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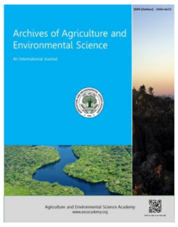

ORIGINAL RESEARCH ARTICLE

Effect of nitrogen rates and irrigation regimes on nitrogen use efficiency of potato (*Solanum tuberosum* L.) in southwest Ethiopia

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ABSTRACT

Despite the high production potential of potato in Ethiopia, the national average yield is low mainly due to poor fertilizer and irrigation water management. Various scholars have indicated existence of knowledge gap among potato growers with regard to nitrogen application rates and irrigation regimes that could potentially enhance efficient use of both water and nitrogen in relation to variety. This work therefore was initiated to assess effects of nitrogen rates and irrigation regimes on nitrogen use efficiency of selected potato varieties in south western Ethiopia. The experiment was 3^3 factorial with three replication managed by Randomized Complete Block Design using Jalene, Guassa and Degemegn potato varieties; 130, 110, 90 kg/ha nitrogen rates, and 100%, 80% and 60% irrigations. Nitrogen content, uptake and utilization efficiency data collected were subjected to analysis of SAS Software version 9.2 and the mean separation was done by list significant difference (LSD). Irrigation and variety significantly affected the nitrogen utilization efficiency while only irrigation highly significantly influenced the nitrogen up take efficiency, nitrogen up take and shoot nitrogen content. Decreasing irrigation water from 20-40% decreased average nitrogen up take efficiency by 20.1- 38.86% and average nitrogen up take by 20.2-38.89%. The interaction of variety and irrigation significantly affected the average tuber nitrogen content. Reducing irrigation water by 40% caused tuber nitrogen content reduction of 51.7 and 56.6% in case of Jalenie and Guassa varieties, respectively. It can be concluded that irrigation regimes and variety significantly affected nitrogen use efficiency of the potato varieties while the nitrogen rates did not influence the nitrogen use efficiency of the potato varieties significantly. Guassa and Jalenie varieties were more efficient than Degemegn variety.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is among the most important root and tuber crops serving many people of the country as source of food. It is a good strategy for avoiding food insecurity especially in disaster situations. Based on FAO estimated production data, potato production in Ethiopia had increased from 280, 000 tons in 1993 to around 525, 000 tons in 2007 (FAO, 2004). Currently, potato is planted on around 180,000 hectares producing an estimated total tuber yield of 1,610,000 tons (CSA, 2013). This indicates that further increment in production volume and expansion of land allocated to potato production as the average land used for potato production each year before was estimated to be 160,000 hectares (FAO, 2006). According to this data the productivity is 8.9ton/ha which is very low when compared with world average (16.7ton/ ha). This lower productivity is partly due to improper nutrient management (Geremew *et al.,* 2015). Especially, nitrogen applications to production land have got considerable negative impacts on the environment (Han *et al.,* 2015). This impact is higher in potato cultivation lands due to high amount application and inefficient nitrogen use nature of the crop.

Inefficient Resource use is the problem of most developing countries. In addition, plant nutrient, land and water are also major constraints to the production of food required to meet the demands of country with increasing population. When considering water for irrigation the amount and quality of water is a factor to be managed well for better yields (Brück *et al.,* 2008, Nagaz *et al.,* 2007; Darwish *et al.,* 2006). Potatoes respond well to the application of both farmyard manure and inorganic fertilizers. Application of 110 kg N and 90 kg P_2O_5/ha is recommended for potato production on the black soil of Holetta. Regardless of location and variety this recommendation is applied to most potato growing areas. Hence, fertilizer requirement varies across locations and varieties under cultivation. Enhancing fertilizer management in potato and ensuring efficiency use is particularly important because relatively high rates of fertilizer and water are necessary to compensate for an inefficient rooting system and extreme sensitivity to deficiencies. In addition, the evaluation of fertilizer efficiency is needed for maximizing profit, environmental concerns (water and soil acidification of high nitrogen fertilizer applied to potato), and resource conservation in sustainable production. Understanding the efficiency leads to select most profitable variety (Powell *et al.,* 2010). Various scholars have indicated existence of knowledge gap among potato growers with regard to nitrogen application rates and irrigation regimes that could potentially enhance efficient use of both water and nitrogen in relation to variety. For this reason, screening varieties for their nitrogen use efficiencies is very important for production, productivity and breeding purposes. Therefore, this experiment was conducted with the objective of quantifying and comparing the nitrogen use efficiencies and nitrogen content of Jalene, Guassa and Degemegn varieties as well as evaluating the interaction effect of nitrogen rates and irrigation regimes on selected potato varieties nitrogen use efficiencies and nitrogen content.

MATERIALS AND METHODS

Description of study area: This experiment was conducted in Jimma University College of Agriculture and Veterinary Medicine greenhouse, situated at latitude and longitude of 7°40′N 36°50′E and 7.667°N 36.833°E / 7.667; 36.833, respectively in 2011. Jimma is located 354 km southwest of Addis Ababa. The average shading capacity of the greenhouse was 26.87%. There was a variation in light intensity reaching to inside greenhouse during the growing period depending on the season of the year and absence or presence of cloud during measurement. The average relative humidity of the greenhouse throughout the growth period was 36.81% while the maximum and minimum values of the relative humidity were 54.3 and 17.7%, respectively. The average dry bulb temperature of the greenhouse throughout the growth period was 26.69^0C while the maximum and the minimum values of the dry bulb temperature were 30.7^0C and 22.6^0C, respectively. The fluctuation of relative humidity was higher when compared to the other parameters recorded. The soil medium used for growing the potato varieties was prepared from clay soil filled to pots of equal size. The soil had 8.7 pH, 0.86 g/cm^3 bulk density, 0.5 EC/ds/m as well as 4.3, 7.5 and 0.192 % organic carbon, organic matter and nitrogen content, respectively. The weight of the soil medium in pots was 12 kg and the pots' size was 15 liters.

Experimental design, treatment and procedures: The plant materials used for the experiment were sprouted tubers of Jalenie, Guassa and Degemeng potato varieties obtained from potato seed multiplying farmers of Bishida District of Jimma zone (South West Ethiopia). These varieties were selected due to their wide agro-ecological zone adaptability and suitability to Jimma growing condition with high yields. The experiment was arranged in 3×3×3 factorial combination with three replications laid down in randomized complete block design. The factors were nitrogen in three rates (130 kg/ha=2.93 g/pot, 110 kg/ha=2.48 g/pot, 90 kg/ha=2.03 g/pot), irrigation in three regimes (full irrigation=100%, 80% and 60% of full irrigation) and three varieties (Jalenie, Guassa and Degemeng). Soil property test was made before production, taking six representative disturbed samples randomly from top 30 cm depth at six positions and air dried on plastic trays, grinded and sieved to pass through a 2 mm sieve before taken to Debra Zeit Research Center soil laboratory where the analysis was carried out.

The total pots used were 243. Each treatment had three pots per block. The pots were filled with soil and arranged in three blocks. One sprouted tuber was planted at 10 cm depth on one pot after watering the medium well. The sizes of sprouted tubers used for planting were similar. Before planting the tubers, the irrigation scheduling was done using two installed tensiometer at 12 cm and 24 cm depth of the growing media to control irrigation frequency after calculating readily available soil water or irrigation water amount. The irrigation management was carried out between 20 and 50 cent bars (Holder and Cary, 1984). But after April 13, near flowering and tuberization stage, the crop wilts even though the tensiometer readings were not reached. Due to this reason watering was done before adjusted tensiometer readings were achieved. The last irrigation was withheld 10-15 days before harvest to allow the tubers to harden their skin before harvesting. The total available soil water was calculated by subtracting permanent wilting point % from field capacity % in volume multiplied by 1000 times root depth (m) from which irrigation water amount or readily available soil water was determined by again multiplying by available soil water depletion factor. The root depth 30 cm and 60 cm used was obtained from (FAO AGL, 2002) together with P (irrigation depletion fraction or maximum allowable depletion).

Fertilizer application time and method: the fertilizers used were Urea (CO ([NH2]2) (46% N) and 90kg /ha of DAP (46% P_2O_5). The amount of fertilizers used in this study was applied based on soil test result by band method. Nitrogen fertilizer was applied in two splits. Half of the nitrogen fertilizers and entire phosphorus requirement was applied as basal while the remaining amount was applied at 45 days after planting (Zelalem *et al.,* 2009). The amount of phosphorus requirement was 90 kg/ha. All of the other cultural practices used throughout the growing season were similar to those that were practiced by regular farmers.

Crop evapotranspiration used: It was obtained from root zone soil water balance (Samuel *et al.,* 2009) using formula (Waskom, 1994): I+P = ET+Dr+Ro±ΔS, where I= irrigation water applied, P= precipitation, ETC= crop water requirement, Dr= deep percolation, Ro= runoff and ΔS = soil moisture change. Here actually P and Ro=0, as the experiment was conducted in Greenhouse using container or pot. So the net formula for root zone soil water balance applied was I= ETC+ Dr ±ΔS or ETC= I- Dr ±ΔS.

Data collection: The result of soil moisture from tensiometer was recorded. Soil samples before and after production was taken. Three pots of the one treatment whole tuber fresh weight was taken at maturity and averaged for representing treatment output per block while four representative shoot were taken from each pot of the treatment, chopped, weighed and averaged for each treatment. Tuber and shoot sample taken in first case were undergone oven drying at 65^0C until constant weight was reached and weighed again for dry matter data analysis. Tubers and above ground biomass dry weight (g) were added respectively to construct total dry weight. Tuber and shoot dry weight (dried at 65^oC until constant weight) was grinded in to flour and total nitrogen in dry matter was determined by micro-kjeldahl method and nitrogen use efficiency was calculated as follows:

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

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

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

Data analysis: Data were subjected to analysis of variance using proc GLM (general linear model) procedure of SAS 9.2 software (SAS, 2009). The means were compared with Least Significant Difference (LSD) at 5% significance level and correlation analysis was done to investigate relationship of nitrogen use efficiency with other parameters using the same software.

RESULTS AND DISCUSSION

Nitrogen utilization efficiency: Variety and irrigation significantly affected the nitrogen utilization efficiency (Table 1). Significantly the highest nitrogen utilization efficiency was obtained from Guassa variety. However, it was not statistically different from that of Jalene. The least nitrogen utilization efficiency was obtained from Degemeng. The effect of nitrogen on average nitrogen utilization efficiency was not significant. Significantly the highest nitrogen utilization efficiency was recorded at 100% irrigation while the least was obtained at 60% irrigation. The effect of 80% irrigation was statistically not different from both 100% and 60% irrigation effect on nitrogen utilization efficiency. Nitrogen utilization efficiency was found to have significantly strong positive relationship with applied water amount, WUE, total plant dry weight, tuber fresh and dry weight.

Nitrogen up take efficiency: Irrigation highly significantly affected average nitrogen up take efficiency (Table 1). Significantly the highest nitrogen up take efficiency was recorded at 100% irrigation, followed by 80 and 60%. Decreasing irrigation water by 20% decreased average nitrogen up take efficiency by 20.1% while 40% decrease resulted in 38.86% reduction of average nitrogen up take efficiency**.** Varieties, nitrogen and interactions among the different factors did not affect nitrogen up take efficiency significantly. The nitrogen up take efficiency was significantly and positively (r = 0.55) correlated with the amount of water applied. It also was significantly and positively correlated with average above ground biomass, tuber dry and fresh weight, total fresh and total plant dry mass.

Average total nitrogen up take: Irrigation highly significantly affected nitrogen up take (Table 1). Significantly the highest nitrogen up take was recorded at 100% irrigation, followed by 80% and 60% irrigation. Decreasing irrigation water by 20% and 40% decreased average nitrogen up take by 20.2% and 38.89%, respectively. Variety and nitrogen, and the interaction among the different factors did not affect nitrogen uptake.

Average shoots nitrogen content: Irrigation significantly affected above ground dry mass nitrogen content (Table 1). Irrigation to the field capacity produced the highest average above ground dry mass nitrogen content, followed by 80% and 60% irrigation. Decreasing irrigation water by 20% decreased average above ground dry mass nitrogen content in gram by 22.45% while 40% decrease resulted in 38.53% reduction of average above ground dry mass nitrogen content in gram. Variety, nitrogen and interactions among the different factors did not affect above ground dry mass nitrogen content.

Average tuber nitrogen content: The interaction of variety and irrigation significantly affected the average tuber nitrogen content (Figure 1). Maximum average tuber nitrogen content was obtained from Jalenie at 80% and 100% irrigation, and Guassa at 100% irrigation while the minimum value of average tuber nitrogen content was obtained from Degemegn at 60% and 100% irrigation, and both Jalenie and Guassa varieties at 60% . Decreasing the irrigation water by 40% reduced the tuber nitrogen content by 51.7 in Jalenie; 56.6 % in Guassa.

Nitrogen content before planting and after harvest: the nitrogen content of the soil media before planting was 0.192% while it was 0.124% after harvesting. These indicated that there was 23.04g nitrogen in the pot filled with 12kg soil before planting while it was 14.88g after harvesting (Figure 2). The soil nitrogen was depleted or reduced by 8.16gm which accounted to 35.42% implying that applied nitrogen was not enough to nourish the crop planted or lost to environment during the process of manipulations. Variety and irrigation significantly affected the nitrogen utilization efficiency. Irrigation regimes highly significantly affected up take or total plant and shoot nitrogen content. Decreasing irrigation water by 40% reduced average nitrogen utilization efficiency by 41.1%. This is because when irrigation water is decreased from field capacity (100%) to 60% the tuber yield, total dry mass and other parameters were reduced in higher amount. As nitrogen utilization efficiency is the ratio of tuber yield (g) to nitrogen supply (g), higher reduction of tuber yield at 60% irrigation is the cause of nitrogen utilization efficiency reduction by 41.1% which may be attributed to water effect on nutrient up, photosynthesis, translocation and other physiological activity of the varieties. These results agree with findings of Guodong *et al.* (2012) and Eleanor *et al.* (2012). According to Badr *et al.* (2012) the highest utilization efficiency was obtained at 100% irrigation. In contrary, higher nitrogen use efficiency was indicated at 50% than 100% irrigation for tomato (Desire *et al.,* 2013). Inconsistence with these results Tayel *et al.* (2006*)* showed similar finding. Decreasing irrigation water by 20-40% decreased average nitrogen up take efficiency and nitrogen up take by 20.1 - 38.86% and 20.2% - 38.89%, respectively. According to Ahmadi *et al.* (2011) partial, surface deficit and 100% irrigation did not significantly affected tuber, shoot and whole plant nitrogen up take. Varieties, nitrogen and interactions among the different factors did not affect nitrogen up take efficiency and nitrogen up take significantly. The nitrogen up take efficiency was significantly and positively (r = 0.5463) correlated with the amount of water applied. It also was significantly and positively correlated with average above ground biomass, tuber dry and fresh weight, total fresh and total plant dry mass. This implies that increasing water irrigated increased the parameter mentioned earlier. This may be due to occurrence of suitable condition for better uptake of nitrogen and performance of crop with better water supply which in turn has significant effect on photosynthesis, assimilation, metabolism and plant growth and development. These results disagree with the finding of Kakuhenzire *et al.* (2005) in which increased nitrogen uptake efficiency was reported from lower rate of nitrogen applied (0-40 kg/ha) than higher rate (40-80 kg/ha). Similar suggestion was given by Beukema and Van der Zaag (1979). This may be due to variety, nitrogen rate and growing condition difference. Timely application of spliced N fertilizer, monitoring the crop N needs to match crop N requirements and mineral N supply throughout the growing season could bring nitrogen efficiency improvement (Jamaati-e-Somarin *et al.,* 2009). The results are in agreement with the finding result of Wu *et al.* (2009). Supporting findings are presented elsewhere (Brück *et al.,* 2008; Nagaz *et al.,* 2007; Darwish *et al.,* 2006). Similar findings were also reported by Battilani et al. (2008). Decreasing irrigation water by 20% and 40% decreased average above ground dry mass nitrogen content in gram by 22.45 and 38.53%, respectively. Variety, nitrogen and interactions among the different factors did not affect above ground dry mass nitrogen content. This is because of less variability in amount of nitrogen applied between and among rates. The difference of one rate from the other rate was only 20kg/ha which is very small amount when distributed for individual potato plants grown in one hectare. The individual plant received around 0.45gm nitrogen advantage when falling in different rates. Such amount is too small to bring significant variation on yield and yield components, nitrogen use efficiencies among rates in almost all parameter recorded. Different varieties were significantly different in their nitrogen utilization efficiency. In relation to this variation, it is in agreement with the following Authors (Lian, 1991; Tanaka *et al.,* 1964). Again it is also similar with the finding of Guodong *et al.* (2012) and Jamaati-e-Somarin *et al.* (2009) but contradicted with the result of Ahmadi *et al.* (2011) which is due to variety and growing condition difference. Supporting findings were presented in Bertrand *et al.* (2011) which said nitrogen use efficiency is differed by genetic makeup of the crop. Sarah (2015) and Bussan *et al.* (2015) found different petiole nitrogen content for different variety of potato. Interactions of Variety and irrigation regimes also significantly affected tuber nitrogen content. Decreasing the irrigation water by 40% reduced the tuber nitrogen content of Guassa and Jalene by 56.6 % and 51.7, respectively. Varieties response to irrigation regimes result of nitrogen content agrees with findings (Fan and Mylavarapu, 2010). Ahmadi *et al.* (2016) found that significant effect irrigation treatments on tuber nitrogen content.

Table 1. Effect of nitrogen and irrigation on average nitrogen efficiency and uptake.

Treatment	Average nitrogen utilization efficiency (g tuber/ total uptake(g)	Average nitrogen uptakes efficiency (g N in tuber/ total N(g)	Average total nitrogen uptake(g)	Average shoot nitrogen(g)
Variety				
Jalene	63.71a**	16.730ns	4.0380ns	3.5779ns
Guassa	66.178a**	14.304ns	3.4560ns	3.0668ns
Degemegn	23.618b**	15.296ns	3.6953ns	3.4374ns
Nitrogen				
130kg/ha	44.832ns	16.111ns	3.9159ns	3.5579ns
110kg/ha	50.455ns	15.819ns	3.8184ns	3.4244ns
90kg/ha	58.218ns	14.400ns	3.4549ns	3.0999ns
Irrigation				
100%	61.574a*	19.222a**	4.6440a**	4.2180a**
80%	55.631ab*	15.356b**	3.7074b**	3.2711b**
60%	36.301b*	11.752c**	2.8379c**	2.5930c**
LSD	19.776	2.73	0.6586	0.0791
CV% at α=5%	17.99048	16.10404	20.45042	6.242287

*-means of the same factor followed by the same letter with in the column are not significantly different at 5% level of probability. **- means of the same factor followed by the same letter with in the column are not significantly different at 1% level of probability, LSD-Least Significant Difference, CV% - Coefficient of Variance. ns=none significantly difference at 5% level of probability.

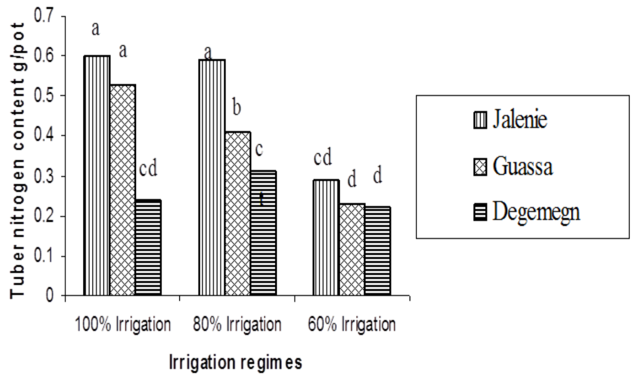

Figure 1. *Interaction effect of variety and irrigation on tuber nitrogen content.*

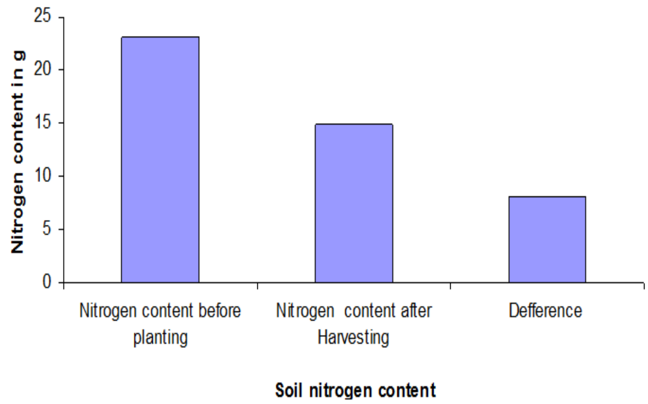

Figure 2. *Nitrogen content before planting and after harvest.*

Conclusions

The present study concluded that irrigation and variety were found to significantly affect the nitrogen utilization efficiency while only irrigation highly significantly influenced the nitrogen up take efficiency. Irrigation regimes affected up take and shoot nitrogen content highly significantly. Guassa and Jalene produced similar maximum nitrogen utilization efficiency while Degemeng provided the lowest. Interaction of variety and irrigation regimes affected tuber nitrogen content significantly. From the results, it can be concluded that irrigation regimes and variety significantly affected nitrogen use efficiency of the potato varieties while the nitrogen rates and interaction among factors holding nitrogen combination did not influence the nitrogen use efficiency of the potato varieties significantly. Guassa and Jalenie varieties were found to be more nitrogen efficient than Degemegn Variety. 100% Irrigation regimes was provided highest Nitrogen up take and Utilization efficiency even though the latter is on par with 80% irrigation regime. As this is output of greenhouse condition, open field experiment with more variable nitrogen rates is suggested to be come up with possible comprehensive results.

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