) and tuber minerals content of the Jalanie, Gudenie and Belete potato varieties.

MATERIALS AND METHODS

A field experiment was conducted in 2014 and 2015 at Holetta Agricultural Research and Jeldu sub-center including three factors, potato varieties (Jalenie, Gudenie and Belete), nitrogen at rates 87, 110 and 133 kg/ha and potassium at rates 0, 34.5, 69 and 103.5 kg/ha, respectively. The experiments were laid out using completely randomized block design with three replications. The fertilizers source used were urea (CO ($[NH_2]_2$) (46% N) and 90 kg/ha of diammonium phosphate (DAP) (46% P_2O_5) and

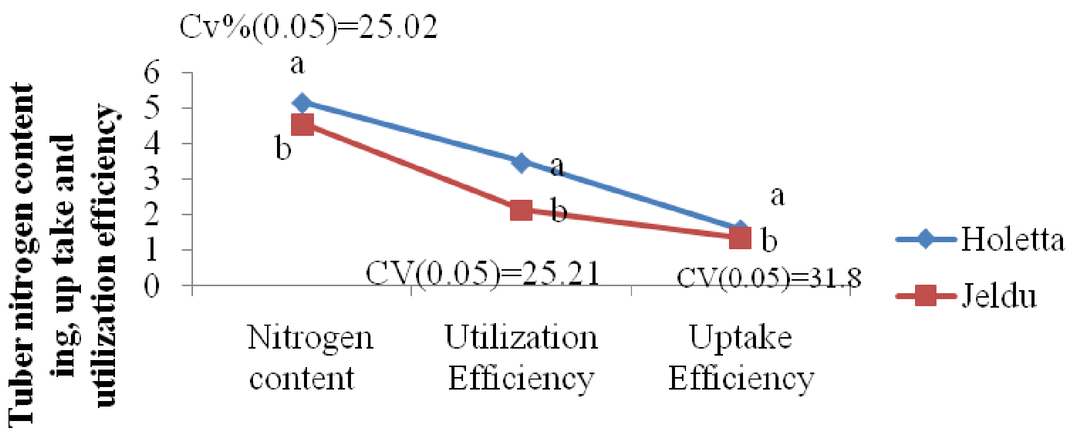

Figure 1. Effect of growing year on tuber up take and nitrogen efficiency.

potassium nitrate (KNO_3=13%N and 46% K_2O). The land was prepared well in similar ways of land preparation rule for potato fields in Holleta research center and potato tubers used for planting were similar in size for the three varieties. Planting was carried out using sprouted tubers in 10 cm depth with 75 cm distance between rows and 30 cm between plants on 3 m × 3 m plot size. The nitrogen fertilizer was applied in two split: Half as basal at planting and half at 45 days after planting (Girma and Ravishanker, 2008) at 5 cm around the root zones as reported in Teriessa (1997). Phosphorus at a rate of 195 kg/ha in the form of DAP and potassium fertilizer was applied during planting. A fungicide, Ridomil MZ 68% WP at the rate of 2 kg/ha was applied to control late blight following incidence of 24 to 36 h. Others cultural practices were done in the same practice as Holetta Research Center recommended practice for potato production. tuber harvesting was done once at proper physiological maturity (70% leaves withering). Tuber fresh weight and dry mass was measured after drying sample biomass in oven dry at 65°C until constant weight was achieved. Tuber dry weight (dried at 65°C until constant weight) was grinded in to flour and total nitrogen in dry matter was determined by micro-kjeldahl method using the following formula.

$$\textbf{Absorption or uptake efficiency} = \frac{\text{Total plant uptake (g)}}{\text{Nitrogen supply (g)}}$$

$$\textbf{Utilization efficiency} = \frac{\text{Average tuber fresh weight (g)}}{\text{Nitrogen supply (g)}}$$

Where = total plant nitrogen uptake at maturity (tuber + haulm), average tuber fresh weight (g) at maturity and Nitrogen Supply (g) = applied N + Soil N.

Data was subjected to analysis of variance using proc GLM (general linear model) procedure of SAS 9.2 software (SAS Institute Inc. 2009). The means was compared with Duncan's multiple rage test at 5% significance level.

RESULTS AND DISCUASION

The growing locations affected the tuber nitrogen content (g/m^2), uptake and utilization efficiency highly significantly (Figure 1). It also affected percent phosphorus, potassium, and total available nitrogen as well as organic matter content of tuber highly significantly (Table 1). Higher tuber nitrogen content (g/m^2), uptake and utilization was obtained from Holetta location than Jeldu. The effect of potassium rates on tuber nitrogen content (g/m^2), up take and utilization efficiency was not significant (Table 2). The higher tuber phosphorus and organic matter was recorded from Jeldu while the higher potassium and total available nitrogen was recorded from Holetta location.

The nitrogen rates were highly significantly affected uptake and utilization efficiency (Table 3). The highest nitrogen uptake and utilization efficiency was produced at a rate of 87 kg/ha, while the lowest was obtained at a rate of 133 kg/ha (Table 3). Increasing nitrogen rates decreased the efficiencies of nitrogen fertilizer. Increasing nitrogen fertilizer from 87 to 133 kg/ha reduced the tuber nitrogen uptake and utilization efficiency by 75.56 and 75.49%, respectively.

The potato varieties produced significantly different uptake and utilization efficiency and highly significantly different tuber dry matter nitrogen percentage and gram nitrogen (Table 4). The higher tuber nitrogen percentage was produced from potato variety Gudenie, while two remaining varieties provided statistically not different lower values. The highest gram nitrogen content and uptake efficiency was obtained from Gudenie variety though the value is not significantly different from Belete. The maximum utilization efficiency was recorded from Belete even though the value is not statistically different from Gudenie.

The interaction between location and nitrogen rates was highly significant (Table 5). The highest utilization efficiency was produced from Holetta location at a rate of 87 kg/ha nitrogen, while lowest was obtained from Jeldu location at a rate of 133 kg/ha nitrogen. The tuber nitrogen content in gram from dry matter and uptake efficiency was not significantly affected by the interaction

Table 1. Effect of growing location on tuber content.

Location	P (%)	K (%)	OM (%)	TN (%)
Jeldu	0.22^{a}**	0.73^{b}**	96.23^{a}**	0.93^{b}**
Holetta	0.17^{b}**	1.17^{a}**	95.37^{b}**	1.18^{a}**
CV(0.05)	13.35	17.83	0.52	16.38

Means followed by same letter(s) are not significantly different from each other at $p \leq 0.05$. **- indicate means which are significantly different at 1% level of probability. CV%, Coefficient of variance.

Table 2. Effect of potassium rates on tuber up take and nitrogen efficiency.

K_2O kg/ha	Tuber nitrogen (g)	Uptake efficiency	Utilization efficiency
0	4.85^{ns}	1.44^{ns}	2.6^{ns}
34.5	4.79^{ns}	1.45^{ns}	2.78^{ns}
69	4.92^{ns}	1.49^{ns}	2.86^{ns}
103.5	4.88^{ns}	1.44^{ns}	2.96^{ns}
CV%($_{0.05}$)	25.02	31.78	25.21

CV%, Coefficient of variance. Ns, Means which are not significantly different at $p \leq 0.05$.

Table 3. Effect of nitrogen rates on tuber up take and nitrogen efficiency.

Nitrogen (kg/ha)	Tuber nitrogen (g)	Uptake efficiency	Utilization efficiency
87	4.76^{ns}	2.66^{a}**	5.14^{a}**
110	4.92^{ns}	1.05^{b}**	2.0^{b}**
133	4.89^{ns}	0.65^{c}**	1.26^{c}**
CV%($_{0.05}$)	25.02	31.78	25.21

Means followed by same letter(s) are not significantly different from each other at $p \leq 0.05$. **Indicate means which are significantly different at 1% level of probability. CV%, Coefficient of variance. Ns, means which are not significantly different at $p \leq 0.05$.

Table 4. Effect of variety on tuber up take and nitrogen efficiency.

Variety	Tuber nitrogen (g)	Total nitrogen (%)	Up take efficiency	Utilization efficiency
Belete	5.03^{ab}**	1.036^{b}**	1.45^{ab}*	2.92^{a}*
Gudenie	5.09^{a}**	1.098^{a}**	1.54^{a}*	2.81^{ab}*
Jalenie	4.46^{c}**	1.022^{b}**	1.33^{c}*	2.67^{b}*
CV%($_{0.05}$)	25.02		31.78	25.21

Means followed by same letter(s) are not significantly different from each other at $p \leq 0.05$. **- indicate means which are significantly different at 1% level of probability. CV%, Coefficient of variance.

Table 5. Effect of location and nitrogen rates on tuber up take and nitrogen efficiency.

Nitrogen (kg/ha)	Tuber nitrogen (g)		Uptake efficiency		Utilization efficiency	
	Holetta	Jeldu	Holetta	Jeldu	Holetta	Jeldu
87	5.09^{ns}	4.44^{ns}	2.86^{ns}	2.46^{ns}	6.37^{a}**	3.92^{b}**
110	5.3^{ns}	4.54^{ns}	1.14^{ns}	0.97^{ns}	2.47^{c}**	1.54^{d}**
133	5.09^{ns}	$4.7n^{s}$	0.69^{ns}	0.62^{ns}	1.55^{d}**	0.97^{e}**
CV%($_{0.05}$)	25.02		31.78		25.21	

Means followed by same letter(s) are not significantly different from each other at $p \leq 0.05$. **, means which are significantly different at 1% level of probability. CV%, Coefficient of variance. Ns, Means which are not significantly different at $p \leq 0.05$.

Table 6. Effect of growing location and variety on tuber up take and nitrogen efficiency.

Variety	Tuber nitrogen (g)		Uptake efficiency		Utilization efficiency	
	Holetta	Jeldu	Holetta	Jeldu	Holetta	Jeldu
Belete	5.08b**	4.98b**	1.52^{ns}	1.48^{ns}	3.62^{a}*	2.23^{b}*
Gudenie	5.76a**	4.42c**	1.73^{ns}	1.35^{ns}	3.45^{a}*	2.17^{b}*
Jalenie	4.63bc**	4.28c**	1.44^{ns}	1.23^{ns}	3.31^{a}*	2.03^{b}*
CV%$_{(0.05)}$	25.02		31.78		25.21	

Means followed by same letter(s) are not significantly different from each other at p≤0.05. **- indicate means which are significantly different at 1% level of probability. CV%, Coefficient of variance. Ns, Means which are not significantly different at p≤0.05.

Table 7. Interaction between N and variety on nitrogen and protein content.

Nitrogen rates (kg/ha)	Varieties					
	Available nitrogen (%)			Protein content		
	Belete	Gudenie	Jalenie	Belete	Gudenie	Jalenie
87	0.99^{c}*	1.11^{ab}*	0.99^{c}*	6.16^{c}*	6.94^{ab}*	6.21^{c}*
110	1.114^{a}*	1.12^{a}*	0.99^{c}*	6.96^{a}*	6.99^{a}*	6.17^{c}*
133	1.01^{bc}*	1.07^{abc}*	1.09^{abc}*	6.31^{bc}*	6.66^{abc}*	6.78^{abc}*
CV%(0.05)		16.38			16.37	

Means followed by same letter(s) are not significantly different from each other at p≤0.05. *, indicate means which are significantly different at 5% level of probability. CV%, Coefficient of variance. Ns, means which are not significantly different at p≤0.05.

between nitrogen and growing location. The interaction between variety and location also highly significantly affected tuber nitrogen content and nitrogen utilization efficiency (Table 6). The highest tuber nitrogen content (g) was obtained from Gudenie variety grown at Holetta location and the lowest was produced from Jalenie and Gudenie grown at Jeldu location. In addition, higher utilization efficiency was obtained from Belete variety even though it was not significantly different from nitrogen utilization efficiency of Gudenie and Jalenie at same location. The lowest was obtained from Jalenie at Jeldu location, while it was not statistically different from both Gudenie and Belete utilization efficiency of Jeldu location.

The interaction between location and variety significantly affected tuber potassium content (Figure 2). The highest tuber potassium was recorded from Gudenie produced at Holetta location however, on par with Jalenie value produced from same location. The lowest tuber potassium content was obtained from Gudenie grown at Jeldu location even though on par with Belete content at same location. The interaction between nitrogen and variety affected tuber nitrogen in percent and protein content is highly significant (Table 7). The highest tuber nitrogen in percent and protein content was obtained from Belete and Gudenie varieties at a rate of 110 kg/ha nitrogen however, the values were on par with Gudenie at a rate of 87 kg/ha nitrogen, and Gudenie and Jalenie at 133 kg/ha nitrogen rate.

Uptake efficiency was affected by the factors; 65% as R^2 for regression indicated at 0.65. The model for regression analysis was uptake efficiency = 3.61+0.1 k-N-variety. Nitrogen was affected the parameter significantly even at p-value <.0001 while the direction is inverse. Potassium affected the nitrogen uptake efficiency non significantly by 10% that means a unit change in potassium application cause 0.1 increase in up take efficiency.

According to David et al. (2016) there were varietal variability in their nitrogen use efficiencies and the maximum efficiency was recorded at low nitrogen level which makes this experiment and present finding similar. Increasing nitrogen rates from 0 to 250 kg/ha increased tuber nitrogen concentration from 0.68-0.81 to 1.27-1.49% DM (Millard, 1986). It was also mentioned that increment of amount of each amino acid contained in a unit weight of fresh tuber increased with increasing nitrogen supply. According to Ochi-e-Ardabili et al. (2010) there is a significant effect of nitrogen rates on tuber nitrogen content. They also described the interaction between nitrogen rates and spacing had imposed significant impact on protein and potassium content. Increasing nitrogen increased tuber potassium content (Mahmoodi and Hakimian, 2005). Again, these results are in agreement with the finding of Kakuhenzire et al. (2005) in which higher nitrogen uptake efficiency was reported from lower rate of nitrogen applied (0-40 kg/ha) than higher rate (40-80 kg/ha). Similar results were reported by Beukema and van der Zaag (1990). According to Singh and Lal (2012) there was significant

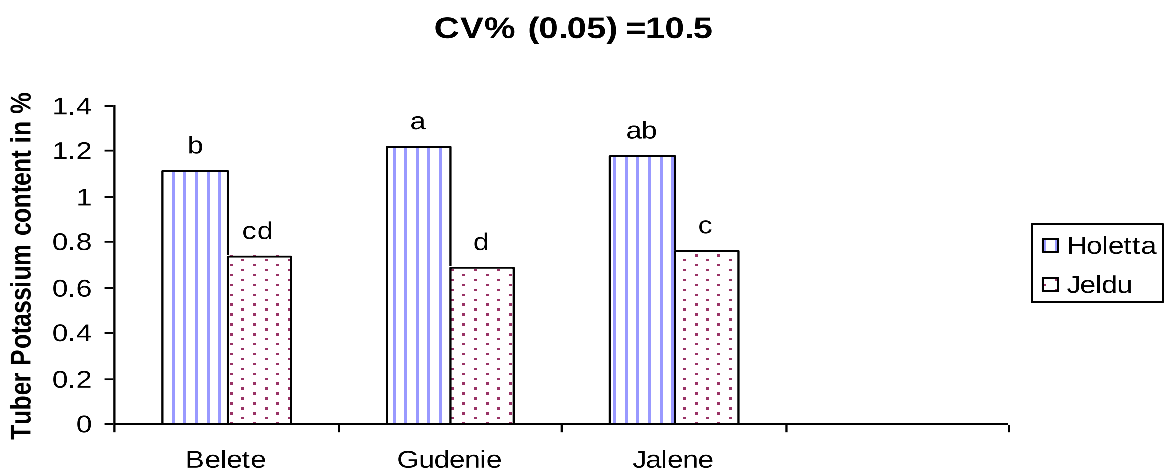

Figure 2. Interaction effect between location and variety on potassium content.

positive interaction between N and K. At each level of N, increasing levels of K application increased the tuber yield, N and K uptake by potato at harvest (Singh and Lal, 2012). Optimal N-K ratios favored crop growth and enhanced K and N use efficiency (Regmi et al., 2002). Higher nutrient content at higher level of fertilizer application together with higher dry matter production resulted in higher nutrient uptake (Chettri and Thapa, 2002). Potassium enhances N uptake and protein synthesis there by increasing the N uptake (Marschner, 1995). Increasing nitrogen increased leaf petiole N significantly and the interaction between nitrogen and potassium significant affected N content (Abu-Zinada, 2009), they also reported that petiole K significantly increased as K increased, whereas nitrogen was of insignificant effect on K, but the interaction between N and K imposed significant influence on K content. Also, Bertrand et al. (2011) indicated increasing mechanisms of controlling plant N economy is essential for improving NUE and for reducing excessive input of fertilizers, while maintaining an acceptable yield and sufficient profit margin for the farmers. It also further explained its combination with gene, protein and metabolite profiling to build up a comprehensive picture depicting the different steps of N uptake, assimilation and recycling to produce either biomass in vegetative organs or proteins in storage organs. Who, also indicated higher NUE at lower level nitrogen input use which are in agreement with the present findings. The genetic variability for both N absorption efficiency and for N utilization efficiency for most crops was showed in Hirel et al. (2007). Not only NUE but also each step of it (N uptake, transport, assimilation, and remobilization) is variable based on both genetic and environmental factors (Xu et al., 2012). In most intensive agricultural production systems nitrogen leaching may reach up to 50 to 75% from N applied to environment (Asghari and Cavagnaro, 2011) which can be a serious risk for human health due to contaminating water (Umar and Iqbal, 2007). According to Sutton et al. (2011) energy crops have a large capacity to produce higher biomass with the minimal amount of N fertilizer while at the same time protecting the environment. Others strategies to improve NUE are to use genetic modification or to breed for new varieties that take up more organic or inorganic N from the soil N and utilize the absorbed N more efficiently (Hirel et al., 2007). According to Hirel et al. (2007), N uptake and utilization efficiencies (NUE) are species-specific. Genotypic and environment interactions also have considerable impact on varieties NUE (Ludewig et al., 2007). Species and cultivars are expected to play a primary role in determining NUE as it affects both the N uptake and the use of absorbed N (Schenk, 2006). Furthermore, the same genotype can show different NUE response to different levels of N available (Burns, 2006).

CONCLUSION AND RECOMMENDATION

Similar to other finding done on nitrogen use efficiency, this experiments result indicated that, there were location variation in their tuber phosphorus, potassium, organic matter and nitrogen content. There was also growing year highly significant impact on nitrogen use efficiencies and tuber nitrogen content. The nitrogen also affected highly significantly the nitrogen use efficiencies, while the variety showed highly significant variation in their tuber nitrogen content and significantly different response in their nitrogen use efficiencies. The interaction between nitrogen and variety also significantly affected the tuber nitrogen and protein content. The interaction between location and nitrogen affected nitrogen utilization efficiency highly significantly, while variety and location interaction affected significantly the tuber nitrogen content and nitrogen use efficacies' as well as tuber potassium content highly significantly. The higher nitrogen use efficiency was attained at a rate of 87 kg/ha nitrogen, while the potassium rate not significantly affected nitrogen use efficiency and tuber nitrogen content. Gudenie variety was the most nitrogen use efficient followed by Belete while Jalene is the least in its nitrogen use efficiency.

Conflicts of Interests

The authors have not declared any conflict of interests.

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