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Research Article

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Effect of Nitrogen Rates and Irrigation Regimes on Water Use Efficiency of Selected Potato Varieties in Jimma Zone, West Ethiopia

Egata Shunka Tolessa[1]*, Derbew Belew[2], Adugna Debela[2] and Beshir Kedi[2]

[1]*Ethiopian Institute of Agricultural Research, Holetta Research Center, Horticulture Research Division, Ethiopia*
[2]*Jimma University College of Agriculture and Veterinary Medicine, Ethiopia*

Abstract

Ethiopia has possibly the greatest potential for potato production. But its contribution to food security is less due to poor agronomic techniques and other factors which require improving the ways of resources use. This experiment was conducted in Jimma University College of Agriculture and Veterinary Medicine greenhouse to study the effect of nitrogen rates and irrigation regimes on water and nitrogen use efficiency of selected potato varieties (Jalenie, Guassa and Degemegn), using three nitrogen rates (130, 110, 90 kg/ha), and three irrigation regimes (full irrigation (100%), 80% and 60% of full irrigation) on clay textured fine top soil filled to poly ethylene pot of 15 liter and 30 cm upper diameter. The experiment was 3 × 3 × 3 factorial with three replications laid down in a Randomized Complete Block Design. Interaction of variety and irrigation significantly affected water use efficiency (WUE). Jalenie variety recorded the highest WUE at 80% irrigation, but was on par with Guassa varieties at 100% irrigation. The lowest WUE was obtained from Degemegn variety at 100% irrigation even though there was no significant difference among the three irrigations. From the results, it can be concluded that irrigation regimes and variety were significantly affected water use efficiency of the potato varieties while the nitrogen rates and interaction between or among factors holding nitrogen combination were not influenced the water use efficiency of the potato varieties significantly. As this is output of greenhouse condition, open field experiment is suggested to be carried out to come up with conclusive results.

Keywords: Variety; WUE (water use efficiency); Irrigation regimes; Nitrogen rates

Introduction

Potato (*Solanum tuberosum* L.) ranks fourth among the world's crop production in volume after wheat, rice and corn [1]. But it is first from Root and Tuber crops followed by cassava, sweet potato and yam [2]. Potato has got production potential of about 327 million tons and 18.6 million hectares worldwide [3]. Potato was introduced to Ethiopia in 1858 (19th century) by a German Botanist Schimper [4]. Since then, farmers in Ethiopian high lands began cultivating the potato tuber as compensation when other crops failed. In Ethiopia, the estimated land under potato cultivation each year is over 160,000 hectares [5]. Based on FAO data, potato production in Ethiopia has increased from 280, 000 tons in 1993 to around 525, 000 tons in 2007 [6].

Potato is temperate crop that satisfactorily grows and yields well in cool and humid climates [7]. 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 [8]. Since the highlands are also home to higher percent of Ethiopia's population, the potato can play a key role in ensuring national food security if production potentials are exploited well [6].

The ideal growth requirements for potato include high and nearly constant soil matric potential, high soil oxygen diffusion rate, adequate incoming radiation and optimal soil nutrients [9]. Among other environmental conditions, temperature and photoperiod are known to affect the various physiological processes of the potato plant [10]. Optimum temperatures for foliage growth and net photosynthesis are 15-25°C and 20°C for tuberization. At temperature above 29°C tuberization is inhibited, foliage growth is promoted and net photosynthesis and assimilate partitioning to the tubers are reduced [11]. In natural environment plants are subjected to many stresses that have a great impact on growth, development and finally yield of crops. These factors can be biotic and abiotic. Among these factors, drought and nutrients suboptimal use are major abiotic factors that limit crop production [12].

Early studies have shown that water is the most important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing season for efficient use of water [13]. Most researchers reporting the influence of water stress on potato yield in terms of its effect on aerial parts [14]. In course of improving water and nitrogen use efficiency researchers indicated use of drip irrigation for most crop commodities; mainly for vegetables and fruits [15]. For efficient use of water, supplementing rainfall by irrigation water to satisfy the needs of the crop at each growth stages is important to attain the required yields, especially in periods of limited rainfall. This is a key operation to avoid water shortage and over-irrigation which can reduce yields through reducing soil aeration that in turn reduce uptake(water and nutrient) and increasing nitrogen leaching [15].

Potatoes are generally sensitive, especially to deficiencies and excesses of N [16]. After beginning the tuber bulking phase, potatoes require a higher and steady supply of N. Mid-season N shortage reduces canopy growth and often causes premature senescence, which can reduce yields [17]. Potatoes require relatively high amounts of fertilizer

***Corresponding author:** Egata Shunka Tolessa, Ethiopian Institute of Agricultural Research, Holetta Research Center, Horticulture Research Division, PO Box 3002, Addis Abba, Ethiopia, Tel: +251931796885; E-mail: egata.shunka@yahoo.com

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because of high nutrient demand and a shallow, as well as inefficient rooting system [18,19]. In addition to shallow rooting, many potato cultivars have relatively inefficient nutrient and water use efficiency systems [20]. The consequence of poor efficiency and high water/fertilizer rates in potato is the potential for significant N contamination to surface and groundwater [21,22]. Although not studied as extensively as N in potatoes, high soil P is a potential environmental problem as well [23]. Understanding nitrogen application rates and irrigation regimes that enhance the efficient use of both water and nitrogen, and developing wisdom of efficient use of resource management practices could minimize the potential N losses thereby reducing production cost and increasing farm profit.

Water use efficiency is defined as the tuber yield obtained per unit of water consumed. According to Hassan et al. [24] WUE of potato ranges from 69 to 233 kg ha^{-1} mm^{-1}. Kiziloglu et al. [25] reported change of WUE between 63.4 to 44.1 kg ha^{-1} mm^{-1}. The WUE varied with growing season [26].

Though potato has been under cultivation for 154 years in the country, its production was not widely spread and it contributed little to food security in the country. According to Yilma [8], about 70% of cultivated agricultural land is suitable for potato production. But the production potentials are not exploited well as still it is under produced and utilized. The national average yield is approximately 7.9 tons/ha [27], which is very low compared to the world average of 16.4 tons/ha [2]. The main reason associated to this under production and utilization of potato is lack of high yielding and disease resistant improved potato varieties, problems of pests and disease especially potato late blight [28], are also the causes of underutilization of potato in Ethiopia. Moreover, lack of sufficient quantity of good quality seed, poor agronomic techniques and lack of storage facilities.

In Ethiopia, utilization of irrigation water for potato production is not well known [27]. When irrigated there is excessive and shortage problem as the farmers were using the same amount of water and intervals, regardless of crop species and growth stage [29]. Excessive irrigation of potatoes results in water loss and significantly increases of runoff (soil erosion) from production fields. There is also soil nutrient leaching which leads to contamination of the groundwater due to fertilizers and other chemical products [30]. In addition, it increases production costs, reduce yield by affecting soil aeration, favors the occurrence and severity of diseases and pests. On the other hand, deficient irrigation promotes a reduction of tuber quantity and lower yield due to reduced leaf area and/or reduced photosynthesis per unit leaf area [31]. Optimizing the water and nitrogen supply is an important issue as it varies with many external and crop factors.

In Ethiopia, information about plant water and nitrogen use efficiency is limited. The rates of nitrogen fertilizer used for released potato varieties from Ethiopian research centers are similar. But application of 138 kg N and 20 kg P/ha is found to be the appropriate rate for optimum productivity of Gorebiella variety on the vertisols of Debere Berhan in the central highlands of Ethiopia under rain fed conditions [32] even though the variety is one of the newly released ones, that can be an insight to conduct trials for other varieties to develop optimum rate enhancing economic return. On the other hand, other varieties are cultivated by applying blanket recommendation which is equal to 110 kg N/ha. This blanket application can lead to excessiveness or shortage. When excessive nitrogen is applied crop yield is reduced; cost of production increased and environment is polluted especially soil and ground water is acidified [21]. Shortage of nitrogen application is also reducing yield. Achieving optimum nitrogen rate applications should be considered as it varying with soil, crop and water available to the crop for optimum return and farm profit.

In addition to this, the information about effect of rates of N-fertilizer application and irrigation regimes on water and nitrogen use efficiency is also scarce. Therefore, the present research was conducted in Jimma University College of Agriculture and Veterinary Medicine in the greenhouse to quantify and compare the water use efficiencies of three potato varieties (Jalenie, Guassa and Degemegn) and also to determine the interaction effect of rates of nitrogen and irrigation regimes on water use efficiency of the three varieties.

Materials and Methods

Area description

The 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, respectively in 2011. Jimma is located 354 km southwest of Addis Ababa.

Light condition in greenhouse

The average shading capacity of the greenhouse was actually 26.87%. There were variations 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.

Relative humidity and temperature

The average relative humidity of the greenhouse throughout the growth period was 36.81% while the maximum and the 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°C while the maximum and the minimum values of the dry bulb temperature were 30.70°C and 22.60°C respectively. The fluctuation of relative humidity was highest when compared to the other parameters recorded.

Growing media soil water conditions

The soil medium used for growing the potato varieties was prepared from clay with 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. 12 kg soil was filled to 15 litter pots and the pots were arranged in three blocks.

The field capacity of the soil was 37.82% while the permanent wilting point of the soil was 23.11%. The water holding capacity of the soil was 147.1 mm/m. The water amount below the permanent wilting point was unavailable to plants. The depletion factor for the irrigation were 0.25 for the 55^{th} day after planting 0.3 and 0.5 for 56-90^{th} and beyond 90^{th} days after planting, respectively [33].

Experimental treatment, design and procedures

The plant materials used for the experiment were sprouted tubers of Jalenie, Guassa and Degemegn potato varieties obtained from potato seed multiplying farmers of Bishida District of Jimma zone. Jalenie and Guassa were light green potato varieties with white flower released in 2002 from Holleta Agricultural Research Center and Adet, respectively. Jalenie grows in altitude rage of 1600-2800 masl with 750-1000 mm annual rain fall and has maturity period of 90-120 days after planting while Guassa grows 2000-2800 masl with 1000-1500 mm annual rain fall and matures in 110-115 days after planting. Degemegn variety is deep green none flowering potato variety released from Holleta research center in 2002 and grows in 1600-2800 masl altitude range with 750-1000 mm annual rain fall and matures in 90-120 days after planting. Jalenie and Guassa grow up to 95.24-126.11 cm and 97.54-115.71 cm heights respectively while Degemegn grows up to 93.39- 107.73 cm heights. These varieties were selected due to their wide agro-ecological zone adaptability and suitability to Jimma growing condition.

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 Degemegn).

Soil property test

Soil property test before production was made taking six representative disturbed samples randomly from top 30 cm depth at six positions.

Growing media prepared

The soil media used for growing the potato varieties was prepared from uniform soil and 12 kg filled in each of 243 pots of equal size. Each treatment had three pots. The filled pots were arranged in three blocks where one sprouted tubers of the same size were planted at 10 cm depth after watering the media well. 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 [31,34]. 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 reading was achieved.

Irrigation water amount applied

The amount of water irrigated once was calculated based on field capacity and wilting point concept of the soil in the pots which was determined in laboratory together with soil property tests. The total available soil water was calculated by subtracting permanent wilting point % from field capacity % in volume from which irrigation water amount or readily available soil water was determined by multiplying by 1000 times root depth (m) and available soil water depletion factor.

Effective rooting depth used

30 cm and 60 cm root depth used was obtained from FAO AGL [33] together with P (irrigation depletion fraction or maximum allowable depletion) but the active uptake is confined to the top 30 cm.

Irrigation methods and criteria used

Watering was done manually using watering cane. The lower limit water potential to begin irrigation was determined by applying pre-experimental trial, installing two tensitiometers (Reich BSR Jecknik mmbar or kpa 35 cm and 30 cm length) at 12 and 24 cm on one media having 25-50% available soil water depletion [33]. The irrigation was performed at irrigation criteria of 20-25 cent bars for 25% available soil water depletion, 30-35 cent bars for 30% available soil water depletion and 44-50 cent bars for 50% available soil water depletion. The last irrigation was with held 10-15 days before harvest to allow the tubers to harden their skin before harvesting.

Fertilizer application time and method used

The fertilizers used were Urea (CO ($[NH_2]_2$) (46% N) and 90 kg/ha of DAP (46% P_2O_5)) The amount of ertilizers used in this study was applied using 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 [32]. 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

Crop evapotranspiration was obtained from root zone soil water balance [35,36] using formula [37]: I+P=ET+Dr+Ro ± S, where I=irrigation water applied, P=precipitation, ETC=crop water requirement, Dr=deep percolation, R_o=runoff and S=soil moisture change. Here actually P and R_o=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 ± S or ETC=I- Dr ± S.

Climatic condition

For understanding and taking a measure for dangerous condition occurrence, the internal greenhouse air temperature, relative humidity and internal and external solar radiation was monitored, measured and recorded.

Harvesting and dry matter preparation

Tuber harvesting was done once at proper physiological maturity (70% leaves withering). Tuber and shoot dry matters were measured after drying sample biomass in oven dry at 65°C until constant weight was achieved.

Data collection

The solar radiation was measured by light meter or LUX meter (TES 1332, BATT 006P9V, NO.:010300137, Made in Taiwan) and recorded while dry bulb and wet bulb temperature, relative humidity were measured using Digital Sling Psychycro meter (AZ8716, REAL S/N: 96788223, Model: 8716, Made in China) and recorded. The result of soil moisture from tensiometer was recorded. Soil samples before and after production was taken.

Tuber and above ground biomass fresh weight (g)

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.

Water use efficiency (WUE)

The ETC was estimated from soil water balance. Water use efficiency was computed using:

WUE=above ground Biomass and tuber weight (g/pot)

ETC (mm) ETC (mm)

Data analysis

Data was subjected to analysis of variance using proc GLM (general linear model) procedure of SAS 9.2 software [38]. The means were compared with Least Significant Difference (LSD) at 5% significance level and correlation analysis was done to investigate relationship of water use and nitrogen use efficiency using the same software.

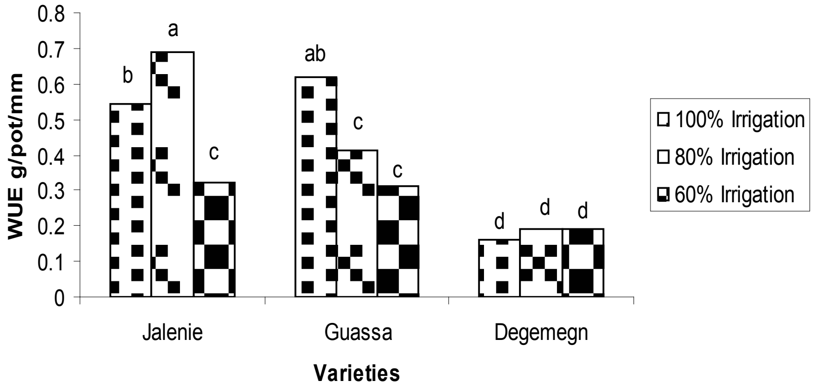

Figure 1: Variety and irrigation interaction effect on water use efficiency of potato.

Treatment	Water amount(mm)	Average tuber weight (g)	WUE (g tuber/pot/mm)	WUE (g above ground fresh weight/pot/mm)
Irrigation				
100%=I1	573.68a**	253.25a**	0.44133a**	0.53741b**
80%=I2	458.95b **	195.81a^{a}*	0.42885a**	0.55924b**
60%=I3	339.5c**	94.21b**	0.27500b**	0.61159a**
Variety				
Jalenie	457.6ns	245.51a **	0.51822a**	0.59599a**
Guassa	457.6ns	216.47a**	0.44704a**	0.57158ab**
Degemeng	457.6ns	81.18b**	0.17993b**	0.54068b**
Nitrogen				
130 kg/ha	457.6ns	170.33ns	0.35730ns	0.56551ns
110 kg/ha	457.6ns	195.03ns	0.40137ns	0.56396ns
90 kg/ha	457.6ns	177.91ns	0.38652ns	0.57878ns
LSD	20	59.371	0.1274	0.0462
C% at α=5%	2.825085	14.25899	19.40995	14.84519

**- 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.

Table 1: Effect of irrigation, variety and nitrogen rates on WUE of potato.

Results and Discussion

Water Use Efficiency (WUE) g/mm: Variety and irrigation interaction significantly affected the WUE calculated from ratio of fresh tuber weight to irrigated water in mm (Figure 1). Jalenie recorded the highest WUE at 80% irrigation, but was not significantly different from Guassa at 100% irrigation. The lowest WUE was obtained from Degemegn at 100% irrigation. However, it was not statistically different from WUE of the same varieties at 80 and 60%. Decreasing the irrigation water by 20% increased the WUE by 14.4% further decreasing to 40% reduced the WUE by 40.33% in Jalenie variety while decreasing the irrigation water by 20% and 40% decreased the WUE of Guassa by 33.6 and 49.6% respectively. In Degemegn variety, decreasing the irrigation water by 20% and 40% had no significant effect on WUE.

Water use efficiency of above ground fresh weight was significantly affected by variety and irrigation (Table 1). Jalenie variety recorded significantly high WUE but was not significantly different from Guassa variety. However, the WUE of Guassa was not significantly different from that of Degemegn variety. Nitrogen rates and interactions holding nitrogen did not affect water use efficiency of above ground fresh weight.

WUE of tuber was increasing with increasing irrigation water from 60-100% (Table 1). A significantly positive correlation coefficient (r=0.225) was observed between WUE and irrigation water amount (Table 2). This may be because when the amount of water irrigated increased to the field capacity, the potato varieties get better supply that satisfy their needs for better tuber formation that directly involved in increment of the WUE. Significantly strong positive association was also found between WUE and Harvesting index, tuber to shoot ratio, total dry weight, tuber number, tuber fresh and dry weigh (Table 2).

The WUE of tuber in this study was variable with varieties and increased with increased irrigation water amount. These results agree with findings of Darwish et al. [39] which obtained the lowest WUE from 60% of full irrigation while 80%, 100% and 120% irrigation provided maximum WUE, respectively. Steyn et al. [40] reported similar results in similar experiment with irrigation regimes of 100, 80 and 60%. On the other hand, Kirda [41] found a contradictory result from drip irrigation. Onder et al. [7] also reported decreasing WUE with increasing water supply. Similar reports were presented in Kashyap and Panda [42] and Yuan et al. [9]. According to Badr et al. [43] finding, fully irrigated potato increased N uptake and tuber yield which implies that better water use efficiency than water stressed treatment. 80% irrigation was reduced nitrogen losses by 58 to 81% compared to 20% irrigation regime [44], indicating that better watering to the field capacity encourages better utilization of not only water but also other nutrients. David et al. [45] showed different response of potato varieties to fully irrigate and stressed treatments which correlate the two findings as varieties recorded significantly different water use efficiencies resulted in due to different yield development of the varieties under same and different irrigation regimes. Finding

	AWA	TWUE	SFWUE	ATW	ATDW	ATPDW	ATNO.	HI	LAI	APNO.
APNO.	0.25*	0.40**	0.68**	0.42**	0.40**	0.29**	0.53**	0.26ns	0.62**	1
LAI	0.23*	0.34**	0.48**	0.37**	0.40**	0.31**	0.38**	0.32**	1	
HI	0.28**	0.85	-0.20ns	0.84**	0.79**	0.66**	0.76**	1		
ATNO	0.31**	0.83**	0.32**	0.83**	0.79**	0.67**	1			
ATPDW	0.58 **	0.78**	0.60**	0.84**	0.92**	1				
ATDW	0.44**	0.88**	0.20ns	0.91**	1					
ATW	0.42**	0.97**	0.42**	1						
SFWUE	-0.11ns	0.38**	1							
TWUE	0.225**	1								
AWA	1									

*, **: significant correlation at P<0.05 and P<0.01 probability levels, respectively; ns: non- significant; I=Irrigation, N=Nitrogen, AWA=Average water amount, TWUE=water use efficiency from fresh tuber weight, FWWUE=water use efficiency from fresh shoot weight, NUE=Nitrogen utilization efficiency, UPTNUE=Nitrogen uptake Efficiency, ATW=Average Tuber Weight, ATDW=Average tuber dry weight, ATNO=Average tuber number, HI=Harvesting Index, LAI=Leaf area index, APNO=Average stem number

Table 2: Relationship of WUE with yield and yield components.

of Ahmadi et al. [46] indicated non-significant different water use efficiencies between potato varieties subjected to different irrigation water amounts in contrary to this experiment which may be due to growing condition and managements other than irrigation. Decreased water use efficiency was reported with increasing water supply [47]. Maximum potato performance was recorded at full irrigation [48].

Conclusion

Many researchers had reported Variability of WUE with variable variety, irrigation regimes and nitrogen rates. In similar way, interaction of variety and irrigation significantly affected water use efficiency (WUE). Jalenie variety recorded the highest WUE at 80% irrigation, but was on par with Guassa varieties at 100% irrigation. The lowest WUE was obtained from Degemegn variety at 100% irrigation even though there was no significant difference among the three irrigations. From the results, it can be concluded that irrigation regimes and variety were significantly affected water use efficiency of the potato varieties while the nitrogen rates and interaction between or among factors holding nitrogen combination were not influenced the water use efficiency of the potato varieties significantly. Jalane variety is the most water efficient of all followed by Guassa variety. As this is output of greenhouse condition, open field experiment is suggested to be carried out to come up with conclusive results.

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