EFFECT OF NITROGEN RATES AND IRRIGATION REGIMES ON WATER AND NITROGEN USE EFFICIENCIES OF SELECTED POTATO VARIETIES

M.Sc. Thesis

EGATA SHUNKA

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Jimma, Ethiopia

EFFECT OF NITROGEN RATES AND IRRIGATION REGIMES ON WATER AND NITROGEN USE EFFICIENCIES OF SELECTED POTATO VARIETIES

M.Sc. Thesis Submitted to School of Graduate Studies Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirement for the Degree of Master of Science in Horticulture (Vegetable Science)

By

Egata Shunka

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APPROVAL SHEET

JIMMA UNIVERSITY

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As thesis research advisors, we hereby certify that we have read and evaluated the thesis prepared by Egata Shunka under our guidance, which is entitled 'Effects of Nitrogen Rates and Irrigation Regimes on Water and Nitrogen Use Efficiency of Selected Potato Varieties'**.** We recommend that the thesis be submitted as it fulfills the requirements for the Degree of Master of Science.

Derbew Belew (PhD)	____________________	____________________
Name of Major Advisor	Signature	Date
Adugna Debela (M.Sc.)	____________________	____________________
Name of Co-advisor	Signature	Date

As members of the Board of Examiners of the M.Sc. Thesis Open Defense examination of Egata Shunka, we certify that we have read and evaluated the thesis and examined the candidate. We recommend that the Thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Horticulture (Vegetable Science).

____________________	____________________	____________________
Name of Chairperson	Signature	Date
____________________	____________________	____________________
Name of Internal Examiner	Signature	Date
____________________	____________________	____________________
Name of External Examiner	Signature	Date

DEDICATION

I dedicate this thesis to my mother **Golbe Tiki Dagi** for her affection.

STATEMENT OF THE AUTHOR

First, I declare that this Thesis is my bonafide work and that all sources of materials used for this Thesis have been duly acknowledged. This Thesis has been submitted in partial fulfillment of the requirements for M.Sc degree in Horticulture (Vegetable Science) at the Jimma University and is deposited at the University Library to make available to borrowers under rules of the Library. I solemnly declare that thesis is not submitted to any other institutions anywhere for award of any academic degree, diploma or certificate.

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Name of the student: Egata Shunka Tollesa Signature ---------------

Place: Jimma University, Jimma

Date of Submission -------------------

BIOGRAPHICAL SKETCH

The Author, Egata Shunka, was born on 16 January 1974 in Gindeberet Wereda, Tapisa Madalle Kebele. When he reached school age, he enrolled in Abuye Roge Elementary School found in Wine Roge Kebele. After completing elementary education in the subsequent years, he enrolled in Chulute Junior Secondary School found in the Amdo Kebele. He then enrolled in Kachise senior Secondary School found in Wereda's town called Kachisi. On completion of grade 12, he joined Mekelle University in 1993 and obtained the Bachelor Degree of Science in Agriculture (Dry Land Crop Science) in 1996. After employed by the Ministry of Agriculture in 1997 and assigned to work at Agarfa Agricultural Technical, Educational and Vocational Training College as an instructor in the department of Plant Sciences for two years and three months, he was transferred to Gode Agricultural Technical, Educational and Vocational Training College to work as an instructor in the same department of Plant Sciences for three years. Then, he joined the School of Graduate Studies of Jimma University College of Agriculture and Veterinary Medicine in 2001 leading him to the Degree of Master of Science in Horticulture.

LIST OF ACRONYMS AND ABBREVIATIONS

ATVET	Agricultural Technical, Vocational, Education and Training
ASMD	Available Soil Moisture Depletion
DAP	Days after Planting
EARO	Ethiopian Agricultural Research Organization
DM	Dry Matter
ETC	Crop Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
HI	Harvesting Index
KC	Crop Coefficient
LAI	Leaf Area Index
NUE	Nitrogen Use Efficiency
SLN	Specific Leaf Nitrogen
SWT	Soil Water Tension
VPD	Vapor Pressure Difference
WUE	Water Use Efficiency
ETO	Reference Evapotranspiration
EP	Evaporation from Pan

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ABSTRACT

Among African countries, 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 and increasing farm return. This experiment was conducted in JUCAVM 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 3x3x3 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. Irrigation and variety was significantly affected the nitrogen utilization efficiency while only irrigation highly significantly influenced the nitrogen up take efficiency. Guassa and Jalenie produced statistically similar maximum nitrogen utilization efficiency while Degemegn provided lowest. Significantly the highest nitrogen utilization efficiency was recorded at 100% irrigation and the least was obtained at 60% irrigation, while 80% irrigation statistically similar to both irrigation effects. The highest nitrogen up take efficiency was recorded at 100% irrigation, followed by 80 and 60%. From the results, it can be concluded that irrigation regimes and variety were significantly affected water and nitrogen use efficiency of the potato varieties while the nitrogen rates and interaction between or among factors holding nitrogen combination were not influenced the water and nitrogen 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.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) ranks fourth among the world's crop production in volume after wheat, rice and corn (Fabeiro *et al*., 2001). But it is first from Root and Tuber crops followed by cassava, sweet potato and yam (FAO, 2004). Potato has got production potential of about 327 million tons and 18.6 million hectares worldwide (FAO, 2006). Potato was introduced to Ethiopia in 1858 (19^{th} century) by a German Botanist Schimper (Pankhrust, 1964; Horton, 1987). 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 (Ktheisen, 2009). Based on FAO data, potato production in Ethiopia has increased from 280, 000 tons in 1993 to around 525, 000 tons in 2007 (FAO, 2008).

Potato 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). 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 (FAO, 2008).

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 (Yuan *et al*., 2003). Among other environmental conditions, temperature and photoperiod are known to affect the various physiological processes of the potato plant (Tsegaw, 2006). Optimum temperatures for foliage growth and net photosynthesis are 15-25^{o}C, and 20^{o}C for tuberization. At temperature above 29^{o}C tuberization is inhibited, foliage growth is promoted and net photosynthesis and assimilate partitioning to the tubers are reduced (Levy, 1992). 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 (Reddy *et al*., 2004).

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 (Chowdhury *et al*., 2001; Panigrahi *et al*., 2001). Most researchers reporting the influence of water stress on potato yield in terms of its effect on aerial parts (Deblonde *et al*., 1999; Lahlou *et al*., 2003). In course of improving water and nitrogen use efficiency researchers indicated use of drip irrigation for most crop commodities; mainly for vegetables and fruits (Shirie-e-Janagrad *et al*., 2006). 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 (Shirie *et al*., 2006).

Potatoes are generally sensitive, especially to deficiencies and excesses of N (Biemond and Vos, 1992). According to Kleinkopf *et al.* (1981), excessive application of N at early stages can delay the linear tuber growth period for 7 to 10 days for indeterminate cultivars and potentially reducing tuber yields. 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 (Stark *et al.*, 2004; Westermann, 2005). Excess mid-season N slows tuber bulking in favor of vegetative growth (Maynard *et al*., 1979; Waddell *et al*., 1999). Fluctuating N levels have been shown to cause irregular tuber growth and can increase the susceptibility of internal and external tuber deformities (Struik *et al*., 2004). Again deficiencies or fluctuations of soluble nutrients (especially N) increase pathogen and insect susceptibility, decrease tuber yields, and reduce tuber quality (Ojala *et al*., 1990; Struik *et al.*, 2004). Potatoes require relatively high amounts of fertilizer because of high nutrient demand and a shallow, as well as inefficient rooting system (Munoz *et al*., 2005; Pack *et al.*, 2006). In addition to shallow rooting, many potato cultivars have relatively inefficient nutrient and water use efficiency systems (Sattelmacher *et al*., 1990; Love *et al*., 2003). The consequence of poor efficiency and high water/fertilizer rates in potato is the potential for significant N contamination to surface (Honisch, 2002) and groundwater (Madramootoo *et al*., 1992). Although not studied as extensively as N in potatoes, high soil P is a potential environmental problem as well (Davenport *et al.*, 2005). 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 (Doorenbos and Pruitt, 1977). According to Hassan *et al.* (2002), WUE of potato ranges from 69 to 233 kg ha^{-1} mm^{-1}. Kiziloglu *et al.* (2006) reported change of WUE between 63.4 to 44.1 kg ha^{-1} mm^{-1}. The WUE varied around 0.008-0.009, 0.006-0.008 and 0.011-0.014 kg ha^{-1} mm^{-1}, for autumn, winter and spring respectively (Nagaz *et al.*, 2007).

Nitrogen use efficiency (NUE) is broken down into two components (Moll *et al*., 1982**)** which can be absorption efficiency or uptake [total N in the plant at maturity (tuber + haulm) divided by nitrogen supply or rate of fertilizer N] and utilization efficiency [tuber weight divided by total N in the plant at maturity (tuber + haulm)]. Potatoes respond well to the application of both farmyard manure and inorganic fertilizers. According to Bereke (1988), 150 kg N and 66 kg P_2O_5/ha application under rain-fed conditions resulted in a tuber yield advantage of 32% over the unfertilized control. An experiment conducted at Haramaya on clay soil indicated that application of 87 kg N and 46 kg P_2O_5/ha is needed for optimum potato production (Getu, 1998). Application of 110 kg and 90 kg P_2O_5/ha is recommended for potato production on the black soil of Holetta (IAR, 2000). Hence, fertilizer requirement varies across locations and varieties under cultivation.

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 (1991), 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 (Peter *et al*., 2009), which is very low compared to the world average of 16.4 tons/ha(FAO,2004). The main reason associated to this under production and utilization of potato is the narrow genetic base of the early introductions and the traditional view towards potato as most of the people use cereals as staple food. In addition to this, lack of high yielding and disease resistant improved potato varieties, problems of pests and disease especially potato late blight (Gebre Medhin *et al.*, 2001), are also the causes of under utilization of potato in Ethiopia. Moreover, lack of sufficient quantity of good quality seed, poor agronomic techniques, lack of storage facilities, inefficient marketing and transportation system and shortage of skilled man power also contribute to the under utilization considerably(EARO, unpublished).

Efficient use of available resources, especially water and nutrients, is one of the most important objectives in the sustainable management of cropping systems. In Ethiopia, utilization of irrigation water for potato production is not well known (Peter *et al*., 2009). When irrigated there is excessive and shortage problem (Geremew, 2008). 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 (Feibert *et al*., 1998; Al-Jamal *et al*., 2001). 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 (Van Loon, 1981). Optimizing the water and nitrogen supply is an important issue as it varies with many external and crop factors.

Potatoes productions require relatively high amounts of fertilizer (Munoz *et al*., 2005; Pack *et al.,* 2006). But this crop has shallow root system and relatively poor nutrient and water use efficiency systems (Sattelmacher *et al*., 1990; Love *et al*., 2003). The consequence of poor efficiency and high water/fertilizer rates in potato is the potential for significant N acidification to soil as well as surface (Honisch, 2002) and groundwater (Madramootoo *et al*., 1992). Unless it is checked, the environmental pollution due to these effects is hazardous for future life sustenance. Nitrogen rate and irrigation regimes determination for varieties relating with the water and 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).

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 (Zelalem *et al*., 2009) 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 kgN/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 (Madramootoo *et al.*, 1992; Honisch, 2002). 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 and nitrogen 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 and nitrogen use efficiency of the three varieties.

2. LITRETURE REVIEW

2.1. Effects of Nitrogen Rates and Irrigation Regimes on Water and Nitrogen Use Efficiency of Potato

Irrigation regimes are important in determining plant uptake ability of nitrogen available in the soil since well watered crop is more capable to take benefit of applied fertilizers (Luisa *et al.,* 1997). This aspect helps especially, to estimate nitrogen use efficiency at different irrigation water regimes and consequently the environmental impact of nitrogen fertilizer. Optimizing resource use efficiency by better management of water and nutrients through temporal and spatial irrigation and fertilization strategies in crop production is now getting concern in the world. Nitrogen is one of the macro nutrients greatly affecting yield and yield components of potato. According to Zelalem *et al*. (2009) aboveground and underground biomass yields of potato are significantly increased by N and P application. The authors indicated that there is increment of aboveground biomass yield to 224.5% and 32% tuber yield due to application of 207 kg N/ha and 60 kg P/ha compared to the control, respectively. Similarly, the same authors explained the existence of underground biomass yield increase by about 108% due to application of 207 kg N/ha compared to the control. A significant increase in canopy dry matter yield in response to N fertilization is reported by Millard and Marshall (1986). They also added that the increment of marketable yield by 176% and total tuber yield by 119% as a result of increment of application of nitrogen rates from 0 to 207 kg N/ha.

Transpiration water use efficiency (WUE) is affected by nutrient and water supply (Bruck *et al*., 2008). According to Bruck *et al*. (2008), two edible canna genotypes were studied in semi-controlled greenhouse at the International Potato Centre, near Quito, Ecuador and the result indicated decreased shoot dry matter (DM), leaf area and specific leaf nitrogen under conditions of low water supply while WUE was high. In another experiment the authors grew plants with three different levels of nitrogen supply, shoot DM increased significantly from 16 to 37 g, along with leaf area and SLN (Specific Leaf Nitrogen) as the rate of nitrogen application increased. At a lowest level of nitrogen supply (N0), WUE was significantly lower.

Rational use of natural resources, especially water and nutrients, is one of the most important objectives in the sustainable management of cropping systems. To achieve these objectives it is useful to consider some efficiency indices in order to optimize the scheduling of water and nitrogen application. Battilani *et al*. (2004) estimated water and nitrogen use efficiency on the basis of the results of irrigation regimes, where ETC 100% drip irrigation control was compared with treatments provided early or late water stress or over-watered conditions (ETC= 120%). In this field experiment, the effects of three treatments (Rain-fed, ETC= 120%, ETC=100% followed by ETC= 70%, with a change of irrigation regime at an average tuber diameter of 35 mm) on four varieties (one determinate and three indeterminate) were compared. Accordingly, the WUE of the irrigated plots was 38% lower than under rain fed conditions, depending on rain distribution during the growth cycle and whether the WUE is calculated on fresh matter or on dry matter (DM) base. Nitrogen use efficiency was found to be related to water availability and increased up to 22% for the 100% ETC treatment. Water supplies of approximately 300 mm y^{-1} resulted in the highest yields both of fresh tubers and tuber dry matter. In terms of profitability Water and nitrogen use efficiency from dry matter were optimal when the total available water was approximately 250 mm y^{-1}.

According to Darwish *et al*. (2006) the lowest water use efficiency is observed from 60% of full irrigation regimes while 80, 100 and 120% irrigation provided maximum water use efficiency, respectively. Kirda (2002) find that in successful deficit irrigation of potato, the relative water use efficiency in comparison with full water supply was 1.06 for drip irrigation. Onder *et al*. (2005) reported decreasing of WUE due to increase in water supply. Kashyap and Panda (2003) and Yuan *et al*. (2003) also reported similar findings for potato. Irrigation water use efficiency and water use efficiency were not affected by drip irrigation treatments and the highest WUE was generally obtained from application of irrigation when 30% of the available water was consumed (Erdem *et al.,* 2006). Water use efficiency is not varying much among water stresses (Kashyap and Panda, 2003). Kang *et al*. (2004) and Onder *et al*. (2005) also registered similar WUE values for potato. Biomass production was significantly reduced in drought-treated plants (Bergaten *et al*., 2003).

2.2. Water Use Efficiency

Water use efficiency (WUE) is a broad concept which has many definitions. In production, WUE is estimated considering harvested crop yield and water supplied. It is calculated as a ratio of tuber yield, biomass dry or fresh weight to water consumed in potato production (Doorenbos and Pruitt, 1977). Improving WUE in crop production requires an increase in water productivity which in turn increases marketable crop yield while reducing water losses from the plant rooting zone.

Proper use of natural resources, especially water and nutrients, is one of the most important objectives in the sustainable management of cropping systems (Batilani et al., 2004). Water use efficiencies (WUE) vary with irrigation regimes and planting time (Steyn *et al*., 2007). Trabejo and Midmore (1990) reported a water use efficiency of 127 kg ha^{-1} mm^{-1} in unstressed treatment, full water requirement irrigation condition of autumn planting. Walker *et al*. (1991) pointed out that efficient water use is optimizing water usage and ensuring efficiency in its use. Arreguin (1991) stated that efficiency may be obtained by optimizing the use of water and infrastructures through active participation by users with a sense of social responsibility. One mechanism of proper resource use is supplementing rainfall by irrigation water to satisfy the crop needs in growth stages to attain the required yields, when there is limited rainfall in the growing season as it 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 (Shirie *et al*., 2006). The other basic issue is understanding management practices that promote the efficient use of both water and nitrogen, and developing wisdom of efficient use of resource which minimize the potential N losses and will create safe environment, thereby reducing production cost and increasing farm profit.

2.2.1. Accounting for water use and productivity

Water accounting is a process of quantifying the depletion, and productivity of water in a water basin context (Gebreegziabher, 2005). It is a supporting methodology used in assessing impact of field level intervention and performance of irrigation agriculture. The water accounting methodology works depending on water balance approach which considers inflows and outflows from different streams and levels such as irrigation systems or fields (Molden, 1997). Water accountings in greenhouse include the water balance components irrigation water and water depletion which encompass evaporation, deep percolation, transpiration and incorporation to product. It also holds precipitation in actual field.

2.2.2. Water use performance indicators

The water use performance indicators of irrigation benefits evaluation include quantification of irrigated amount, drainage volumes, crop yields, water costs and enterprise returns (Skewes and Meissner, 1998). Some examples of water use efficiency indicators are provided in Table.1

Table 1.Water use efficiency indicators for the evaluation of irrigation performance

Terms	Key Definitions
Gross Production Water Use efficiency	= Total Product (kg) / Total Water Applied (ML)
Irrigation Water Use efficiency	= Total Product (kg) / Irrigation Water Applied (ML)
Marginal Irrigation Water Use efficiency	= Marginal Production due to irrigation (kg) / Irrigation Water Applied (ML)
Crop Water Use Index /efficiency	= Production (kg) / Evapotranspiration (mm)
Economic Gross Production Water Use efficiency	= Economic return ($) / Total Water Applied (ML)
Irrigation Economic Water Use efficiency	= Economic return ($) / Total Irrigation Water Applied (ML)
Marginal Irrigation Economic Water Use efficiency	= Marginal return due to irrigation ($) / Irrigation Water Applied (ML)
Crop Economic Water Use efficiency	= Economic Return ($) / Evapotranspiration (mm)

Source : Raine,1999.as cited in Gebreegziabher, 2005

2.3. Crop Evapotranspiration and Irrigation Requirements

Crop consumptive water use is the sum of water transpired by the plants, the water evaporated from the soil and the fraction of water held by the plant tissues. It may include amount of water evaporated from plant parts when over head irrigation is used. Plants use 1% of water taken up for their metabolic activity. Thus, in practical terms crop water consumption corresponds to crop Evapotranspiration (ETC). Potato ETC can be estimated using weather data and is the amount of water to be applied during the growing season in order to assure potential tuber yields at a given site. Potato ETC is important to consider in irrigation as a well-developed strategy to improve the effectiveness of production.

Excessive irrigation of potatoes results in water loss and significantly increases of runoff and soil erosion from production fields. There may be also soil nutrient leaching which leads to contamination of the groundwater due to fertilizers and other chemical products (Feibert *et al*., 1998; Al-Jamal *et al*., 2001). In addition it increases production costs, can reduce yield by affecting soil aeration and root system respiration, 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 (Van Loon, 1981). Optimizing the water supply is an important issue as it varies with many external and crop factors. Local atmospheric conditions, surface soil wetness, crop type, stage of growth, and the amount of crop cover are the factors that govern the daily fluctuations of potato Evapotranspiration (Wright and Stark, 1990). According to Wright and Stark (1990) the ETC increased as the leaf area and transpiration increased and reached near-maximum levels just before effective full cover. The leaf area index (LAI) reached 3.5 by effective full cover coincident with the highest daily ETC of 8.5 mm.

Potato ETC varies greatly from region to region and season to season. Seasonal potato ETC in the humid Wisconsin area for June through August ranged from 293 to 405 mm during 3 years of study (Tanner, 1981). The maximum daily potato ETC measured by a weighing lysimeter in a sub-humid region in India is found to be 4.24 mm d^{-1} (Kashyap and Panda, 2001). Under a hot and dry climate in northeastern Portugal, peak ETC rates reached 12-13 mm d^{-1} on the days immediately following irrigation, but crop water use declined logarithmically with time to about 3 mm d^{-1} within 5 days (Ferreira and Carr, 2002). Growth-stage specific crop coefficients (Kc) and the water balance method provided a valuable tool in scheduling overhead irrigation of Russet Burbank potatoes in the Columbia Basin of Oregon (Hane and Pumphrey, 1984). According to Simonne *et al.* (2002), Kc values ranged from 0.3 at emergence to 0.8 during maximum leaf area, and declined as the crop matured. ETC is usually calculated by the product of Kc and ETO (reference evapotranspiration), or as a function of a number of climatic elements to provide the atmospheric potential demand. ETC is an essential agro-meteorological index, which can be used to determine both the amount of water to be applied and the irrigation frequency for a particular crop and site.

Total ETC in mm also vary with climate, crop, soil and other factors. Onder *et al*. (2005) reported the highest evapo-transpiration of 473 and 391 mm at full irrigation in 2000 and 2002 years, respectively. Yuan *et al*. (2003) declared that during the experimental period (total 110.5 mm before starting of irrigation applied for all treatments); the total amount of applied water and ETC was 157.7, 205.0, 252.2, 299.3 and 346.6 mm for Ep0.25, Ep0.50, Ep0.75, Ep1.00 and Ep1.25, respectively. Erdem *et al*. (2005) reported that in the non-stressed treatments, the amount of total irrigation water applied and seasonal ETC was 417 and 524 mm, respectively for drip irrigation. Early research reported that seasonal potato ETC ranged from 350 to 800 mm for different climatic and environmental conditions (Fabeiro *et al*., 2001; Onder *et al.*, 2005). Low water levels or excessive fluctuation of water levels outside the desirable range can also reduce quality, contributing to growth deformities such as hollow heart, knobbiness and growth cracks in potatoes. Table 2 shows the rate of water use by potatoes at various stages of development and temperatures in mm per day. Note that at full canopy cover (7-8 weeks after emergence) and temperatures of 32°C, water use can be as high as 7.62mm per day.

Table 2. Average potato water use

Temperature °C	Weeks after emergence														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15°c	0.508	0.762	1.016	1.27	1.778	2.032	2.032	2.032	2	2.03	2.032	1.778	1.524	1.27	1.016
16-20	0.762	1.016	1.778	2.286	2.794	3.302	3.556	3.556	3.6	3.3	3.302	3.048	2.54	2.286	1.778
21-26	1.016	1.524	2.286	3.048	3.81	4.318	4.826	4.826	4.8	4.83	4.572	4.318	3.556	3.048	2.54
27-31	1.27	2.032	3.048	4.064	4.826	5.588	6.35	6.35	6.4	6.1	5.842	5.334	4.572	4.064	3.302
32-37	1.524	2.54	3.556	4.826	6.096	6.858	7.62	7.62	7.6	7.37	7.366	6.604	5.842	4.826	4.064
Growth stages	Vegetative.			Tuber set		Tuber bulking								Maturation	
Source: NDS (1988)															

2.3.1. Irrigation of crops

Ideally, a soil should hold enough water to facilitate plant growth, and have good drainage system for excess water. Soils ability to store water varies depending on their texture (Table 3). Most soil profiles are a mixture of the various textural classes, and the total water storage capacity depends on the cumulative storage capacities of the various layers within the profile. So water irrigators should consider the water holding capacity of the soil.

Table 3. Soil water contents for agricultural soils.

Texture Class	Soil Water Content on Volumetric Basis (%)							
	Field Capacity		Permanent Wilting Point		Available Water		Water Holding Capacity (mm / m)	
	Average	Range	Average	Range	Average	Range	Average	Range
Sand	12	7-17	4	2-7	8	5-11	0.96	0.60-1.32
Loamy Sand	14	11-19	6	3-10	8	6-12	0.96	0.72-1.44
Sandy Loam	23	18-28	10	6-16	13	11-15	1.56	1.32-1.80
Loam	26	20-30	12	7-16	15	11-18	1.80	1.32-2.16
Silt Loam	30	22-36	15	9-21	15	11-19	1.80	1.32-2.28
Silt	32	29-35	15	12-18	17	12-20	2.04	1.44-2.40
Silty Clay Loam	34	30-37	19	17-24	15	12-18	1.80	1.44-2.16
Silty Clay	36	29-42	21	14-29	15	11-19	1.80	1.32-2.28
Clay	36	32-39	21	19-24	15	10-20	1.80	1.20-2.40

Source: Jensen *et al*. (1990)

Soil moisture status is expressed in percent total available soil water (TAW) content or soil water tension (SWT). Total available soil water content is the amount of water that plants can extract from a given volume of soil in the crop effective rooting zone. Total available soil water is usually expressed as a percent between “field capacity” (100%) and “permanent wilting point.

Soil water tension is the force roots exert to extract water from the soil. At “field capacity” (100% TAW), the SWT is often between 10 and 25 kPa depending on soil type and the method of determination. Soil water is not available at the “permanent wilting point”, generally assumed to be at a SWT of 1,500 kPa. Soil water tension can be measured directly using tensiometers or granular matrix sensors (Shock, 2003).

Total available water (TAW): TAW is defined as the volume of water retained between field capacity (FC) and permanent wilting point (WP) as described above. TAW is the amount of water that a crop can extract from its root zone and its magnitude depends on the type of soil and rooting depth (FAO, 1998). It is stated as:

$$TAW = 1000(\theta fc - \theta wp) \times Ze, \qquad \text{Eq.1}$$

Where TAW = the total available soil water in the root zone (mm); θfc = moisture content at field capacity (m3m-3); θWP = moisture content at wilting point (m3 m-3); and Ze = rooting depth (m).

Readily available soil water (RAW): Initial soil moisture depletion or readily available water (RAW) is the fraction of TAW that a crop can extract from the root zone without suffering water stress (FAO, 1998). It can be stated as:

$$RAW=p*TAW \qquad (2)$$

Where TAW = the total available soil water in the root zone (mm); RAW = the readily available soil moisture in the root zone (mm) and p= average fraction of TAW that can be depleted from the root zone before moisture stress occurs.

The factor p differs from one crop to another. It varies from 0.3 for shallow rooted plants to 0.7 for deep-rooted plants. Generally a value of 0.5 for p is commonly used for many crops (Gebreegziabher, 2005). It can also be 0.5-0.3 (Doorenbos and Kassam, 1979) to optimize yield and 0.35 (Curwen, 1993) as well as 0.45 (Kashyap and Panda, 2002) on sandy loam soil in a sub-humid sub-tropical region in order to attain maximum water use efficiency. It can also be 0.4 (Jim Bauder and Linzy, 2010)**.** 0.25- 0.50% P was used to calculate readily available soil water from total available soil water (FAO AGL, 2002). The allowable depletion fraction (p) varies with soil type, crop stage and climate.

Irrigation water amount also depends on effective rooting depth. According to Gebreegziabher (2005) 100 cm was used as effective root depth for potato and other vegetables in Tigiray, northern Ethiopia. As potato is shallow rooted crop (Tanner *et al*., 1982) about 90% of the root length of potato is found in the top 25.4 cm, while most other crops root deeper. According to Stark (2005) the root depth of potato varies from 12.5-50.8 cm. But it can grow for maximum length of 40-60 cm according to Ayers and Westcott (1985*)* and higher root density occur between 15 and 30 cm (Bishop and Grimes, 1971-74). FAO AGL (2002) use 30 cm irrigation depth from 1-100 days after planting and 60 cm after 101days after planting for potato growing.

2.3.2 Irrigation scheduling

Nitrogen rates and irrigation regimes are among the basic factors considerably affecting the water and nitrogen use efficiencies of varieties. According to Brück *et al*. (2001) report decreased shoot dry matter (DM), leaf area, nitrogen up take efficiency and increased WUE was recorded under low water supply. On the other hand, they reported significantly lower WUE under lowest level of nitrogen supply. In experiment of comparing control or zero nitrogen application with treatment applied nitrogen to the requirement of the crop, increase of WUE from dry matter and yield was indicated with increasing nitrogen supply (Caviglia and Sadras, 2000). Similar results was reported by Kelm *et al*. (1999-2000) in which the lowest WUE was indicated under none fertilized while highest was obtained from highest rates. They also narrated reason for lowest WUE under lowest application of nitrogen and it was due to very low total dry matter production and higher stomata opening under N stress, which was reflected in the observed higher transpiration rate. Plants mostly suffer from nutrient deficiencies (especially N and P), which could be regulated by climate and environment changes, fundamentally increased water stress (Wu *et al.*, 2009) due to the close relationships between water and nutrient availabilities. Nitrogen (N) fertilizer plays a crucial role in enhancing canola yield. Water management has a severe effect on N movement. But well watered crop is more capable to take benefit of applied fertilizers (Luisa *et al.*, 1997). Even though leaching of nitrate due to heavy rainfall cannot be completely prevented, following the N management strategies can minimize the losses of nitrogen. Some of the nitrogen losses minimization management strategies considerations for irrigated potatoes are determination of nitrogen rate, timing of N application, and use of diagnostic procedures to determine N needs during the growing season, effective water management, sources of N, and establishment of a cover crop after harvest (BMPNU, 2008). However, over-irrigation even with optimum N rate and proper application time can cause substantial leaching losses. Therefore, effective water scheduling techniques based on soil moisture content and demand by the crop should be followed to prevent such losses (BMPNU, 2008).

Irrigation of crops sensitive to water stress requires systematic scheduling of irrigation decisions. There are three methods for matching irrigation with crop water requirements (Pereira and Shock, 2006). These are measuring how much water the soil contains, monitoring some attribute of the plant that is related to water deficits, calculating how much water the atmosphere can extract from a well watered crop. These types of scheduling are also described by other authors as atmospherical based, plant-based, or soil-based data matching or scheduling (Shae *et al*., 1999).

Plant data may include canopy temperature, xylem water potential, and visible wilting. Soil-based data include soil water content and soil water tension (SWT). In practice, plant, soil, and atmospheric data are often used concurrently, especially when changes in irrigation schedules are required to adjust for changes in crop water use. Soil-based irrigation scheduling methods range from the simple "feel" method to such technologically advanced methods as the neutron probe and time-domain reflectometry (Shock, *et al.*, 1998). Tensiometers and gypsum blocks provide technology and cost between these extremes, but they have limitations for practical use by growers.

Tensiometer - Measures soil moisture **(**the soil moisture tension) directly (Shock, 2003). The moisture level at which irrigation starts can be controlled by installing tensiometer in most irrigations and the best lower limit water potentials based on potato yield and grade responses to irrigation ideally as irrigation criteria includes 50 kPa using furrow irrigation on loam soil in California (Timm and Flockner, 1966), 50 to 60 kPa using sprinklers on silt loam in Oregon (Eldredge *et al*., 1992, 1996), 25 kPa using sprinklers on silt loam in Maine (Epstein and Grant, 1973), 60 kPa and 30 kPa using furrow and drip irrigation, respectively, for silt loam in Oregon (Shock *et al*., 2002), and 20 kPa using sprinklers on sandy loam in Western Australia (Hegney and Hoffman, 1997).

Gravimetric soil moisture measurement is the standard method of soil water content measurement which involves taking a physical sample of the soil, weighing it before any water is lost, and drying it in an oven before weighing it again (Hignett and Eventt, 2008). The mass of water lost on drying is a direct measure of the soil water content (Equation 3).

$$\theta m = \frac{W1-W2}{W1} \qquad (3)$$

Where, θm = Gravimetric soil water content, W1 and W2 are weight of wet and dry soil, respectively.

The above soil moisture value is on mass basis water content of a field soil which can be used for comparative purposes and is useful when soil volume changes, as with tillage. However, for most irrigation, crop water use, and irrigation and water use efficiency work, what is required is the volume of water in a certain volume of soil or the equivalent depth of water in a certain depth of soil (Hignett and Eventt, 2008). Both of these require knowledge of the volumetric water content.

The equation for determining soil water content in volume is

$$\theta V = W2/\rho w)/Vs \quad (4)$$

Where, ρw is water density=1 g/cm^3, W2= weight of soil water and Vs is Soil sample Volume.

Potato requires well drained soil and good aerated root environment for healthy development of large size tubers. Soil moisture depletion, in fact, should never be allowed to fall below 30-40% of available soil moisture of the root zone in top 100 cm soil (PWM, 2000). The same source also implies irrigation at frequency of 7-10 days and schedule based on this does not allow the crop to suffer from any water stress; when it corresponds to irrigation at available soil moisture depletion (ASMD) of 20-30 per cent or irrigation at soil moisture tension of 0.3 bars, measured at 15-20 cm depth.

It is also possible to schedule irrigation applications using root zone water balance approaches (Evans *et al*., 1996), which apply the Checkbook or budgeting approach to account for all inputs and withdrawals of water from the soil (Jones, 2004). Under favorable conditions, irrigators tend to over irrigate, believing that applying more water will result in increased crop yields. But, over irrigation can reduce yields because the excess soil moisture often results in plant disease, nutrient leaching, and reduced pesticide effectiveness. In addition, water and energy are wasted.

The amount of water irrigated can often be reduced without reducing yield. Studies have shown that irrigation scheduling using water balance methods can save 15 to 35% of the water irrigated without reducing yield (Evans *et al*., 1996). Maximum yield does not equate to maximum profit usually. The optimum economic yield is less than the maximum potential yield. Irrigation scheduling methods aimed at achieving maximum yield that maximizes profit and optimizes water and other resource use should be considered for good economic return from production.

Soil Water Balance: - Evapotranspiration can also be determined by measuring the various components of the soil water balance. The method consists of assessing the incoming and outgoing water flux into the crop root zone over some time period (Samuel *et al*., 2009). Irrigation (I) and rainfall (P) add water to the root zone. Part of I and P might be lost by surface runoff (RO) and by deep percolation (DP) that will eventually recharge the water table. Water might also be transported upward by capillary rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SF_{in}) or out (SF_{out}) of the root zone in actual field but in greenhouse especially when the tubers are planted in pots, there is no vertical or horizontal water fraction movement from water table or soil moisture reservoir except leakages which can be managed well to become zero through decreasing irrigation interval and amount of water applied ones. There is no rain also as the experiment is conducted in greenhouse. According to Samuel *et al*. (2009) in many situations, except under conditions with large slopes, SF_{in} and SF_{out} are minor and can be ignored. Soil evaporation and crop transpiration are the main water depletion from the root zone. If all fluxes are known and only evapo-transpiration (ET) can be assessed, it can be deduced from the change in soil water content (ΔS) over the time period (Equation 5):

$$ETC = I + P - RO - DP + CR \pm \Delta SF \pm \Delta S \text{ for Actual field.} \quad (5)$$

Where ETC is Evapotranspiration, I is irrigation water, P is rain fall, RO= surface runoff, DP= Deep percolation, CR=water raised upward by capillary movement, ΔSF= Difference of water moved by surface flow in and out of the root zone and ΔS = Change in soil water content. Generally, the soil water balance equation used in greenhouse container grown crops is: $ETC=I-DP\pm\Delta S$. (6)

Precipitation and other parameters are negligible or zero, but ΔS **(**Change in soil water) is obtained either from soil sample or calibrated tensiometer soil moisture value.

The limitation of this method is some parameters such as subsurface flow, deep percolation and capillary rise from a water table are difficult to assess in actual field and short time periods cannot be considered. The soil water balance method can usually give ET estimates over long time periods of the order of week-long or ten-day periods.

2.4. Nitrogen Use Efficiency

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. As a concept, NUE includes N uptake and utilization efficiency, expressed as a ratio of output (total plant N, tuber N, biomass yield, tuber yield) and input (total N, soil N or N-fertilizer applied). According to Moll *et al*. (1982) NUE is also defined as the amount of N taken up by the crop per unit of N available to the crop, while N utilization efficiency is the tuber yield per unit of N uptake by the crop.

NUE can also be expressed based on apparent nitrogen recovery using physiological and agronomic parameters (Ravi *et al*., 2008). Agronomic efficiency is an integrative index of total economic outputs relative to the available soil N (native and applied) and apparent nitrogen recovery is related to the efficiency of N uptake while Physiological NUE deals with N utilization to produce tubers or total plant dry matter and it is directly related to nitrogen utilization efficiency.

The most suitable way to estimate NUE depends on the crop, its harvest product and the processes involved in it. According to Battilani *et al*. (2008) field experiments conducted to assess the nitrogen use efficiency (NUE) of two fertigation treatments (Static and Dynamic) in comparison with a Non-Irrigated/Non-Fertilized (NINF) and an Irrigated/Non-Fertilized (INF) control, expressed as marketable DM yield per kg available N, is 229.0, 188.2, 166.2 and 173.5 kg kg^{-1} N for NINF, INF, Static and Dynamic treatments, respectively.

2.4.1. Utilization efficiency

All absorbed nitrogen is not involved in producing tuber yield. It can be portioned into formation of above ground biomass and below ground biomass and is measured by the ratio of tuber weight to total plant nitrogen (Moll *et al*., 1982). At senescence stage of potato, the nitrogen utilization efficiency of Dynamic, Static, NINF and INF in fertigation treatments are 80.6, 77.2, 89.5 and 80.6 kg of total DM per kg of nitrogen uptake, respectively (Battilani *et al*., 2008).

There is variation between different cultivars of the same species, and even more, between crops of different species in nitrogen utilization efficiency. Efficiency generally declines with increased N fertilizer applications (http://www.agnet.org/copying.html). It is this type of response which determines the productivity of crops. There are varietal differences of traditional rice varieties and improved ones in nitrogen response and NE which are mainly due to the differences in their nitrogen uptake and leaf morphology (Taraka *et al.,* 1964). There are higher NE of potato and sugar beet compared to other crops, as result of their longer period of sink activity (Tanaka *et al.,* 1984). Thus, the factors affecting NE are mostly genetic, although environment and the interaction between the genetic character of the variety and the environment, are also important. The growth of the crop is closely affected by these factors, resulting in different patterns of growth. As the pattern of nitrogen uptake during growth is the main factor which can be manipulated to affect the growth pattern, the timing of nitrogen applications improves the absorption efficiency by controlling uptake stage. The ability of absorbed nitrogen to produce grain or straw varies according to the growth stage at which the nitrogen is absorbed (Ishizuka, 1980). The nitrogen absorbed at different stage of growth affects the harvest index of nitrogen and the nitrogen concentration of the harvest organ (Tanaka *et al.,* 1984). But there is little information about time of application that resulted into optimum utilization of nitrogen.

2.4.2. Nitrogen uptake efficiency

Nitrogen up take is a yield determining parameter that indicates the amount of nitrogen absorbed by the plant root. It is a secondary data obtained from total plant analysis for nitrogen content in laboratory. This nitrogen up take is used for calculating nitrogen uptake efficiency which computed by dividing total plant nitrogen to the total nitrogen supplied or rate of nitrogen applied (Moll *et al*., 1982). According to Battilani *et al*. (2008) field experiments conducted to assess the nitrogen use efficiency (NUE) of two fertigation treatments (Static and Dynamic) in comparison with a Non-Irrigated/Non-Fertilized (NINF) and an Irrigated/Non-Fertilized (INF) control, resulted in potato nitrogen up take of 159, 166, 95 and 83 kg ha^{-1} y^{-1} for Dynamic, Static, INF and NINF, respectively. The absorption/uptake efficiency is varying with crop type in 10-70% amount, soil conditions, the method and time of application (Lain, 1991). In relation with dependence of absorption efficiency to time of application (Dong *et al*., 2010) results indicated that highest rate of 15N absorption occurred during the first 2 days after application, then decreased to 0.03 g m^{-2} day^{-1} by Day 4 .On the other hand, they also suggested that at twenty days after foliar urea application, 63.6% of absorbed 15N had been exported from leaves.

Different crops or different varieties of crops absorption of nitrogen are different due to variation in rooting ability and physiological activity requirement of nitrogen. In many cases, ample amounts of fertilizer N, which are more than the crop requirement, are applied in the field which increases the cost of production. Different varieties of crops may also be cropped receiving the same amount of nitrogen fertilizer which is true in potato production in Ethiopia. In such cases, due to lack of knowledge of how efficient the variety can use there may be shortage or excessiveness of the applied fertilizer that affect the yield. Understanding the up take efficiency it is also possible to select most profitable variety as more efficient variety can be produced with lesser cost of production related to nitrogen fertilizer (Powell *et al*., 2010). So it is better to calculate varietal nitrogen efficiency for more profitable production choosing more efficient variety in absorption as well as utilization. Key indicators of nitrogen use efficiency include the following:

1. Absorption eff./uptake = $\frac{\text{total plant nitrogen}}{\text{Soil nitrogen+ applied}}$ (7)
2. Utilization efficiency = $\frac{\text{tuber weight or biomass}}{\text{Total plant nitrogen}}$ (8)
3. Agronomic efficiency = $\frac{\text{integrative index of total economic outputs}}{\text{Soil N (native and applied).}}$ (9)
4. Physiological NUE = $\frac{\text{produced tubers or total plant dry matter weight}}{\text{N utilized}}$ (10)

NUE is calculated for identification of which variety is most efficient to estimate ability to give reasonable yield under marginal nitrogen content of soil. It helps also for declining cost of production by which farm profit is improved and increasing regulations to reduce environmental pollution (Powell *et al*., 2010).

2.5. Factors Affecting Tuber Yield and Biomass

2.5.1. Effect of nitrogen on yield and yield components of potato

Nitrogen is one of the macro nutrients greatly affecting yield and yield components of potato. According to Zelalem *et al*. (2009) aboveground and underground biomass yields of potato are found to be significantly increased by N and P fertilizer application. They indicated that the increment of aboveground biomass yield by 224.5% due to application of 207 kg N/ha and 32% yield increment due to application of 60 kg P/ha compared to the control. Similarly, the same authors explained the existence of underground biomass yield increase by about 108% due to application of 207 kg N/ha compared to the control. A significant increase in canopy dry matter yield in response to N fertilization is reported by Millard and Marshall (1986). They also reported the increase of marketable yield by 176% and total tuber yield by 119% as a result of application of 0 to 207 kg N/ha.

N fertilization increased potato plant height with differential response between varieties (Yibekal, 1998). The author also indicated the presence of positive and significant correlation (r = 0.61**) between plant height and total tuber yield. This implies that when plant height increases, the total tuber number also increased as a result of nitrogen application. N plays a significant role in production of stem and axillary branches (Moorby and Morris, 1967). Continuous supply of N to plants promote shoot and root growth while reducing tuberization in potato (Gunasena and Harris, 1969).

Nitrogen and P fertilization can improve both the marketable and total tuber yield of potato. Reason for increment of total tuber yield as a result of N fertilization application can be attributed to increased radiation interception during the first part of the season and lower rates of decline in photosynthetic efficiency of the canopy during the later part (Millard and Marshall, 1986). Kotsyuk (1995) also revealed that fertilization increased leaf areas which encourage the formation of many tubers and increased duration of tuber bulking. N fertilizer affects yield by its effect on the number of tubers produced per plant, the average weight of tubers, the establishment and leaf area duration (Wilcox and Hoff, 1970). Timm and Flocker (1966) indicated optimum tuber yield when N fertilizer is applied at the rate of 204 kg/ha and yield reduction is noted when applied above this rate. Tuber number increase in response to N fertilization can be attributed to an increase in stolon number through its effect on Gibberellins biosynthesis in the potato plant (Zelalem *et al*., 2009). The involvement of gibberellins in regulating stolon number through stolon initiation is described by Kumar and Wareing (1972). N effect on tuber formation in potato is by influencing the activity and phytohormone balance in the plant, especially, on the levels of gibberellic and abscissic acids as well as cytokinins (Amzallag *et al*., 1992).

2.5.2. Climate of the area

Air temperature, solar radiation and photoperiod:-Among the climatic condition temperature, solar radiation and photoperiod are the most important potato growth and development determinants. The review by Haverkort (1990) points out that potato is best adapted to cool climates such as tropical highlands with mean daily temperatures between 15 and 18^{o}C as encountered in its center of origin. Higher temperatures favor foliar development and retard tuberization. In addition, heat stress leads to a higher number of smaller tubers per plant; lower tuber specific gravity with reduced dry matter content, and usually to a paler skin color of the tubers. Temmerman *et al*. (2002) examined the effect of latitude, seasonal mean air temperature (ranging from 13.8 to 19.9^{o}C), global solar radiation (ranging from 12.0 to 21.3 MJ m-2 d-1), air humidity, soil moisture, and atmospheric Co_2 concentrations on tuber yield in European experiments. Ignoring Co_2 enrichment, the yield of potato (cv. 'Bintje') increased from south to north Europe. Marketable tuber yields increased at higher latitudes. Climatic conditions, not only affected by the latitude but also by altitude, influence potato plant growth and development. Moreno (1985) found that plants grown at low (coastal) altitudes have low yield of tubers per plant as compared with those grown in the Andean highlands.

Gawronska and Dwelle (1989) studied the effect of high light levels (maxima between 500 and 1200 E $m^{-2}s^{-1}$) and shaded low light levels (approximately one-quarter of the high light) on potato plant growth, biomass accumulation and its distribution. They observed that plants under low light do not produce auxiliary shoots. Tubers of plants under low light were very small and irregular in shape. The most evident plant response to low light was greater stem elongation as well as a reduction in total biomass accumulation and in tuber weights. The reduction in total biomass under low light was 34 to 45%. Reduction in tuber dry weights under low light ranged from 39 to 57%, depending on the growth stage and harvest time. In addition, at all growth stages, the percentage of biomass partitioned to the tubers was higher under high light than under low light conditions.

Soil temperature:-Soil temperature also affects the various activities of growing potato. The rate of development of sprouts from planted seed pieces depends on soil temperature. Very little sprout elongation occurs at 6°C. Elongation is slow at 9°C and is maximized at about 18°C. The time between planting and emergence depends on soil temperature. Phytotron and field experiments carried out by Sale (1979) showed that emergence was linearly related to mean soil temperature and relatively independent of diurnal fluctuations up to an optimum of 22-24^{o}C. Up to this optimum emergence can be considered as a degree-day requirement calculated either from soil temperature at tuber depth or air temperature. At temperatures above the optimum, emergence was inhibited. Sattelmacher *et al*. (1990)

studied the effect of 20^{o}C and 30^{o}C root-zone temperatures on root growth and root morphology of six potato clones. Significant genotypic differences in the responses of potato roots to 30^{o}C were observed, indicating the potential for selecting heat tolerant potato clones. In both heat tolerant and heat sensitive clones, the size of the root system was reduced by a 30^{o}C root-zone temperature explained by a reduction in the cell division followed by cessation of root elongation. Tuberization stimulus favors both tuber initiation and tuber enlargement. Through artificially prolonged exposure to short days and cool temperatures, it is possible to attain such a high level of stimulus that induction is irreversible, even if potato plants are subsequently exposed to long days for weeks or months. The optimum soil temperature for initiating tubers ranges from 16 to 19°C (Western Potato Council, 2003).

Atmospheric humidity and wind:-There are very few recent studies dealing with the direct effects of relative humidity (RH) on potato growth, tuber yield and grade. Most of the contributions related to the influence of RH on potato refer to potato storage where RH is an important factor in tuber weight loss and the occurrence and severity of diseases and pests. The same scarcity of research exists with regard to the wind regimes at a particular location as an agro meteorological factor affecting potato production systems. Wheeler *et al*. (1989) studied the effect of two RH levels, 50% and 85%, on the physiological responses of three cultivars of potato (Russet Burbank, Norland, and Denali) in controlled-environment rooms under continuous light intensity at 20^{o}C. No significant differences in total plant dry weight were measured between the atmospheric humidity treatments, but plants grown under 85% RH produced the higher tuber yields. Leaf areas were greater under 50% RH and leaves tended to be larger and darker green under drier than at more humid atmospheric conditions. The elevated humidity appeared to shift the allocation pattern of photosynthesis to favor allocation to the tubers over leaves and stems. Gordon *et al*. (1999) estimated sap flow from solar radiation and vapor pressure deficit data for three field-grown potato cultivars (‘Atlantic’, ‘Monona’ and ‘Norchip’) at Nova Scotia, Canada, under non-limiting soil water conditions. Sap flow rates for all cultivars were closely linked with solar radiation under conditions where soil water was not limiting. The vapor pressure deficit (VPD), a function of relative humidity and air temperature, had less effect on sap flow, although the magnitude of the VPD during the growing season was generally 2 kPa.

All cultivars maintained actual daily transpiration near the potential energy limiting rate under well-watered conditions. When the soil was drier (percent available soil water 30%), Monona potato plants had a much more rapid decline in transpiration than the other two cultivars. Another physiological parameter closely related to yield is water use efficiency. According to Bowen (2003) the cool humid conditions favored growth and promoted a more efficient use of irrigation water in coastal Peru condition when grown during winter time. During winter, less soil water evaporation caused by smaller VPD enhanced water use efficiency when compared with that observed during the summer. Sinclair *et al.* (1984) also showed that generally more humid environments provide greater water use efficiency because of a lower VPD. Stomatal resistance governs photosynthesis and transpiration. Two major feedback loops are reported by Raschke (1979) as the direct controllers of stomatal resistance. The first involves photosynthesis where a reduction in intercellular carbon dioxide (Co_2) occurs as the photosynthetically active radiation increases, the stomata open and stomatal resistance decreases. The second involves an increase in stomatal resistance whenever leaf water potential reaches a critical threshold as a result of transpiration intensity (Raschke, 1979).

Wind also affects transpiration rates and, therefore, photosynthetic activity and crop yield. At sites where winds are frequently strong throughout the year, increased stomatal resistance can cause reduction in potato yield (Sun and Dickinson, 1997; Pavlista, 2002).

2.5.3. Effect of irrigation regimes and methods on tuber yield and yield components

When considering irrigation the amount and quality of water is a factor to be managed well for better yields**.** Faberio *et al*. (2001) reported a requirement of 597 mm irrigation water to reach maximum tuber yield of 45.18 t /ha. Regarding methods of irrigation, Onder *et al*. (2005) suggested that surface drip irrigation and subsurface drip irrigation methods did not significantly affect tuber yield. Shock *et al*. (1998) and Yuan *et al.* (2003) reported increased tuber yield with irrigation applications. It was found that marketable tuber yield for 120% of full irrigation is significantly highest but yield for 60, 80 and 100% of full irrigation wasn't considerably different. Tuber dry matter yield increased with increasing water supply from 60, 80 and 100% full irrigation, respectively but it decline at 120% of full irrigation (Darwish *et al*., 2006). Onder *et al*. (2005) related that irrigation levels significantly affected all yield parameters in two consecutive years and yield for 66 and 100% irrigation regimes were significantly superior to 33% and non-irrigated treatments. Also, Nagaz *et al*. (2007) indicated similar findings. Tuber fresh and dry weight from first harvest to three harvests for full irrigation tend to be higher than partial root zone drying but at fourth harvest partial root zone drying has got highest amounts (Shahnazari *et al*., 2007).

Erdem *et al*. (2006) narrated that effect of irrigation regimes on tuber weight wasn't significant in two consecutive years but tuber yield only in 2005 was significantly affected by irrigation regimes. On the other hand, Darwish *et al*. (2006) stated deficit irrigation lowering both the tuber dry matter production and the average weight of the commercial tuber, leading to 21% loss in fresh yield. In addition, Onder *et al*. (2005) report indicated that treatment of 66 and 100% of full irrigation provided the highest tuber mean weight. Nagaz *et al*. (2007) explained that the reduction in tuber yield was a result of reduction in tuber number and weight as a consequence of water supply shortage during tubers initiation and development.

Highest plant yield for 66 and 100% full irrigation is reported which was significantly different from other treatments (33% and non-irrigated) (Onder *et al.,* 2005). Yuan *et al*. (2003) reported that use of 0.25 and 0.50 Evapotranspiration produced significantly lower plant biomass than 0.75, 1.00 and 1.25 times of evapo-transpiration. Plant and total dry matter yield decreased with increase in water stress (Kashyap and Panda, 2003). Darwish *et al*. (2006) found out that harvest index increased with increase in water supply and highest amount was obtained at 100% of irrigation. Similar result was reported by Shahnazari *et al*. (2007). In an experiment of irrigation regimes of 100, 80 and 60% there was 0.0098, 0.00754 and 0.00536 g wet tuber yield per one mm irrigation in one meter square, respectively (Steyn *et al*., 2007). The soil texture was sandy loam and average temperature was 26^0C.

2.5.4. Effect of irrigation and nitrogen interaction on potato yield

Land and water can be major constraints to the production of food required to meet the quantitative and qualitative world's demand with greatly increasing population. Therefore, it is critical to optimize agricultural water use efficiency (WUE) defined as the ratio of crop yield to the applied water. This agricultural water use efficiency optimization requires both maximizing productivity per unit of land area and maximizing productivity per unit of water consumed (Stefania *et al*., 2011). To maximize WUE, it is necessary to conserve water and promote maximal crop productivity which intern requires combined works involving minimization of water losses through seepage, runoff, evaporation, and evapotranspiration by weeds; and planting well adapted high-yielding crops/cultivars. Improving cropping environment by proper management of planting and harvesting time, tillage, fertilization, and pest control also contribute to enhancement of crop growth and productivity. The water use efficiency not only depends on the crop yield but also affected by water application level (Kumar *et al*., 2007). When the water application level increased beyond the requirement of the crop, the water use efficiency decreases. Studies found a poor correlation (R2 = 0.24) between the WUE and water application level which indicated that increasing the water application did not always increase the WUE (Kireger and Blake, 1994; Speer *et al*., 2008). Significant influence of irrigation regimes and methods on water and nitrogen use efficiency was indicated in Lehrsch *et al*. (2002).

Nitrogen rates cause change on water use efficiency by potentially affecting biomass, evaporations, transpirations and HI through primarily influencing photosynthesis. There is close relationships between water and nutrient availabilities (Wu *et al.*, 2009). Response of all major crop species to nitrogen supply in biomass per unit transpiration was indicated in Brueck (2008). Cooper *et al.* (1987) demonstrated the increment of WUE associatation with nitrogen and phosphorous fertilization in low-fertility soils of west Asia and North Africa. On the other hand, significantly lower WUE under lowest level of nitrogen supply was indicated in Brück *et al.* (2001). A similar result was reported by Kelm *et al.* (1999-2000) in which the lowest WUE was indicated under none fertilized condition than fertilized condition. Hence, ensuring adequate nitrogen supply is therefore, critical for high yield per unit evapotranspiration or better improvement of water use efficiency.

In same manner with these, nitrogen application rates affect nitrogen use efficiency. Increasing nitrogen application from 80 kg/ha to 160kg/ha or 200kg/ha, reduced agronomical nitrogen and nitrogen use efficiency (Shahzad *et al.*, 2010). This indicates that the increment of NUE with increasing nitrogen supply is up to the maximum yield potential gaining nitrogen rates as suggested by Hartemink *et al.* (2000) for sweet potato. In relation with this, Darwish *et al.* (2006) found that decreasing N application to 125 kg /ha, from 250, 375 or 500 kg N /ha, resulted in production of significantly higher N recovery or nitrogen up take efficiency. Similarly, according to Shahzad *et al.* (2010) highest nitrogen levels resulted in lowest physiological nitrogen use efficiency. Increasing water use efficiency from dry matter and yield was indicated with increasing nitrogen supply to the optimum level (Caviglia and Sadras, 2000). So, it is considerable to find the common effect of irrigation and nitrogen rates on potato yield, water and nitrogen use efficiencies for better farm return.

Nitrogen and irrigation have important interactive effects on N and water use efficiency, potato yield and quality, as well as, N and water losses to the environment. Meyer and Marcum (1998) found out maximum tuber yields from 1.1 to 1.2 ETC and 0 to 56 kg ha^{-1} N in combination 1992, while 1.1 to 1.3 ETC and 168 to 224 kg ha^{-1} N maximized yield in 1993. Feibert *et al*. (1998) reexamined nitrogen fertilizer rates and timing for four potato cultivars in the Treasure Valley of Oregon throughout 3 consecutive years on silt loam. They concluded that with careful irrigation scheduling (initiated when the SWT at 0.2-m depth reached 60 kPa and with amounts corresponding to accumulated ETC) less nitrogen fertilizer was required to optimize yield than usual recommendations. Nitrogen at 135 kg ha^{-1} increased total yield in 19-23% compared to the 0 N rate check treatment. Optimal potato petiole N levels through the growing season were known for Russet Burbank (Jones and Painter, 1974). Potato petiole analyses should be incorporated into commercial N and irrigation management strategies.

3. MATERIALS AND METHODS

3.1. 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.

3.1.1. Light condition in greenhouse

The average shading capacity of the greenhouse was actually 26.87%. The light intensity available Lux/2000 and shade level (percent) is displayed in Appendix Figure 1 and 2, respectively. 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.

3.1.2. 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^{0}C while the maximum and the minimum values of the dry bulb temperature were 30.7^{0}C and 22.6^{0}C, respectively. The relative humidity, dew point temperature, dry bulb and wet bulb temperature recorded during the growth periods are presented in Appendix Figure 3. The fluctuation of relative humidity was highest when compared to the other parameters recorded.

3.1.3. Growing media soil water conditions

The soil medium used for growing the potato varieties was prepared from uniform soil characteristics and same weight filled to pots of equal size. The texture of the soil was 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 (Appendix Table 2). The weight of the soil medium in pots was 12 kg and the pots' size was 15 liters. The soil was filled in the pots and arranged in three blocks after weighing on bean balance (Appendix Plate1).

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 total available soil water as varying with stage of crop growth or effective root depth and readily available soil water as varying with stage of crop growth or effective root depth and depletion factor or irrigation regimes are presented in Appendix Table 1. The water amount below the permanent wilting point was unavailable to plants. The deplation factors for growing periods and irrigation regimes were presented in Appendix Table 19. The depletion factor for the irrigation were 0.25 for the 55th day after planting; 0.3 and 0.5 for 56-90th and beyond 90th days after planting, respectively (FAO AGL, 2002).

3.2. Materials

Plant materials: 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 m. a.s.l. with 750-1000 mm annual rain fall and has maturity period of 90-120 days after planting while Guassa grows 2000-2800 m a.s.l. 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 m a.s.l. altitude range with 750-1000 mm annual rain fall and matures in 90-120 days after planting. Jalenie and Guassa grow up to 95.24-126.11cm and 97.54-115.71cm heights respectively while Degemegn grows up to 93.39- 107.73cm heights. These varieties were selected due to their wide agro-ecological zone adaptability and suitability to Jimma growing condition.

3.3. Experimental Design and Procedures

The experiment was arranged in 3x3x3 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).

The model of the design was:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + C_k + \beta + (AC)_{ik} + (BC)_{jk} + (ABC)_{ijk} + \varepsilon_{ijk}$$

Where: I=1, 2…a

J=1, 2….b

K=1, 2…c

- Y_{ijk} is the observation of the ith, jth & kth treatment
- μ is the mean,
- A_i, B_j &C_k is the treatment effect of the ith, jth &Kth treatment,
- AB_{ij} is interaction of A_i and B_j treatment
- AC_{ik} is interactions of A_i and C_k treatment
- BC_{jk} is interactions of B_j and C_k treatment
- ABC_{ijk} is interactions of A_i, B_j and C_k treatment
- β is the replication or block effect, and ε_{ijk} is the experimental error.

Factors level combinations: The total factors level combinations were eighty one while each factor level had 27 combinations (Table 4). These factors levels combinations are called treatments.

Table 4. Factors level combinations

Jalenie			
	130kg N/ha	110kg N/ha	90kg N/ha
100%	JalenieX100%X130kg N/ha	JalenieX100%X110kg N/ha	Jalenie X100%X90kg N/ha
80%	JalenieX80%X130kg N/ha	JalenieX80%X110kg N/ha	JalenieX80%X90kg N/ha
60%	JalenieX60%X130kg N/ha	JalenieX60%X110kg N/ha	Jalenie X60%X90kg N/ha
Guassa			
100%	GuassaX100%X130kg N/ha	GuassaX100%X110kg N/ha	GuassaX100%X90kg N/ha
80%	GuassaX80%X130kg N/ha	GuassaX80%X110kg N/ha	GuassaX80%X90kg N/ha
60%	Guassa X60%X130kg N/ha	GuassaX60%X110kg N/ha	GuassaX60%X90kg N/ha
Degemegn			
100%	Degemegn X100%X130kg N/ha	Degemegn X100%X110kg N/ha	Degemegn X100%X90kg N/ha
80%	DegemegnX80%X130kg N/ha	Degemegn x80%X110kg N/ha	Degemegn X80%X90kg N/ha
60%	DegemegnX60%X130kg N/ha	Degemegn X60%X110kg N/ha	Degemegn X60%X90kg N/ha

Soil property test: Soil property test before production was made taking six representative disturbed samples randomly from top 30 cm depth at six positions. The samples were taken to Debra Zeyit Research Centor soil laboratory for chemical and physical properties determination after making two composite samples in Jimmy University College of Agriculture and Veterinary Medicine Soil science laboratory where samples were air dried on plastic trays, ground and sieved to pass through a 2 mm sieve. Following the same procedure, after harvest soil nitrogen recovery analysis was made in Jimmy University College of Agriculture and Veterinary Medicine animal nutrition laboratory taking soil samples from three pots per treatment per block and composited into one sample before air dried on plastic trays, ground and sieved to pass through a 2 mm sieve.

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 (Appendix Plate 1). 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 (Appendix Table 1). The soil water potential obtained from each tensiometer at each depth in cent bar in growth periods was presented in Appendix Figure 4. As presented in Appendix Figure 4, the irrigation management was carried out between 20 and 50 cent bars (Holder and Cary, 1984; van Loon, 1981). 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 (Appendix Table1) 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.

Field capacity soil moisture content: 37.82% field capacity **(**moisture content at field capacity or θ Fc% in m^3m^{-3}) was determined by filling 6 pots with soil used for potato growing and saturated as well in Greenhouse. After 72hrs, samples were taken from the 6 pots to laboratory to weigh it before and after oven drying at 105^0C for 24hrs. Then the moisture content was determined by using:

$\rho_b = Ws\text{-}Wrtr / Vs$ (11)

$\theta_m = ws\text{-}wd / wd \times 100\%$ (12)

$\theta_v = \rho_b x \theta_m$, *is fc %(moisture content at field capacity)* (13)

where: ρ_b *=bulk density;* *ws=mass of soil sample;*

vs= volume of soil; *θv = volumetric moisture content;*

wd= mass of oven dry soil; *wrtr= mass of ring, tissue & rubber ring;*

wcont. = mass of container; *w wet soil=mass of wet soil with container;*

θ_m *=gravimetric moisture content;* *wd+wcont.=mass of oven dried soil with container*

Permanent wilting point of soil media: The wilting point moisture content (23.11%) was determined using suctions higher than 1 Bar, in which disturbed samples were put on pressure plates (wetted ceramics) and exposed to high pressure up to 15 Bars (which is almost wilting point) in laboratory. The moisture loss of each suction level was calculated using:

$\theta_m = Ws\text{-}Wd / Wd$ (12)

$\theta_v = \rho_b \times \theta_m$ (13)

Where: Ws=mass of soil sample; ρ_b =bulk density; θv = volumetric moisture content; Wd= mass of oven dry soil; θ_m =Gravimetric moisture content;

Effective rooting depth used: 30 cm and 60 cm root depth used was obtained from FAO AGL (2002) together with P (irrigation depletion fraction or maximum allowable depletion) but the active uptake is confined to the top 30 cm.

Total available soil water (TAW): TAW (44.13 mm and 88.26 mm) was defined as the volume of water retained between field capacity (FC) and permanent wilting point (PWP). It is computed by:

$TAW = 1000(\theta fc - \theta wp) X Ze$, *Eq.1*

Where: TAW = the total available soil water in the root zone (mm);

θFc = moisture content at field capacity (m3m-3);

θWP = moisture content at wilting point (m3 m-3); and Ze = rooting depth (m)

Readily available water (RAW) and depletion factor: Part of TAW that a crop can extract from the root zone without suffering water stress (FAO, 1998). It was calculated using: RAW= P*TAW (2)

Where, TAW = the total available soil water in the root zone (mm); RAW = the readily available soil moisture in the root zone (mm), p= average fraction (percentage) of TAW that was depleted from the root zone before moisture stress occurs; the factor p differs from one crop to another. It varies from 0.25 for shallow rooted and water stress sensitive plants to 0.7 for deep-rooted plants. P value (25%,30% and 50%) used to calculate readily available soil water from total available soil water was taken from FAO AGL (2002) which was stated according to crop growth stages together with TAW as varying with root depth, RAW as varying with depletion factor and irrigation regimes were presented in Appendix Table 1.

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 densitiometers (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 (FAO AGL, 2002). The irrigation was performed at irrigation criteria of 20-25cent bars for 25% available soil water depletion, 30-35cent bars for 30% available soil water depletion and 44-50cent bars for 50% available soil water depletion(Appendix Table 20). The last irrigation was with held 10-15 days before harvest to allow the tubers to harden their skin before harvesting.

Soil water and tensiometer reading adjustment: The soil water lost per periods of days was measured by bean balance assuming one kg weight loss as one litter water loss. The water loss expected to be achieved was equal to the water amounts to be irrigated which was 25% TAW depletion or 0.441liter from one to fifty five days after planting for100% irrigation with adjusted tensiometer reading of 20-25cent bars, 30% TAW depletion or 0.531liter for 56-90 days after planting with adjusted tensiometer reading of 30-35cent bars and 50% TAW depletion or 1.768 liter for beyond 90 days with adjusted tensiometer reading of 44-50cent bars. The weights of the pot, tensiometer reading and weight loss were presented in Appendix Table 20.

Fertilizer application time and method used: 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 done for physical and chemical properties 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 (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: was obtained from root zone soil water balance (Tolga, 2005; Samuel *et al*., 2009) using formula (Waskom, 1994): $I+P = ET+Dr+Ro \pm \triangle S$, where I=irrigation water applied, P=precipitation, ETC=crop water requirement, Dr=deep percolation, Ro=runoff and $\triangle S$ = 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 $I=ETC+ Dr \pm \triangle S$ or $ETC= I- Dr \pm \triangle S$ (6)

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) as described in EARO (2004). Tuber and shoot dry matters were measured after drying sample biomass in oven dry at 65^0C until constant weight was achieved.

3.4. Data Collection

3.4.1. Climatic data

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.

3.4.2. Soil data

The result of soil moisture from tensiometer was recorded. Soil samples before and after production was taken. Soil pH was determined from the filtered suspension in 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Page, 1982). Organic carbon content of the soil was determined based on oxidation of organic carbon with acid dichromate medium following the Walkley and Black method as described by Dewis and Freitas (1970). Total nitrogen in soil was determined by micro-kjeldahl method (Dewis and Freitas, 1970) and soil cation exchange capacity (CEC) was determined by ammonium acetate method (Cottenie, 1980). Available phosphorus was determined using Olsen method as described by Olsen and Dean (1965). Particle size (soil texture) was determined by using hydrometer method of Bouyoucos (Day, 1965). Exchangeable potassium was determined with a flame photometer after extracting K from the soil with 1N ammonium-acetate at pH 7 as described by Hesse (1971). The micronutrient content was determined by DTPA Extraction.

3.4.3. Crop data

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.

Total tuber and above ground biomass dry weight (g): 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.

Number of tubers and stems/pot: The total tuber and plant number were also counted per three pots of treatments and averaged to represent treatment.

Leaf area index (LAI): Five plants were randomly selected from the central part of three pots of each treatment of the block and the total area of leaf determined using Leaf area meter AM.200, Model NO. SE213C, FCC ID: EMJSE 203C, S/N: 97021309, US Pat.NO:S212376, TW Pat.NO:80028 Made in Taiwan R.O.C. from which LAI were calculated using formula suggested by Sestak *et al.* (1971).

$$\textbf{Leaf area index (LAI)} = \frac{\text{Total leaf area } (cm^2)}{\text{Land area covered } (cm^2)}$$

Land area covered= Area of the Pot (πr^2)

Tuber to shoot ratio: was calculated by ratio of sample tuber fresh weight (g) to shoot fresh weight (g) per treatment.

Plant height (cm): The height from the soil surface to the top most growth point of nine (9) randomly selected plants from the central part of the pot of each treatment was measured using ruler at harvesting.

3.4.4. Water use efficiency (WUE) and nitrogen use efficiency (NUE) data

The ETC was estimated from soil water balance (Waskom, 1994). Water use efficiency was computed using: $WUE = \frac{\text{above ground Biomass}}{\text{ETC (mm)}}$ and $\frac{\text{tuber weight (g/pot)}}{\text{ETC (mm)}}$

Tuber and shoot dry weight (dried at 65^{o}C until constant weight) was grinded in to flour and total nitrogen in dry matter was determined by micro-kjeldahl method (Dewis and Freitas, 1970). The results were used to calculate nitrogen percentage applying formula:

$$\% N = \frac{(a-b) \, x N x 0.014 x 100 x mef}{W}$$

Where a=ml of H_2So_4 required for titration of samples

b=ml of H_2So_4 required for titration of blank

W = air dried sample weights in gm

N=Normality of H_2So_4 (0.1N)

0.014=meq weights of Nitrogen in gram

Mcf= moisture correction factor

NUE was computed in two primary components (Moll *et al*., 1982):

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

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

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

3.5. Data Analysis

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 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.

4. RESULTS AND DISCUSSION

The study was carried out in greenhouse until the crop physiologically matured well. All the data were gathered at this stage and analysis was made using methodology under (3.5). The results are presented in table and graph form. The discussions are made properly under five categories such as Water Amount Irrigated, Effect of Nitrogen Rates and Irrigation Regimes on Water Use Efficiency (WUE) of Potato Variety, Effect of Nitrogen Rates and Irrigation Regimes on Nitrogen Use Efficiency and Up Take, Effect of Nitrogen Rates and Irrigation Regimes on Yield and Yield Components of Potato Variety and Comparison of Uptake, Total Soil Nitrogen Percentage Before and After Production.

4.1. Water Amount Irrigated

The amount of water applied per each irrigation regime and growth stages is shown in Appendix Table 8. The amount of water used for irrigation significantly varied with irrigation regimes, and were 573.68, 458.95 and 339.5 mm for 100, 80 and 60% irrigations, respectively (Figure 1). The irrigated water increased with increasing growth stages of the potato crop in each irrigation regime (Appendix Table 8).

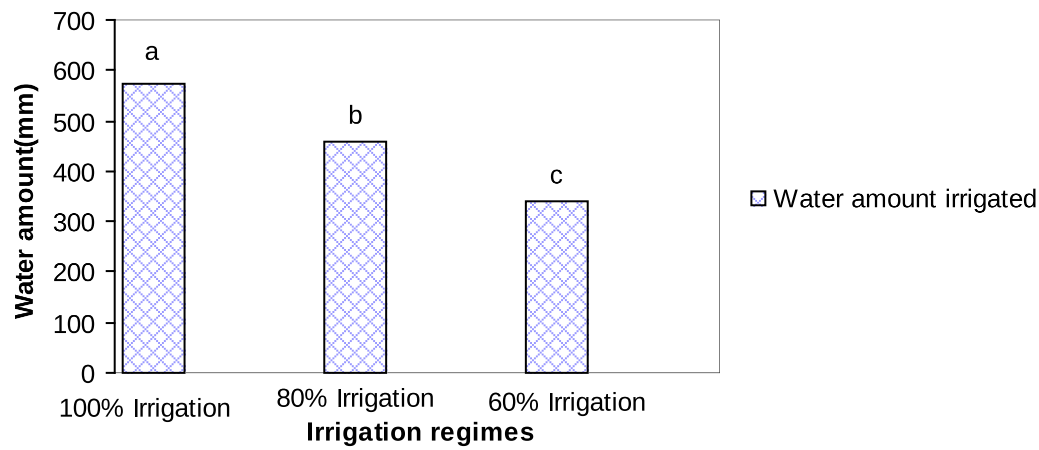

Figure 1. Average water amount (AWA) irrigated per irrigation regimes.

The amount of water used for irrigation significantly different due to high amount variability among the regimes selected that were enough produced statistically different WUE(Figure 2), nitrogen uptake efficiency, and total, shoot and tuber up take nitrogen(table 6) and Shoot biomass dry matter(Table 7**).** As presented in Figure 1 and Appendix Table 8, the 100% (full water amount) used for irrigation was smaller than 662 mm (Gebreegziabher, 2005). This lower amount could be due to environment, season of production and varietals difference. The total water used for production of potato varied based on location and method of computing the water requirements (Gebreegziabher, 2005). Results of the present study are in agreement with those reported by Fabeiro *et al*. (2001), Panigrahi *et al*. (2001), Ferreira and Carr (2002), Onder *et al*. (2005) and Steyn *et al*. (2007).

4.2. Effect of Nitrogen Rates and Irrigation Regimes on Water Use Efficiency (WUE) of Potato Variety

Variety and irrigation interaction significantly affected the WUE calculated from ratio of fresh tuber weight to irrigated water in mm (Appendix Table 4, Figure 2). 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.

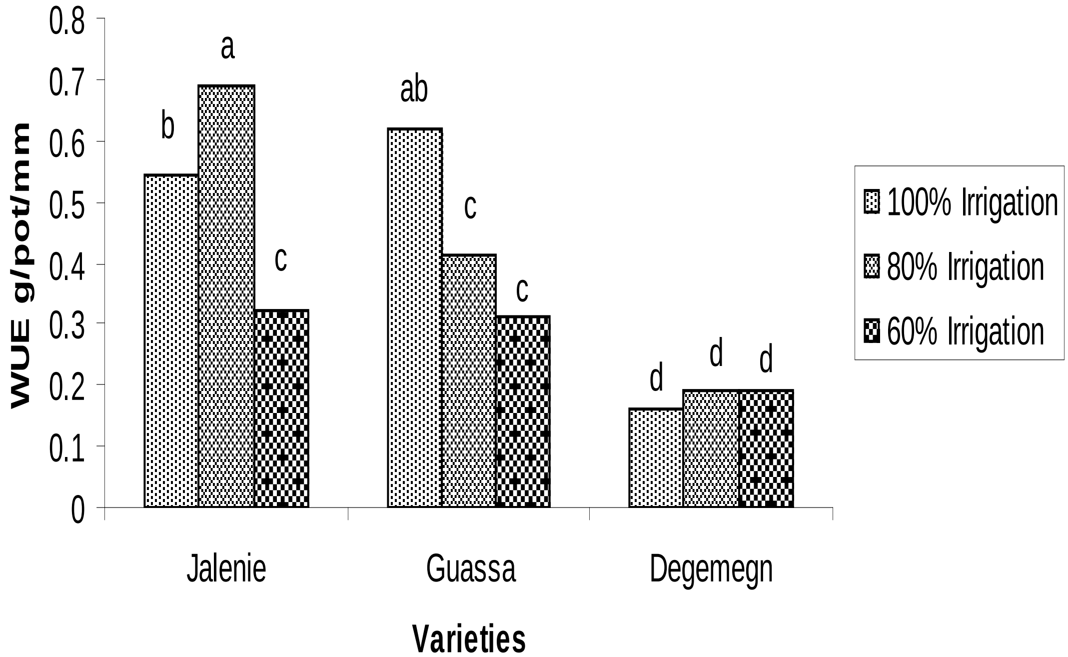

Figure 3. Variety and irrigation interaction effect on water use efficiency of potato.

Water use efficiency of above ground fresh weight was significantly affected by variety and irrigation (Appendix Table 5 and Table 5). 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 interaction did not affect water use efficiency of above ground fresh weight.

WUE of tuber was increasing with increasing irrigation water from 60-100% (Table 5). A significantly positive correlation coefficient (r= 0.225) was observed between WUE and irrigation water amount (Appendix Table 3). 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 nitrogen utilization efficiency, tuber to shoot ratio, total dry weight, tuber fresh and dry weight (Appendix Table 3).

Table 5. Effect of irrigation, variety and nitrogen rates on WUE 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 **	195.81[a]*	0.42885[a]*	0.55924b**
60%=I3	339.5c**	94.21b**	0.27500b**	0.61159[a]**
Variety				
Jalenie	457.6ns	245.51a **	0.51822[a]*	0.59599[a]*
Guassa	457.6ns	216.47[a]**	0.44704[a]*	0.57158ab**
Degemeng	457.6ns	81.18b**	0.17993b**	0.54068b**
Nitrogen				
130kg/ha	457.6ns	170.33ns	0.35730ns	0.56551ns
110kg/ha	457.6ns	195.03ns	0.40137ns	0.56396ns
90kg/ha	457.6ns	177.91ns	0.38652ns	0.57878ns
LSD	20	59.371	0.1274	0.0462
CV% 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 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.*

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.* (2006) which obtained the lowest WUE from 60% of full irrigation while 80%, 100% and 120% irrigation provided maximum WUE, respectively. Steyn *et al*. (2004) reported similar results in similar experiment with irrigation regimes of 100, 80 and 60%. On the other hand, Kirda (2002) found a contradictory result from drip irrigation. Onder *et al*. (2005) also reported decreasing WUE with increasing water supply. Kashyap and Panda (2003), Yuan *et al*. (2003) and Unlu *et al*. (2005) reported similar results.

4.3. Effect of Nitrogen Rates and Irrigation Regimes on Nitrogen Use Efficiency and Up Take

4.3.1. Nitrogen utilization efficiency.

Variety and irrigation significantly affected the nitrogen utilization efficiency (Appendix Table 6 and Table 6). Significantly the highest nitrogen utilization efficiency was obtained from Jalenie variety. However, it was not statistically different from that of Guassa. The least nitrogen utilization efficiency was obtained from Degemegn. The effect of nitrogen on average nitrogen utilization efficiency was not significant.

Significantly the highest nitrogen utilization efficiency was recorded at 100% irrigation, which was on par with that recorded at 80% irrigation (Appendix Table 6 and Table 6), while the least was obtained at 60% irrigation. However, it was on par with 80% irrigation. 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. But it had got weak and non significant correlation with nitrogen. 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 (Table 6) than up take nitrogen. As nitrogen utilization efficiency is the ratio of tuber yield (g) to nitrogen up take (g), higher reduction of tuber yield at 60% irrigation is the cause of nitrogen utilization efficiency reduction to 41.1% which may be attributed to water effect on nutrient up other than nitrogen, photosynthesis translocation and other physiological activity of the varieties.

These results agreed with findings of Stevenson *et al*. (1982) and Gallis and Hirel (2003). In contrast, results of Tayel *et al*. (2006) showed slight variation with the present finding which might be attributed to varietal, growing condition and management differences in addition to variable used to compute the utilization efficiency.

Table 6. Average nitrogen utilization and uptake efficiency, total plant and shoot nitrogen up take

Treatment	Average Nitrogen Utilization Efficiency (g tuber/ total uptake(g))	Average Nitrogen uptakes Efficiency (g tuber/ total N(g))	Average total Nitrogen up take (g)	Average shoot Nitrogen (g)
Variety				
Jalenie	63.71ᵃ**	0.16730ns	4.0380ns	3.5779ns
Guassa	66.178ᵃ**	0.14304ns	3.4560ns	3.0668ns
Degemegn	23.618b**	0.15296ns	3.6953ns	3.4374ns
Nitrogen				
130kg/ha	44.832ns	0.16111ns	3.9159ns	3.5579ns
110kg/ha	50.455ns	0.15819ns	3.8184ns	3.4244ns
90kg/ha	58.218ns	0.14400ns	3.4549ns	3.0999ns
Irrigation				
100%	61.574a*	0.19222a**	4.6440a**	4.2180a**
80%	55.631ab*	0.15356b**	3.7074b**	3.2711b**
60%	36.301b*	0.11752c**	2.8379c**	2.5930c**
LSD	19.776	0.0273	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.*

4.3.2. Nitrogen up take efficiency

Irrigation highly significantly affected average nitrogen up take efficiency (Appendix Table 7, Table 6). 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 between and among the different factors did not affect nitrogen up take efficiency significantly.

The nitrogen up take efficiency was significantly and positively (r=0.5463) correlated with the amount of water applied (Appendix Table 3). This may be due to occurrence of suitable condition for better uptake of nitrogen with better water supply which in turn has significant effect on photosynthesis, assimilation, metabolism and plant growth and development.

Decreasing nitrogen amount per rates and irrigation water amount per irrigation regimes decreased the amount of nitrogen uptake efficiency probably as a result of lesser and lesser up take, shoot dry and fresh weight as well as total plant dry weight per pot (Table 6). Nitrogen up take efficiency is significantly and positively correlated with total water applied, average above ground biomass, tuber dry and fresh weight, total fresh and total plant dry mass. The 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 (1990). This may be due to variety, nitrogen rate and growing condition difference. Splitting N fertilizer application, 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).

4.3.3. Average total nitrogen up take

Irrigation highly significantly affected nitrogen up take (Appendix Table 8 and Table 6). Significantly the highest nitrogen up take was recorded at 100% irrigation, followed by 80% and 60% irrigation. Decreasing irrigation water by 20% decreased average nitrogen up take by 20.2% while 40% decrease resulted in 38.89% reduction of average nitrogen up take. Variety and nitrogen, and the interaction between and among the different factors did not affect nitrogen up take. The results are in agreement with the finding of Dalla *et al*. (1997) in which they found increasing nitrogen uptake with increasing water supply. Similar findings were also reported by Van Loon *et al*. (1994) and Battilani *et al*. (2008).

4.3.4. Average shoot nitrogen content

Irrigation significantly affected above ground dry mass nitrogen content (Appendix Table 9 and Table 6). 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 to 38.53% reduction of average above ground dry mass nitrogen content in gram. Variety, nitrogen and interactions between and 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, water and nitrogen use efficiencies among rates in almost all parameter recorded. That is why nitrogen and nitrogen holding interactions effect is always not significant. Efficiency variation of varieties was confined to utilization efficiency under low level of nitrogen supply (Gallis and Hirel, 2003). The results agree with findings of Jamaati-e-Somarin *et al*. (2009) but contradicted with the results of Ahmadi *et al.* (2011) who reported that variations in above ground dry mass nitrogen content could be due to differences in terms of soil media, variety, irrigation regimes and other growing factors.

4.3.5. Average tuber nitrogen content

The interaction of variety and irrigation significantly affected the average tuber nitrogen content (Appendix Table 10, Figure 4). 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% irrigation 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. The results agree with findings of Millard (1986) and Fan and Mylavarapu (2010).

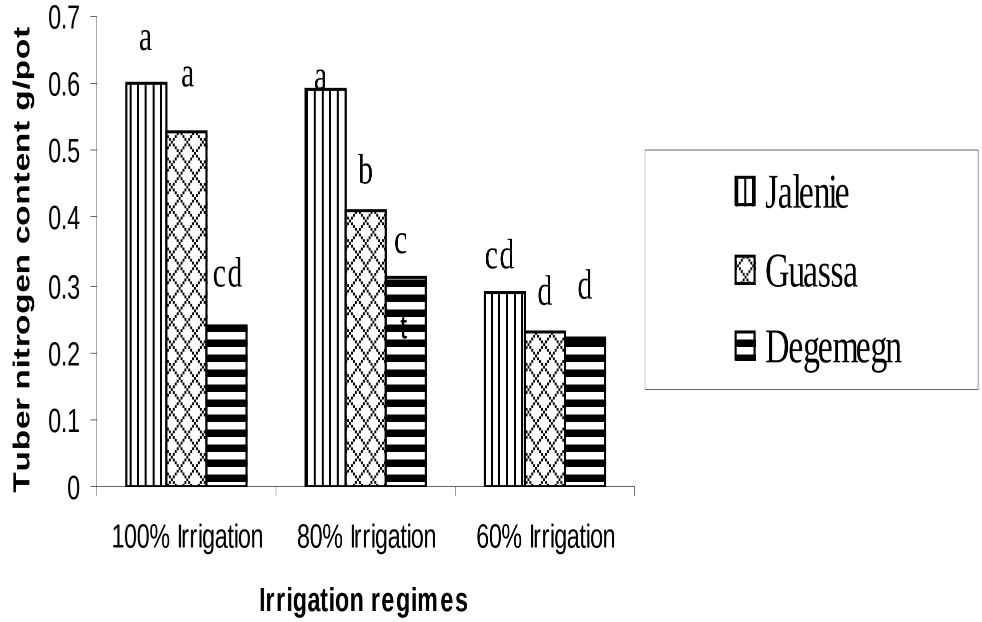

Figure 4. Interaction effect of variety and irrigation on tuber nitrogen content.

4.4. Effect of Nitrogen Rates and Irrigation Regimes on Yield and Yield Components of Potato Variety

4.4.1. Number of stem per pot

Number of stems per pot was significantly influenced by effects of variety and irrigation. The interactions between and among factors, and nitrogen rates did not affect stem number per pot significantly (Appendix Table 11 and Table 7**).** Stem number per pot of Jalenie and Guassa varieties were not significantly different. Highest stem number per pot was registered from Jalenie and Guassa varieties while the lowest was obtained from Degemegn. Significantly high stem number (8.15), was obtained at 100% irrigation, but was not statistically different from that obtained at 80% irrigation. The least number of stems per hill (6.85) was recorded at 60% irrigation.

These results agreed with findings of Zelalem *et al*. (2005) in which stem density was influenced by potato varieties. Similarly, different authors reported dependence of stem number on very early ontogeny of plant (Lynch and Tai, 1989; De la Morena *et al*., 1994; Lynch and Row-berry, 1997). Stem number variability due to influence of other factors rather than influence of mineral nutrients was reported by some Authors. As indicated in Allen (1978) number of stems was strongly influenced by storage condition of tubers, number of viable sprouts at planting, sprout damage at the time of planting and growing conditions. Physiological age of the seed tuber (Iritani, 1968), variety (Lynch and Tai, 1989) and tuber size (Harris, 1978) were also reported to play a significant role in determining stem number per planted tubers.

4.4.2. Leaf area index (LAI)

The leaf area index of the three potato varieties was significantly affected by variety and irrigation (Appendix Table 12 and Table 7). The maximum leaf area index was obtained from Guassa and Jalenie varieties while the minimum LAI was obtained from Degemegn variety. The effect of nitrogen rates and interaction on the LAI was not significant. Significantly the highest LAI was obtained at 80% irrigation, but was not statistically different from that recorded at 100% irrigation. The least LAI was observed at 60% irrigation. Decreasing irrigation water by 40% resulted in 15.62% reduction of LAI. This is due to water stress effect. As irrigation water is decreasing from field capacity (100%) to 60% irrigation the potato plant is facing more and more water shortage which reduces cell growth and expansion, nutrient up take, translocation, photosynthesis and growth of all organs of the crops. That is why the leaf area indexes which is a function of leaf area, is decreased by 15.62% when irrigation water is reduced by 40%. Not only LAI it also affected significantly all parameters measured (Table 5, 6 and 7) and (Figure 4).

LAI results of potato varieties of the present investigation were slightly higher than those reported by Pereira *et al*. (2008) for different varieties of potato. This could probably be due to difference in area coverage used for calculating the leaf area index and other conditions such as environmental and crop factors. Higher leaf area index results in more land coverage

Table 7. Influence of nitrogen rates and irrigation regimes on varieties 'vegetative and tuber yield parameter

Treatment	Average Stem number	LAI	Tuber/ Shoot	Average Shoot Dry Weight	Average Tuber Dry Weight	Total plant Dry mass	Average Tuber Number	Average Tuber Fresh Weight
Variety								
Jalenie	8.4681a**	4.1994a*	1.6684a**	32.333b**	42.007a**	75.185a**	21.741a **	245.51a**
Guassa	7.9507a**	4.3126a*	1.5328a**	31.683b**	36.372a**	68.055b**	21.148a**	216.4a**
Degemegn	6.4078b**	3.4594b*	0.6921b**	38.789a**	24.63b**	63.423b**	10.407b**	81.18b**
Nitrogen								
130kg/ha	7.8030ns	4.0562ns	1.2612ns	34.439ns	34.784ns	69.223ns	18.037ns	170.33ns
110kg/ha	7.8637ns	4.1939ns	1.3435ns	33.574ns	35.208ns	68.782ns	18.667ns	195.03ns
90kg/ha	7.1600ns	3.7213ns	1.2886ns	34.792ns	33.865ns	68.658 ns	16.593ns	177.91ns
Irrigation								
100%	8.1493a*	4.1581a*	1.6242a**	37.662a **	41.458a**	79.120a**	21.037a**	253.25a**
80%	7.8259ab*	4.3047a*	1.4538a**	34.294b**	38.799a**	73.093a**	18.481a**	195.81a**
60%	6.851b*	3.5086b*	0.8153b**	30.849c**	23.600b**	54.450b**	13.778b**	94.21b**
LSD	0.9757	0.5001	0.5532	2.8239	6.5495	6.8916	3.9787	59.317
CV% at α=5%	13.127	16.981	16.363	4.434346	17.86053	13.50192	12.24522	14.25899

** --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.

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and light interception which in turn results in higher photosynthesis and yield (Geremew, 2008).LAI results at different irrigation regimes were smaller than the autumn maximum leaf area index of none stressed and stressed treatments (Kagabo, 2006) while it was higher than spring unstressed treatments. This difference is attributed to variation in climate, variety and season of production. LAI was reported as variable component with variable irrigation scheduling methods with variable water amount (Geremew, 2008).

4.4.3. Tuber to shoot weight ratio

Variety and irrigation significantly affected harvest index, but nitrogen and interaction between or among the factors did not affect harvest index (Appendix Table 13 and Table 7). Degemegn variety recorded significantly the lowest tuber to shoot weight ratio compared to Jalenie and Guassa varieties, both of which were statistically similar. Significantly the lowest tuber to shoot weight ratio was recorded at 60% irrigation, while the highest was obtained from 100% irrigation. However, it was not significantly different from that obtained from 80%. These results are in agreement with those reported by Darwish *et al*. (2006) and Shahnazari *et al*. (2007) in which tuber to shoot weight ratio was reported to be increased with increased water supply and reached the highest amount at 100% irrigation.

4.4.4. Total, above ground and tuber biomass dry weight

Effects of irrigation and variety highly significantly affected total dry weight (Appendix Table14 and Table 7). Significantly the lowest total dry weight was recorded by Degemegn variety, followed by Guassa and Jalenie. However, there was no significant difference among the latter two varieties. Significantly the highest total dry weight was obtained at 100% irrigation even though statistically similar with 80% irrigation, while 60% irrigation produced the lowest. Decreasing irrigation water by 40% resulted in 18.1% reduction in total dry weight. Nitrogen and interaction between or among the factors did not affect tuber dry weight

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Effects of irrigation and variety highly significantly affected above ground dry weight (Appendix Table 15 and Table 7). Significantly the highest above ground dry weight was recorded by Degemegn variety, followed by Jalenie and Guassa. However, there was no significant difference between the latter two varieties. The effect of nitrogen and interaction between and among factors did not affect total dry weight of potato. Significantly the highest total dry weight was obtained at 100% irrigation while the lowest was recorded from 60% irrigation. Decreasing irrigation water by 20% reduced the above ground dry weight by 8.94% while 40% further reduction resulted in 18.1%.

Tuber dry matter was highly significantly (P<0.01) affected by variety and irrigation (Appendix Table 16 and Table 7). But it was not significantly affected by nitrogen and interaction among the different factors. The maximum tuber dry weight was obtained from Jalenie and Guassa varieties while the minimum was obtained from Degemegn variety. Significantly the highest tuber dry weight was obtained at 100% irrigation even though statistically similar with 80% irrigation, while 60% irrigation produced the lowest.

Bergaten *et al*. (2003), Kashyap and Panda (2003), Yuan *et al*. (2003), Onder *et al*. (2005) and Darwish *et al*. (2006) reported similar results. In addition, Costa *et al*. (1997) and Kagabo (2006) reported reduction of total biomass, tuber dry weight and above ground dry weight from stressed treatments.

4.4.5. Average tuber number and fresh weight

Effects of irrigation and variety highly significantly (P< 0. 01) affected the tuber numbers per plant (Appendix Table 17 and Table 7). Significantly the highest number of tubers per plant was recorded by Jalenie followed by Guassa variety. However, there was no significant difference between these two varieties. Nitrogen and interaction levels between or among the factors did not affect average tuber number. Statistically similar highest tuber numbers were obtained from 80% and 100% irrigation while the lowest tuber number was recorded by 60% irrigation.

Interaction between *v*ariety and irrigation significantly affected tuber fresh weight (Appendix Table 18, Table 7 and Figure 4). As shown in Figure 4, Guassa variety at 100%

irrigation recorded significantly the highest tuber fresh weight. However it was not significantly different from that obtained from Jalenie variety at 100% and 80% irrigations. Degemegn variety at 60% irrigation recorded the lowest tuber fresh weight. However, it was not statistically different from that recorded by the same variety at 80% and 100% irrigations, Jalenie and Guassa varieties at 60% irrigation. Decreasing the irrigation water by 40% resulted in 64.4% reduction of tuber weight in Jalenie variety. Decreasing the irrigation water by 20% and 40% reduced the tuber yield of Guassa by 47.3 and 60.3%, respectively. In Degemegn variety, decreasing the irrigation water by 20% and 40% resulted in no significant reduction in tuber yield.

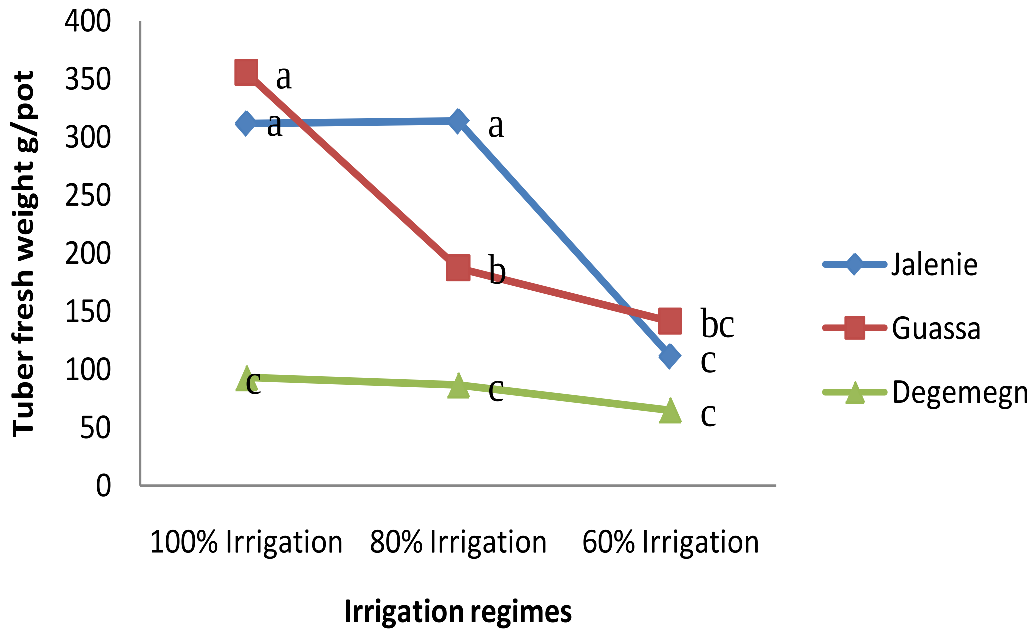

Figure 5. Interaction effects of variety and irrigation on average fresh tuber weight.

The results of the present investigation revealed that increasing the amount of water from 60% to 100 % (field capacity) increased both average tuber number and tuber fresh weight. This may be because when the amount of irrigation water increases to the field capacity, the potato varieties get better supply that satisfy their needs for better tuber formation as water has significant effect on cell expansion, metabolism, translocation and part of plant body formation. These results agreed with findings of Onder *et al*. (2005) and Nagaz *et al*. (2007). Similarly, increase in tuber yield with increase in water supply was reported by various workers (Kashyap and Panda, 2003; Yuan *et al*., 2003; Erdem *et al*., 2006). Kang *et al*. (2004), Unlu *et al*. (2005) and Shiri-e-Janagrad *et al*. (2006) also reported similar results. Decrease in the number of tuber under un-irrigated conditions was reported by Walworth and Carling (2002).

4.5. Comparison of Uptake, Total Soil Nitrogen Percentage Before and After Production

The average maximum and minimum nitrogen up take, total soil nitrogen before and after execution of the experiment is shown in Appendix Figure 5. The maximum and minimum nitrogen percentages (before and after) for total soil nitrogen, and plant nitrogen were 0.202, 0.199, 0.089 and 0.2, 0.044, 0.014%, respectively. The averages for total soil nitrogen, potato plant nitrogen and soil recovery nitrogen percentage were 0.201, 0.032 (Ratio of uptake nitrogen to soil mass) and 0.122, respectively. Out of the 100% total soil nitrogen, 61% was recovered in the soil, 15.6 % was taken up by plant and 23.4% was lost to the environment out of the soil media (Appendix Figure 6). The lost nitrogen was smaller compared to that reported by Sanchez and Blackmer (1988), Randall *et al*. (1990) and Randall (1997). This may be because of growing condition, season and varietal difference. Unlu *et al*. (2005) reported a loss of 70% in potato field. Randall *et al*. (1997) stated contribution of timing of N fertilizer application and rate for the loss of nitrate into surface water. N loss by leaching, denitrification, volatilization, and immobilization increases with time between application and plant uptake (Dinnes *et al*., 2002). However, the most important factor to reduce N loss is application of the proper N rate (Aldrich 1984; Olsen and Kurtz, 1982; Fox *et al*., 1986; Power and Scheppers, 1989; Randall *et al*., 2003).

5. SUMMARY AND CONCLUSION

Potato (*Solanum tuberosum* L.) ranks fourth among the world's crop production in volume after wheat, rice and corn. In Ethiopia, the estimated land under potato cultivation is over 160,000 ha each production year. Though potato has been under cultivation for almost 200 years in the country, its production was not widely spread and it contributed little to food security. The national average yield is approximately 10.5 tons/ha, which is very low compared to the world average of 16.4 tons/ha. The main contributing factors for under production and utilization of potato are narrow genetic base of varieties, pests and diseases, lack of appropriate cultural practices such as optimum nutrition and irrigation, lack of good quality seed etc.

This experiment was conducted at Jimma University College of Agriculture and Veterinary Medicine Greenhouse (in 2011) to quantify and compare the water and nitrogen use efficiency of selected potato varieties (Jalenie, Guassa and Degemegn). Two tensiometers were installed at 12 and 24 cm depth of the growing media to manage frequency of irrigation. The irrigation management was carried out between 20 and 50 cent bars. The average amounts of water used for irrigation during the growing period were 573.68, 458.95 and 339.5 mm for 100%, 80% and 60% irrigations, respectively.

Combination 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 variety at 100% irrigation. The lowest WUE was obtained from Degemegn variety at 100% irrigation. Effects of variety and irrigation significantly affected stem number, and the highest stem number was registered from Jalenie and Guassa varieties, while the lowest was obtained from Degemegn. The high stem number was obtained at 100% irrigation, while the least was recorded at 60% irrigation. The leaf area index was significantly affected by variety and irrigation. The maximum leaf area index was obtained from Guassa and Jalenie varieties, while the minimum was obtained from Degemegn variety. Eighty percent irrigation gave the highest LAI which was not statistically different from that recorded at 100% irrigation.

Varieties and irrigation significantly affected tuber to shoot weight ratio. Degemegn variety recorded the highest tuber to shoot weight ratio, compared to Jalenie and Guassa varieties, both of which were statistically similar. Sixty percent irrigation recorded the highest tuber to shoot weight ratio, while the least was obtained from 80% irrigation which was on par with that obtained from 100% irrigation. Effects of irrigation and variety highly significantly affected total dry weight. Degemegn variety recorded the highest dry weight, followed by Jalenie and Guassa. However, there was no significant difference among the latter two varieties. Irrigation regimes significantly affected dry weight, and the highest total dry weight was obtained at 100% irrigation, while 60% irrigation produced the lowest. Decreasing irrigation water resulted in reduced dry weight.

Effects of irrigation and variety highly significantly affected tuber number. The highest number of tubers per plant was recorded by Jalenie followed by Guassa variety. However, there was no significant difference between these two varieties. The effect of nitrogen and interaction between and among the factors did not significantly affect tuber number. Variety and irrigation interaction significantly affected tuber fresh weight. Guassa variety at 100% irrigation recorded the highest tuber fresh weight. However, it was not significantly different from that obtained from Jalenie variety at 100 and 80% irrigations. Degemegn variety at 60% irrigation recorded the lowest tuber fresh weight. However, it was not statistically different from that recorded by the same variety at 80 and 100% irrigations, Jalenie and Guassa varieties at 60% irrigation. Variety and irrigation significantly affected the nitrogen utilization efficiency. The highest nitrogen utilization efficiency was obtained from Jalenie variety which was not statistically different from that of Guassa, while the least was obtained from Degemegn. The highest nitrogen utilization efficiency was recorded at 100% irrigation, which was on par with that recorded at 80% irrigation, while the least was obtained at 60% irrigation. However, it was on par with 80% irrigation. Nitrogen utilization efficiency was found to have significantly strong positive relationship with applied water amount, WUE, total plant dry weight, tuber fresh and dry weights.

Irrigation highly significantly affected average nitrogen up take efficiency. 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 between and among factors did not affect nitrogen up take efficiency. Irrigation highly significantly affected nitrogen up take, and the highest was recorded at 100% irrigation, followed by 80 and 60% irrigation. Decreasing irrigation water by 20% decreased average nitrogen up take by 20.2% while 40% decrease resulted in 38.89% reduction of nitrogen up take. Irrigation significantly affected above ground dry mass nitrogen content. 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 to 38.53% reduction of average above ground dry mass nitrogen content.

The interaction of variety and irrigation significantly affected the average tuber nitrogen content. 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% irrigation and 100% irrigation, and both Jalenie and Guassa varieties at 60%. From the results, it can be concluded that irrigation regimes were significantly affected water and nitrogen use efficiency of the potato varieties while the nitrogen rates and interaction between or among factors holding nitrogen combination were not influenced the water and nitrogen use efficiency of the potato varieties significantly. The Water and nitrogen use efficiencies of the varieties were quantified and compared under the effects of the nitrogen rates and irrigation regimes, and Jalenie and Guassa varieties were found to be more efficient in water and nitrogen utilization than Degemegn variety. It is better to produce Jalenie with 80% irrigation and Guassa with 100% irrigation. Further research on NUE and WUE, involving higher nitrogen rates and irrigation regimes followed by post harvest activity and quality considerations, may be suggested. 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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7. APPENDICES

Appendix Table 1. Irrigation schedules throughout growth periods

Number of days after planting	Depth in m	Total available water in mm/m	Depletion factor	No. Days irrigated	Full irrigation water amount=P*TAW		80%0f Full irrigation water amount		60%0f Full irrigation water amount	
					in mm/m or ml	Total mm	in mm/m or ml	Total mm	in mm/m or ml	Total mm
1-25	0.3	44.13	0.25	10	11.03=441ml	110.30	8.826=353ml	88.26	6.6195=265ml	60.62
30	0.3	44.13	0.25	20	11.03=441ml	220.65	8.826=353ml	176.52	6.6195 =265ml	132.4
45	0.3	44.13	0.3	15	13.24=531ml	198.60	10.5912=425ml	158.868	7.9434=319ml	120
20	0.6	88.26	0.5	1	44.13=1768ml	44.13	35.304=1414ml	35.304	26.4786=1061ml	26.48

Appendix Table 2. Physical and chemical properties of the soil

Particle Size Analysis result				Exchangeable Basis C mol (+)/kg Soil					Micronutrients (ppm)				Field capacit %	Permanent Wilting point%	Bulk density	pH1:25	Ec ds/m	Organic carbo %	Organic matter %	Total nitrogen%	C:N Ratio	Avail p PPm
%Sand	% Silt	% Clay	Class	Na	K	Ca	Mg	Meq /100gm	Cu	Fe	Mn	Zn										
45.0	14.0	41.0	Clay	24.0	2.9	25.4	4.0	32.4	0.1	14.4	1.3	1.9	37.82	23.1	0.86	8.7	0.5	4.3	7.5	0.6	7.7	29.0

Appendix Table 3. Correlation coefficient of parameters measured

	N	AWA	TWUE	NUE	UPTNUE	ATW	ATDW	ATPDW	ATNO.	HI	LAI	APNO.	ASBDW	NUPT	SNUPT	TNUPT
TNUPT	-0.01ns	0.37**	0.82**	0.65**	0.32**	0.83**	0.923**	0.86**	0.71**	0.68**	0.34**	0.40**	-0.06ns	0.32**	0.18ns	1
SNUPT	-0.14ns	0.51**	0.031 ns	-0.27*	0.99**	0.13ns	0.16ns	0.34**	0.094ns	-0.055ns	0.32**	0.58**	0.47**	0.99**	1	
NUPT	-0.14ns	0.55**	0.15ns	-0.16ns	0.999**	0.25*	0.29**	0.45**	0.19ns	0.047ns	0.35**	0.62**	0.44**	1		
ASBDW	0.021ns	0.41**	-0.16ns	-0.25*	0.44**	-0.069ns	-0.08ns	0.31**	-0.32**	-0.26*	-0.18ns	-0.22ns	1			
APNO.	-0.13ns	0.25*	0.40**	0.11ns	0.62**	0.42**	0.40**	0.29**	0.53**	0.26ns	0.62**	1				
LAI	-0.12ns	0.23*	0.34**	0.18ns	0.35**	0.37**	0.40**	0.31**	0.38**	0.32**	1					
HI	0.01ns	0.28**	0.85	0.85**	0.046ns	0.84**	0.79**	0.66**	0.76**	1						
ATNO.	-0.06ns	0.31**	0.83**	0.76**	0.19ns	0.83**	0.79**	0.67**	1							
ATPDW	-0.01ns	0.58 **	0.78**	0.63**	0.45**	0.84**	0.92**	1								
ATDW	-0.023ns	0.44**	0.88**	0.76**	0.30**	0.91**	1									
ATW	0.02NS	0.42**	0.97**	0.85**	0.25**	1										
UPTNUE	-0.13ns	0.55**	0.15ns	-0.16ns	1											
NUE	0.12ns	0.23*	0.87**	1												
TWUE	0.061ns	0.225**	1													
AWA	0.04ns	1														
N	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 use 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 plant number, ASBDW= Average Shoot biomass dry weight, ASBFW= Average Shoot biomass fresh weight NUPT= Nitrogen up take, SNUPT= Shoot Nitrogen up take, TNUPT= Tuber Nitrogen up take.

Appendix Table 4. WUE from tuber analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	0.59518580	0.29759290	5.47	0.0070
Variety	2	1.71774054	0.85887027	15.77	< 0.0001
Nitrogen	2	0.02715336	0.01357668	0.25	0.7803
Irrigation	2	0.46343662	0.23171831	4.26	0.0194
Variety*Nitrogen	4	0.27093879	0.06773470	1.24	0.3039
Variety*Irrigation	4	0.58590820	0.14647705	2.69	0.0411
Nitrogen*Irrigation	4	0.33974183	0.08493546	1.56	0.1989
Variet*Nitrog*Irriga	8	0.51726336	0.06465792	1.19	0.3246

Appendix Table 5. WEU from shoot fresh weight variance analysis

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	0.00084425	0.00042212	0.05	0.9555
Variety	2	0.06791380	0.03395690	3.66	0.0325
Nitrogen	2	0.00400047	0.00200023	0.22	0.8067
Irrigation	2	0.10638262	0.05319131	5.74	0.0056
Variety*Nitrogen	4	0.04020894	0.01005223	1.08	0.3740
Variety*Irrigation	4	0.09103657	0.02275914	2.45	0.0572
Nitrogen*Irrigation	4	0.02449812	0.00612453	0.66	0.6222
Var*Nitr*Irriga	8	0.04857802	0.00607225	0.65	0.7280

Appendix Table 6. Average nitrogen utilization efficiency variance analysis

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	16412.25310	8206.12655	6.26	0.0037
Variety	2	30823.08218	15411.54109	11.75	< 0.0001
Nitrogen	2	2439.49856	1219.74928	0.93	0.4009
Irrigation	2	9429.35897	4714.67948	3.60	0.0345
Variety*Nitrogen	4	5744.63450	1436.15863	1.10	0.3687
Variety*Irrigat	4	11200.94812	2800.23703	2.14	0.0895
Nitrogen*Irrigat	4	5347.20394	1336.80098	1.02	0.4059
Var*Nitr*Irriga	8	9680.36549	1210.04569	0.92	0.5055

Appendix Table 7. Uptake nitrogen use efficiency analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	0.00174254	0.00087127	0.35	0.7072
Variety	2	0.00803232	0.00401616	1.61	0.2102
Nitrogen	2	0.00452314	0.00226157	0.91	0.4107
Irrigation	2	0.07536980	0.03768490	15.08	<.0001
Variety*Nitrogen	4	0.00143309	0.00035827	0.14	0.9651
Variety*Irrigat	4	0.00499331	0.00124833	0.50	0.7361
Nitrogen*Irrigat	4	0.00439316	0.00109829	0.44	0.7794
Var*Nitr*Irriga	8	0.02210306	0.00276288	1.11	0.3746

Appendix Table 8. Uptake nitrogen analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	1.02365262	0.51182631	0.35	0.7050
Variety	2	4.62144047	2.31072023	1.59	0.2139
Nitrogen	2	3.18807388	1.59403694	1.10	0.3418
Irrigation	2	44.05592091	22.02796046	15.15	< 0.0001
Variety*Nitrogen	4	0.82095160	0.20523790	0.14	0.9661
Variety*Irrigation	4	2.91309146	0.72827286	0.50	0.7352
Nitrogen*Irrigation	4	2.60170894	0.65042723	0.45	0.7739
Variet*Nitrog*Irrig	8	12.84334047	1.60541756	1.10	0.3759

Appendix Table 9. Above ground dry mass nitrogen content analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	2.28633956	1.14316978	0.80	0.4532
Variety	2	3.76471667	1.88235833	1.32	0.2751
Nitrogen	2	2.99643652	1.49821826	1.05	0.3562
Irrigation	2	35.97163052	17.98581526	12.64	<.0001
Variety*Nitrogen	4	0.86064881	0.21516220	0.15	0.9616
Variety*Irrigation	4	3.99942615	0.99985654	0.70	0.5936
Nitrogen*Irrigation	4	1.84218274	0.46054569	0.32	0.8608
Var*Nitr*Irriga	8	11.54502348	1.44312794	1.01	0.4370

Appendix Table 10. Tuber nitrogen content analysis of variance

Source	DF	Type III SS	Mean Square	F alue	Pr > F
Block	2	0.29307289	0.14653644	6.98	0.0021
Variety	2	0.56703252	0.28351626	13.51	<0.0001
Nitrogen	2	0.02545267	0.01272633	0.61	0.5492
Irrigation	2	0.62528600	0.31264300	14.89	< 0.0001
Variety*Nitrogen	4	0.04314615	0.01078654	0.51	0.7258
Variety*Irrigation	4	0.27704437	0.06926109	3.30	0.0175
Nitrogen*Irrigation	4	0.08400911	0.021002	1.00	0.4158
Var*Nitr*Irrigan	8	0.13272785	0.01659098	0.79	0.6134

Appendix Table 11. Average stem number per pot analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	8.52978519	4.26489259	1.34	0.2717
Variety	2	62.04214074	31.02107037	9.72	0.0003
Nitrogen	2	8.21060741	4.10530370	1.29	0.2850
Irrigation	2	24.64482222	12.32241111	3.86	0.0273
Variety*Nitrogen	4	11.93691852	2.98422963	0.93	0.4511
Variety*Irrigation	4	21.12299259	5.28074815	1.65	0.1747
Nitrogen*Irrigation	4	8.82563704	2.20640926	0.69	0.6014
Var*Nitr*Irrig	8	38.86074815	4.85759352	1.52	0.1725

Appendix Table 12. Analysis of variance for leaf area index

Source	SS Mean DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	1781.683321	890.841660	8.46	0.0007
Variety	2	997.271344	498.635672	4.74	0.0129
Nitrogen	2	365.255279	182.627640	1.74	0.1865
Irrigation	2	779.147751	389.573876	3.70	0.0314
Variety*Nitrogen	4	262.067458	65.516865	0.62	0.6486
Variety*Irrigation	4	281.309095	70.327274	0.67	0.6170
Nitrogen*Irrigation	4	531.060984	132.765246	1.26	0.2971
Variet*Nitrog*Irriga	8	114.932845	14.366606	0.14	0.9972

Appendix Table 13. Tuber to shoot fresh weight ratio analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	0.11410187	0.05705093	0.33	0.7224
Variety	2	2.84824801	1.42412400	8.17	0.0008
Nitrogen	2	0.04058823	0.02029412	0.12	0.8903
Irrigation	2	2.20600943	1.10300471	6.33	0.0035
Variety*Nitrogen	4	0.78028095	0.19507024	1.12	0.3577
Variety*Irrigation	4	0.62159702	0.15539926	0.89	0.4758
Nitrogen*Irrigation	4	0.41020258	0.10255064	0.59	0.6726
Var*Nitr*Irrigat	8	1.09410726	0.13676341	0.78	0.6183

Appendix Table 14. Total plant dry mass analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
block	2	1344.763148	672.381574	4.22	0.0200
variety	2	1895.870745	947.935372	5.95	0.0047
nitrogen	2	4.774215	2.387107	0.01	0.9851
irrigation	2	8932.921357	4466.460678	28.05	<0.0001
variety*nitrogen	4	1013.937775	253.484444	1.59	0.1903
variety*irrigation	4	758.764142	189.691035	1.19	0.3256
nitrogen*irrigation	4	1039.054433	259.763608	1.63	0.1803
var*nitr*irriga	8	1494.468687	186.808586	1.17	0.3330

Appendix Table 15. Analysis of variance for above ground biomass dry weight

Source	DF	Type III SS	Mean Square	F- Value	Pr > F
Block	2	2.86917290	1.43458645	3.31	0.0445
Variety	2	22.52332450	11.26166225	25.96	< 0.0001
Nitrogen	2	0.37494620	0.18747310	0.43	0.6515
Irrigation	2	12.14376606	6.07188303	13.99	< 0.0001
Variety*Nitrogen	4	2.11345976	0.52836494	1.22	0.3145
Variety*Irrigation	4	2.42540351	0.60635088	1.40	0.2478
Nitrogen*Irrigation	4	1.99842357	0.49960589	1.15	0.3429
Variet*Nitrog*Irriga	8	3.22880650	0.40360081	0.93	0.4998

Appendix Table 16. Analysis of variance for tuber dry matter

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	1542.274452	771.137226	5.61	0.0062
Variety	2	4242.543385	2121.271693	15.43	< 0.0001
Nitrogen	2	30.756119	15.378059	0.11	0.8944
Irrigation	2	4713.767489	2356.883744	17.15	< 0.0001
Variety*Nitrogen	4	768.933007	192.233252	1.40	0.2474
Variety*Irrigation	4	1249.460815	312.365204	2.27	0.0738
Nitrogen*Irrigation	4	902.531170	225.632793	1.64	0.1778
Var*Nitrog*Irriga	8	1048.620548	131.077569	0.95	0.4818

Appendix Table 17. Tuber number analysis of variance

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	316.469136	158.234568	2.01	0.1439
Variety	2	2871.209877	1435.604938	18.26	< 0.0001
Nitrogen	2	9.950617	4.975309	0.06	0.9387
Irrigation	2	856.024691	428.012346	5.44	0.0071
Variety*Nitrogen	4	49.030864	196.123457	0.62	0.6477
Variety*Irrigat	4	639.827160	159.956790	2.03	0.1031
Nitrogen*Irrigat	4	291.530864	72.882716	0.93	0.4555
Var*Nitr*Irriga	8	763.283951	95.410494	1.21	0.3097

Appendix Table 18. Average fresh tuber weight analysis of variance

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Block	2	124138.7585	62069.3793	5.26	0.0083
Variety	2	414796.9830	207398.4915	17.58	< 0.0001
Nitrogen	2	8642.7252	4321.3626	0.37	0.6950
Irrigation	2	350246.5474	175123.2737	14.85	< 0.0001
Variety*Nitrogen	4	19303.9207	77215.6830	1.64	0.1791
Variety*Irrigat	4	187078.1630	46769.5407	3.96	0.0070
Nitrogen*Irrigat	4	87384.0007	21846.0002	1.85	0.1330
Var*Nitr*Irriga	8	14336.6806	114693.4444	1.22	0.3087

Appendix Table 19. Irrigation Depletion factor for the three irrigation levels

Days after planting	Depletion factor		
	100 % = I_1	80%=I_2	60%= I_3
1-55	0.25	0.2	0.15
56-90	0.3	0.24	0.18
90-120	0.5	0.4	0.3

Appendix Table 20. Weight of soil media, tensiometers reading and weight loss

Date in G.c	Weight measured(kg)	Tensiometer Reading(cbar)	Weight loss (kg)
17/01/03	14.84	15	-
20/01/03	14.62	17	0.22
23/01/03	14.27	20-25	0.441
26/01/03	14.15	30- 35	0.531
29/01/03	12.96	44-50	1.768

Appendix Table 21. Irrigation water amount for growth periods and irrigation levels

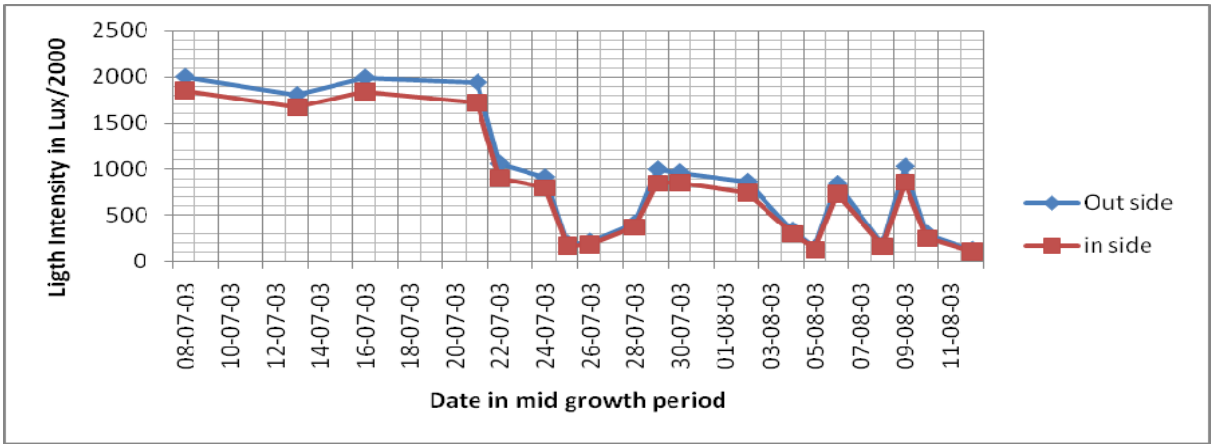
Irrigation periods	No. Of Days	100%irrigation(ml)	80%irrigation(ml)	60%irrigation(ml)
January 16-Feburary11	25	441	353	265
February 12-March 12	30	441	353	265
March13-April28	45	531	425	325
April29-may 12	13	1768	1414	1061

Appendix Table 22. Refill points of irrigation regimes

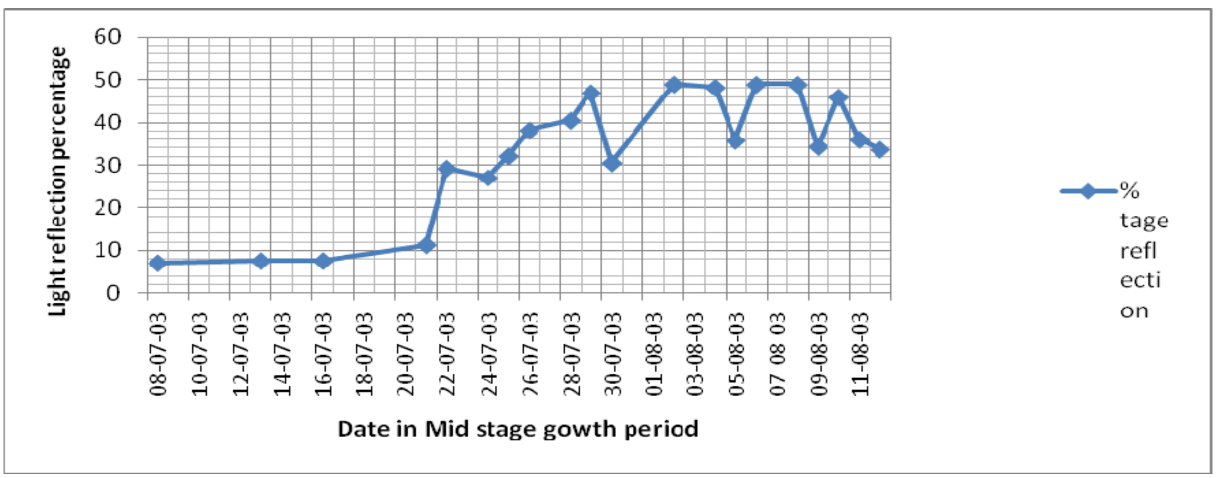
Growth periods	100% Irrigation refill point	80% Irrigation refill point	60% Irrigation refill point
1-55DAP	34.1425	34.878	35.6135
56-90DAP	33.407	34.2896	35.1722
Beyond 90 DAP	30.465	31.936	33.407

DAP=Days after Planting

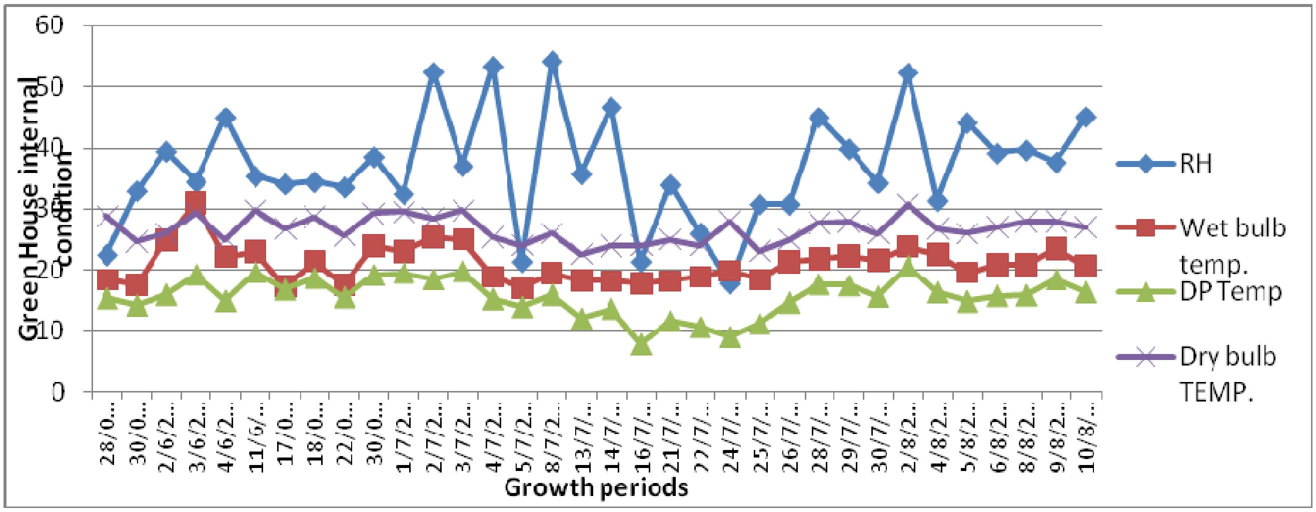
APPENDIX FIGURES



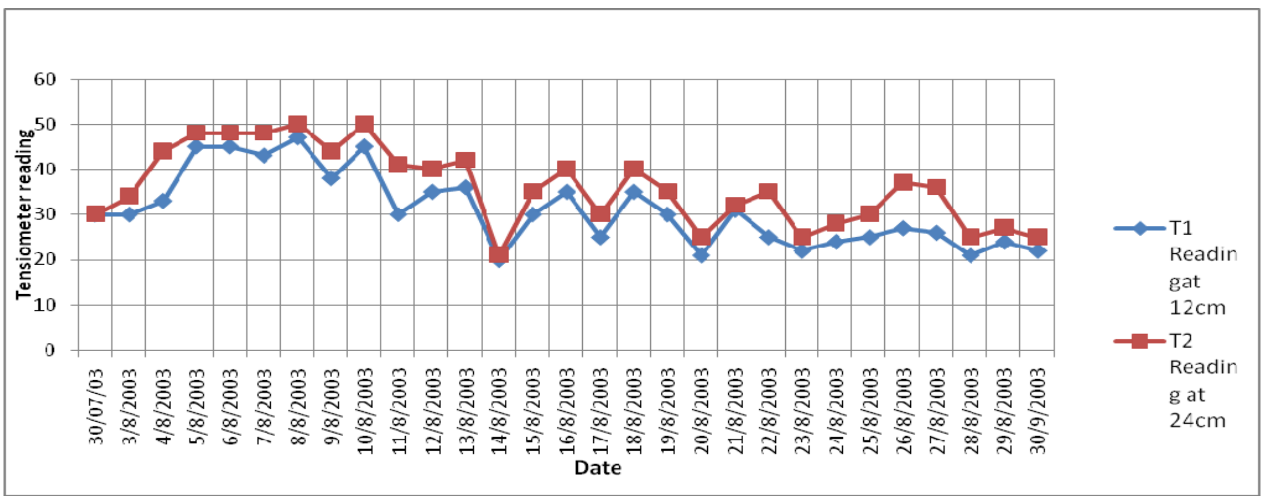
Appendix Figure 1. Out and inside Green House light intensity Lux/2000



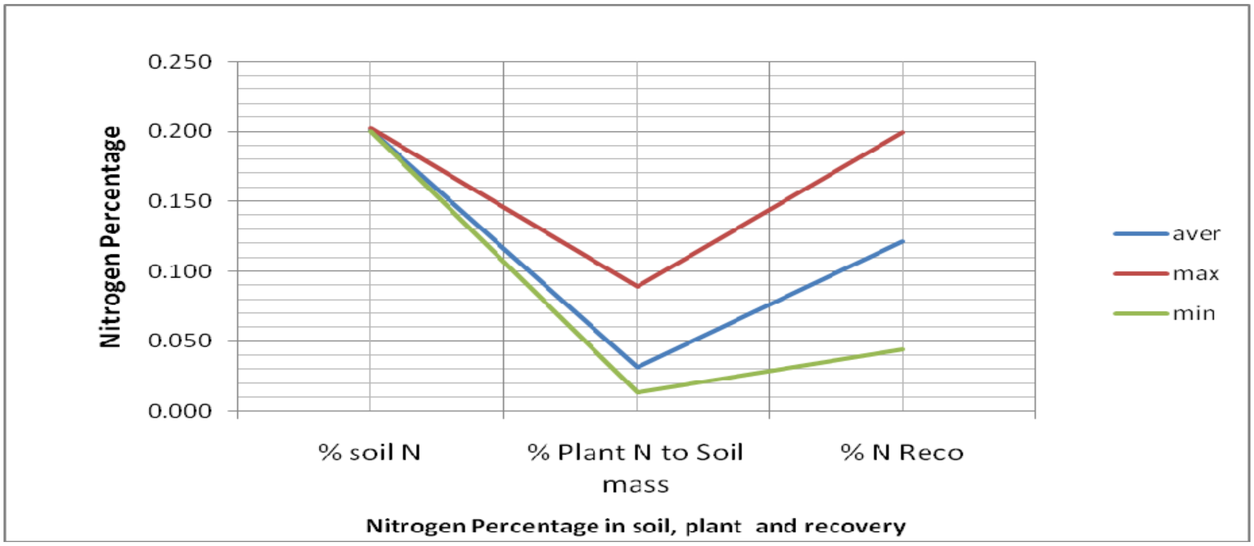
Appendix Figure 2. Reflected light intensity Lux/2000



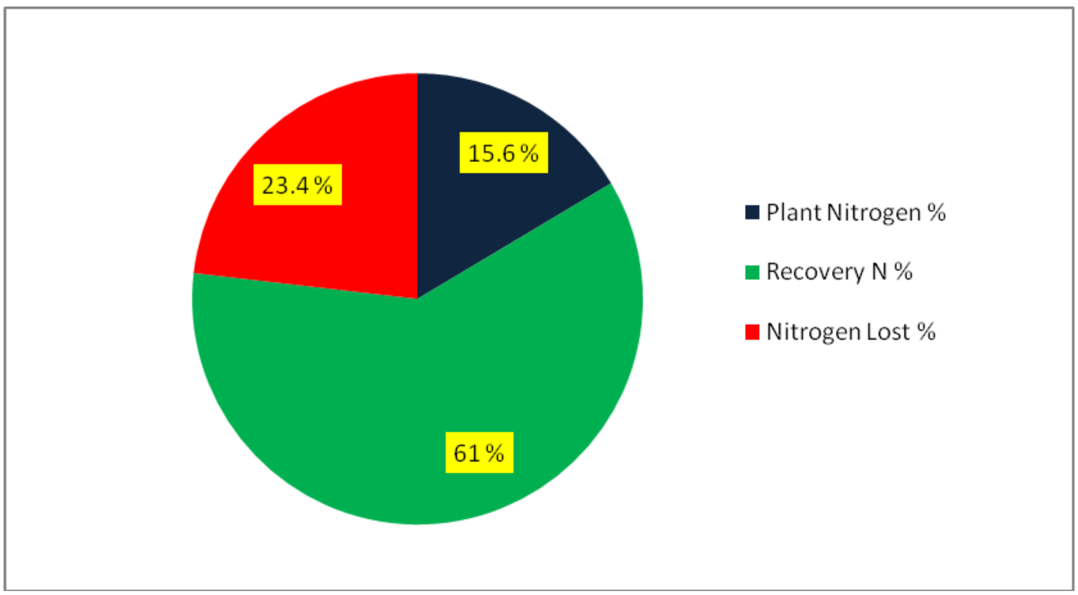
Appendix Figure 3. RH, dew point, dry and wet bulb temperature of the greenhouse



Appendix Figure 4.Tensiometer reading for days of the growing periods



Appendix Figure 5. Up take (%), total soil nitrogen before and after production (%)



Appendix Figure 6. Nitrogen Recovered in soil, Total lost nitrogen and plant up taken

APPENDIX PLATES

Appendix Plate 1. Growing media preparations and blocking

Appendix Plate 2. Tensiometer reading and management

Appendix Plate 3. Plant flowering stage and harvested tubers