



**RESPONSES OF POTATO (*Solanum tuberosum* .L) CROP YIELD TO  
SOIL MOISTURE STRESS CONDITIONS AT DIFFERENT GROWTH  
STAGES: THE CASE STUDY AT WO**

**NDO GENET WOREDA**

**MSc THESIS**

**BY**

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**HAWASSA UNIVERSITY**

**HAWASSA, ETHIOPIA**

**MARCH, 2019**

**RESPONSES OF POTATO CROP YIELD TO SOIL MOISTURE STRESS  
CONDITIONS AT DIFFERENT GROWTH STAGES THE CASE STUDY  
AT WONDO GENET WOREDA**

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**A THESIS SUBMITTED TO FACALITY OF BIO-SYSTEMS AND WATER  
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**(Submission Sheet-1)**

This is to certify that the thesis entitled **Response of Potato (*Solanum tuberosum .L*) Crop Yield to Soil Moisture Stress Condition at Different Growth Stages The Case Study at Wondo Genet Woreda** Submitted in partial fulfillment of the requirement for the degree of Master's of science with specialization in **Irrigation and Drainage Engineering**, to the department of Water Resource and Irrigation Engineering at Hawassa University. Moreover, it is a record of original research carried out by **Aregash Deboch**, Id. No PGIDE/004/09 under my supervision and no part of the thesis has been submitted for any other degree or diploma. The assistance and the help received during the course of this investigation have been regularly acknowledged. Therefore, I recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the department.

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## **DEDICATION**

I dedicate this piece of work to my father DEBOCH JELOS and my mother ABERASH ABIDE for caring me with affection for their devoted are they partners in the success of my life. And also to whom they supported me and pleased by my success of this work.

## **STATEMENT OF AUTHOR**

By my signature below, I declare and affirm that this thesis is my own work. I have followed all technical and ethical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholar matter that is included in the thesis has been given recognition through citation.

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## ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
BD	Bulk density
CV	Coefficient of Variation
CWR	Crop Water Requirement
D	Development stage
EHDA	Ethiopian Horticulture Development Agency
ET	Evapotranspiration
ET <sub>a</sub>	Actual Evapotranspiration
ET <sub>c</sub>	Evapotranspiration of Crop
Et <sub>m</sub>	Maximum Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field capacity
I	Initial stage
IAEA	International Atomic Energy Agency
IL	Initial and Late season stage
IM	Initial and Midseason stage
INSAM	International Society for Agricultural Meteorology
K <sub>y</sub>	Yield response factor
L	Late season stage
LGP	Length of growing period
LSD	Least Significance Difference
M	Midseason stage
MOANRS	Ministry of Agriculture Natural resource sector
PWP	Permanent wilting point
RCBD	Randomized Complete Block Design
SNNPR's	South Nations Nationalities and People Region state
SWMRG	Soil Water Management Research Group
TAW	Total available water
WUE	Water use efficiency

$Y_a$

Actual Yield

$Y_m$

Maximum Yield

**RESPONSE OF POTATO YIELD AND YIELD COMPONENTS TO SOIL MOISTURE  
STRESS CONDITION AT DIFFERENT CROP GROWTH STAGES THE CASE STUDY  
AT WONDO GENET WOREDA**

**ABSTRACT**

*Potato (*Solanum tuberosum* L.) is produced in Central Rift Valley of Ethiopia as one of the staple food and the production and productivity is limited by the scarcity of water. A field experiment was conducted to study the influence of soil moisture stress on different growth stages of potato with the objectives of identifying crop growth stages sensitive to soil moisture stress, to investigate the relative yield response factor of Potato under different treatments, to determine the irrigation water requirement at each treatments and to investigate the water use efficiency under different treatments. The experiment was conducted on sandy loam soil at Wondo Genet in SNNPRs of central rift valley, southern, Ethiopia during the 2017/18 cropping season. The experimental design was randomized complete block design with three replications seven treatments including the control treatment were devised to represent some possible combinations of water application. The result showed that soil moisture stress occurred at different growth stage had a significance ( $p < 0.05$ ) effect on plant height, number of tuber per plant, tuber length, tuber diameter, tuber fresh weight, and total tuber yield of Potato. The highest plant height (92.67 cm and 85.16 cm), number of tuber per plant (11.33), tuber length (7.7cm), tuber diameter (5.73 and 5.53 cm), tuber fresh weight (756.67 and 735.67 g), and total tuber yield (29.16 and 28.36 t /ha) were obtained from T1 and T5 respectively; while the lowest plant height (47.43 cm), number of tuber per plant (4.33 and 3.66 cm), tuber length (2.86 cm), tuber diameter (2.36 cm), tuber fresh weight (216.67 g), and total tuber yield (10.2 t /ha) were recorded from T3, T4 and T6, T4, T6, T3 and T6 respectively. Most of the parameters (dependent variable) that are plant height, tuber number per plant, tuber length, tuber diameter and total tuber yield showed significant yield reduction in their values as moisture stress increased at different growth stages. Growth parameters were slightly affected by moisture stress when the stress was imposed during the initial and late season growth stages but they were not significant. Initial and Midseason growth stage of potato tuber was the most critical stage (causes 65% yield loss) for soil moisture stress followed by development stage (49% yield reduction). The highest water use efficiency was obtained from T5 (7.26 kg/m<sup>3</sup>) and the lowest one were from T3 (3.93 kg/m<sup>3</sup>). Missing irrigation at the late season growth stage (T5) affects potato tuber insignificantly. This study has shown in order to avoid high yield reduction; The variety should not be stressed consecutively at initial and midseason growth stages well established.*

**Keywords:** Deficit irrigation, Potato, Growth stages, Moisture stress.

# 1. INTRODUCTION

## 1.1 Background

Potato (*Solanum tuberosum*-L.) is one of the predominant tuber crops in the world, constituting a large percentage of the staple diet in many developing countries (Watkinson *et al.*, 2008). It is the fourth most important food crop after wheat, rice and corn, with a worldwide production of 364 million tons in 2012 (FAO, 2014). It is also the most important tuber crop, ranking first in volume produced among root and tuber crops; is followed by cassava (*Manihotesculenta* Crantz), sweet potato (*Ipomoea Batatas*-L.), and yam (*Dioscorea* spp.) (FAO, 2010)

Root and tuber crops like potato, sweet potato, cassava, and yam will play an important role in feeding the developing world in the coming decades. The growth rates in production are particularly strong for a potato with an annual average increase of 4.5 million tons per year, greater than those of rice and wheat (Visser *et al.*, 2009). By 2020, more than two billion people in Asia, Africa, and Latin America will depend on these crops for food, feed, or income (Song *et al.*, 1998). Ethiopia is among the top potato producers in Africa, with 70% of its arable land in the high altitude areas above 1500 m being suitable for a potato production (FAOSTAT, 2008).

In Ethiopia potato productivity is low; it could reach 30 t/ha actual yield (Haverkort *et al.*, 2012). There are many complicated reasons for this low yield of potato tubers. Water is one of the main factors limiting yield production in arid and semi-arid regions of the world. When water resources are a limiting factor for yield production, irrigation programming (irrigation scheduling) is necessary to maximize production per m<sup>3</sup> of irrigation water (Oweis *et al.*, 2000; World Bank, 2011).

In arid and semi-arid area, plant production is limited by soil moisture availability and actual evapotranspiration (Biamah, 2005). These two parameters influence the occurrence of water stress in rain fed agricultural systems. Fluctuations in soil moisture often have negative effects on crop productivity (Purcell *et al.*, 2007). So that the lands soil moisture deficits, soil fertility depletion and soil erosion are major constraints to agricultural crop production (Biamah *et al.*, 1998). Moisture loss from the soil through evaporation and presence of erratic rainfall in the middle of the cropping season may leads to crop failure.

According to Woldeamlak (2009), in Ethiopia there is a decreasing of rainfall amount and the distribution is erratic especially in arid and semi-arid regions of the country. This need special emphasis since moisture stress occurs at the main cropping season reduce yield of crops which directly affect the livelihood of the community engaged on agriculture. The country receives sufficient rainfall for crop production if annual rainfall average is considered in most of the areas. However, the production of sustainable and reliable food supply by smallholder farmer is challenged by temporal and spatial variation in rainfall distribution and erratic rainfall (Mulat *et al.*, 2004)

Crop failure due to moisture stress in Ethiopia is common practice especially in moisture stress area of the country which caused by low and erratic rainfall distribution. Different researchers worldwide and in the country also show the diverse effect of moisture stress on the crop production (Marouf *et al.*, 2013; Yenesew and Tilahun, 2009). In times when irrigation water is limiting, the farmer may not have enough water to irrigate all the crop fields. In this case, the farmer may decide to spread the available water over a large area rather than depriving irrigation in some growth stages of a crop. Here, it is good to know i) the crops which mostly suffered by water shortage and ii) the growth stages during which the crops mostly suffered by water shortage (Awulachew, *et al.* 2009).

Bekele and Tilahun (2007) indicated that moisture stress at some growth stages had significantly affected the yield as compared to optimum application. This is due to the fact that yield is more dependent on rainfall or well distributed irrigation over the growing season based on demand at each stage than on total water available through the growing season. Water deficit affects nearly all growth processes; however, the stress response depends upon the intensity, rate, and duration of exposure and stage of plant development (Abdel-Motagally, 2010).

## **1.2 Statement of the problem**

Uneven distribution of rainfall in space and time is one of the main causes for yield reduction of the Potato crop in Ethiopia including Southern Nation Nationality and Peoples Republic states (SNNPRs). Potato is a cool season crop which means low evapotranspiration, but at Wondo Genet area farmers mentioned that there is reduction of yield due to soil moisture stress. Climate

of the area is semi-arid with total annual precipitation of 831.1 mm. In that area farmers are practicing both complementary and supplementary irrigation. Nevertheless, due to competition of irrigation water, the required amount of water needed by the crops in space and time domain might not sufficiently reach to the root zone. This in turn leads to reduction of yield. To resolve such a problem identifying the most sensitive growth stage to water shortage in relation to yield through research is vital from the perspective of water management.

Different works have been done on potato moisture stress at different growth stage (Cantore, *et al.* 2014). They have investigated the moisture stress based on decreasing the amount of irrigation water given on few combinations of growth stage especially on the stolonization and tuberization stages (Hassan *et al.*, 2002). However, research on effect of moisture stress at different potato growth stages e.g. initial, development, mid-season and late-season stages and their combinations with fully missing irrigation are limited. Hence, practicing of in such irrigation requires precise knowledge about sensitive stages and response of crops to water stress at different growth stages, as drought tolerance varies considerably by phenological stage. Therefore, this experimental research was implemented in a plot scale to investigate the response of Potato crop to soil moisture condition under various stage of growing season.

### **1.3 Objective**

The general objective of this study was to examine the effect of soil moisture stress condition at different growth stages on the yield of potato in Wondo Genet Woreda, South Ethiopia.

#### **1.3.1 Specific objectives**

The specific objectives of the study were to:

- To identify growth stages sensitive to soil moisture stress
- To investigate the relative yield response factor of Potato under different treatments.
- To investigate the water productivity under different treatments

### **1.4 Significant of the study**

The increase in human population is stimulating the rise in demand for large quantity of potato tubers yield. Sustaining this population will require increasing grain production of all crops.

There is also a limited amount of arable land and the resources to produce food are becoming scarcer. As population rises, less land will be devoted to agriculture, meaning increased production will have to come from increased yields (Milander, 2015).

In addition to erratic rainfall, the portion of fresh water currently available for agriculture is decreasing (Cai and Rosegrant, 2003). Hence, sustainable methods to increase crop productivity are gaining importance in arid and semi-arid regions. These sustainable approaches are irrigation water saving, limited irrigation and dry land cultivation. For these methods, knowing the response of crops to soil moisture stress is crucial (Dessalegn, 2015). Therefore, practicing of in such irrigation requires accurate knowledge about sensitive stages and response of crops to water stress at different growth stages, to avoid the risk of crop yield reduction, stakeholder and different farmers' gate information and maximizing the efficiency of water used for irrigation are crucial.

## 2. LITERATURE REVIEW

### 2.1 Physiology of Potato

The production volume of potato (*Solanum tuberosum* L.) is estimated to be 368 million tons from 19.3 million hectares, which ranked it as the fourth most consumed staple crop in the world (FAO, 2012). It is moderately frost tolerance and a C<sub>3</sub> plant with a low light saturation point (Hausler *et al.*, 2001). It has an indeterminate growth pattern and produces a fibrous adventitious root system. This develops just above the nodes on underground portion of the stem. The tuber is not only the principal mean for potato propagation, but also a major human food source. (Dwelle and Love, 1993).

The share of potato in average annual diet of a global citizen is 33 kg on weight basis (FAO, 2009). It also an important food for the world population, and has the potential to increased vitamin C, protein content and Being a highly nutritious food. From this it considered as one of the most hopeful crops to reduce hunger, malnutrition, and poverty in the world due to its high yield potential as reflected by a very high harvesting index. (Scott *et al.*, 2000; Thiele *et al.*, 2010).

Potato tubers are actually a modified stem with approximately 70 -75% content of water and a remaining 25-30% of dry mater. They have nodes or eyes from which the new growth begins. The new stems growing from each eye are called sprouts. Sprouts grow from the tuber after a period of dormancy after they are harvested, this varies largely between cultivars. After this dormancy is broken, sprouts grow and when planted, they give rise to the plant stems and from there all the vegetative part of the plant. Underground, lateral shoots called stolons are formed, from which the new tubers will be form (Mosley *et al.*, 2000).

It is one of a cool season crop with an optimal growth temperature range between 21<sup>0</sup>C to 26<sup>0</sup>C are required for sprouting of the tubers when the Temperatures is higher than 27<sup>0</sup>C are unfavorable for the production of economic size tubers (Ahmed 1980).When the temperatures is higher than the optimum level, significantly affect several physiological traits related to yield and quality such as haulm growth, dry matter production and partitioning, tuber initiation and

crop growth stage, photosynthetic speed, and the synthesis of hormones, enzymes, and other metabolites (Levy and Veilleux, 2007).

## **2.2 Potato Production in Ethiopia**

Ethiopia is endowed with suitable climatic and edaphic conditions for quality potato production. About 70% of the available agricultural land are located at an altitude of above 1500 meters above sea level and receives an annual rainfall of more than 600 mm, which is suitable for potato production (FAO, 2014; Tekalign, 2003).

Following the introduction of the potato to Ethiopia in 1858 by a German immigrant, Wilhelm Schimper, adoption by Ethiopian farmers occurred very gradually for several decades (Kidanemariam, 1980). The first available potatoes were most likely a very limited genetic base, hence vulnerable to diseases and pests, and were limited to the colder highlands until wider adoption of the potato occurred at the end of the nineteenth century in response to a prolonged famine (Gebremedihin *et al.*, 2001).

However, potato cultivation declined in the early 1980s, due in part to widespread infestation of the late blight, *Phytophthora infestans*. Starting from 1991, potato production has resumed its increasing trend. Gebremedihin *et al.* (2001), reported that the area of potato was 50,000 ha by the mid 1980's and 160,000 ha in the early 2001's; with average yields around eight tons per hectare (FAO, 2006). The major problems of potato production in Ethiopia include drought, erratic rainfall, high temperature, frost and high disease and insect pressure; among those all constraints soil fertility is the one which limited its productivity (Temesgen, 2008).

In Ethiopia, the main production season for a potato is June to September (*Meher*) at altitudes higher than 2,500 above sea levels. The off-season production in Ethiopia at higher elevations is April to August (*Belg*). However, one should understand in mind that nowadays the main production season for a potato represents only 22% (34,000 ha), while the off season production is around 128,000 ha. The reason for a slowly shift from *Meher* to *Belg* is the fact that the late blight pressure is increasing and farmers experience less risk with cultivation during the small rains combined with irrigation (Birhanu, 2014).

A relatively low average, especially when considering the potential of Ethiopia, with its favorable climate at higher elevations, soils and irrigation potential (EHDA, 2011). An upward trend in potato production might be partly due to the continuing increase in population and subsequent decline in the average size of farm holdings, hence, pressure for agriculture to become more labor intensive. Ethiopia is the 11<sup>th</sup> top potato producing country in Africa (FAO, 2006).

### **2.3 Environmental and Cultural Requirements of Potato Crop**

A Potato is favorable at a cool climate for growth and development. Best suited altitudes ranged between 1500-2800 meters above sea level. However, for healthy tuber production, particularly for planting purpose, it should strictly cultivate in high altitude areas. For high yields, the total crop water requirements about 500 to 700 mm at the root depth of 0.6 m to 1.2 m (MoA, 2011). Potatoes can be grown on all soil types, except heavy water-logged clays, but for optimum yields need a well-drained loam or sandy loam, relatively free from stones. Better tuber yields have been obtained from potatoes grown at soil reaction ranging from pH 5.0 to 7.0 (Agrinet, 2010).

The optimum temperature ranged between 21-26°C is ideal for potato tuber development (Ahmed, 1980). At higher temperatures the plant fails to initiate tuber formation and at low temperatures vegetative growth is restricted by frost (Horton, 1987). The number of tubers produced per plant is higher at lower than at higher temperature. The seed tubers produced at higher temperatures are low yielding compared to seed tubers produced at cooler temperatures (Chatterjee, 1993). The potato (*Solanum tuberosum L.*) crop planting space was 75 cm between rows and 30 cm between plants are recommended for production purpose (Alaa et al., 2012).

Very shallow planting of seed tubers may result in inadequate soil moisture around the seed part and in production of tubers so close to the soil surface that greening caused by exposure to light is a problem. On the other hand, planting too deep will slow tubers to emerge and may be more subject to attack by various diseases. As a result planting have to be deeper on lighter soils than on heavy soils (Alexander *et al.*, 2001). A good rule of thumb is never to have more than 10 cm of soil above the tip of the developing sprout (Ngungi, 1982).

Growing healthy potatoes for maximum yield and quality requires that all the essential nutrients be supplied at the right rate, the right time, and the right place. The total nutrient requirement is determined by a combination of plant, soil, and environmental factors. Many of these factors can be carefully controlled, but other factors (such as temperature and sunlight) cannot be. The main consideration is to manage those factors that can be controlled and keep the plants in the best condition to withstand whatever environmental stresses may occur (Robert, 2006).

## **2.4 Growth stage of potato**

The total growing seasons of crop is usually divided into four stages. These are i) initial stage which includes the time from sowing to 10% ground cover; ii) crop development stage which is from 10% to 70% ground cover; iii) mid-season stage including flowering and grain setting or yield formation; and iv) late season stage including ripening and harvest. In general it is stated that out of the four growth stages, the mid season stage is the most sensitive to water shortages. This is mainly because it is the period of the highest crop water needs. Hence, if water shortage occurs during this stage, the negative effect on yield will be pronounced. To see the effect of limited water application on yield and production, consideration must be given to the effect of the limited water application during the individual growth periods of the crops (Doorenbos and Kassam 1986).

According to Agriculture, Food and Rural Development Department (2005) Potato plant has five growth stages. Which are sprout development (i), plant establishment (ii), tuber initiation (iii), tuber bulking (iv), and tuber maturation (v). Timing and duration of these growth stages depend upon environmental factors, such as elevation and temperature, soil fertility, moisture availability, cultivar and geographic location. At growth stage one (i), sprouts develop from eyes on seed tubers and grow upward to emerge from the soil, roots begin to develop at the base of emerging sprouts, and the seed piece is the sole energy source for growth during this stage. At stage ii, leaves and branches develop on emerged sprouts; roots and stolons develop below ground, and photosynthesis begins (FAO, 2005).

Potato development in stages i and ii lasts from 30 to 60 days, depending on different reason which are planting date, physiological age of the seed tubers, cultivar, soil temperature, and other

environmental factors. At stage three(iii), tubers form at stolon tips but are not yet appreciably enlarged and in most cultivars the end of this stage coincides with early flowering with an average duration of roughly two weeks. At stage four (iV), tuber cells expand with the accumulation of water, nutrients, and carbohydrates. During the tuber bulking stage, tubers become the most dominant site for carbohydrate and inorganic nutrient storage. Tuber bulking can continue up to three months as a function of the cultivar and environmental conditions. During the last stage, photosynthesis gradually decreases, leaves turn yellow, tuber growth rate slows, and the vines die (FAO, 2005).

## **2.5 Potato Crop Evapotranspiration and Irrigation schedule**

### **2.5.1 Reference Evapotranspiration**

The  $ET_o$  is the evapotranspiration from a reference crop such as grass or alfalfa with specific characteristics and standard conditions. In other word the reference crop is considered to be a clipped, well watered and healthy grass (Allen and Pererea, 1994). The evapotranspiration rate from reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as  $ET_o$ .

Many methods are available for estimating reference evapotranspiration ( $ET_o$ ). The methods are the Modified Penman methods which use Temperatures, humidity, wind speed and sunshine hours, Blaney-Criddle method only use temperatures, Radiation method which uses both temperature and sunshine hours, and Pan Evaporation method use only evaporation. From the above method which used to estimate  $ET_o$  by inserting climates data Penman-Monteith method has been selected because it closely grass  $ET_o$  at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. The most accurate, and complex, method is the Penman-Monteith method as presented by (Allen, 1996). Numerous researchers have analyzed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration,  $ET_o$  (Doorenbos and Pruitt 1992).

### 2.5.2 Crop Evapotranspiration

Calculation of crop water requirements and crop irrigation requirements can be carried out from basic information from the crops selected and should include, average planting date and average harvesting data (FAO, 1996). Standard information on crop coefficient, rooting depth, depletion level and yield response factors, and length of individual growth stages are needed.

The water requirements are different from one crop to another. Although growing crops are continuously using water, the rate of water use depends on (1) the kind of crop, (2) the degree of maturity and (3) atmospheric condition, such as radiation, temperature, wind, and humidity. The rate of growth at different soil water contents varies with different soils and crops. During early stages of growth the water needs are generally low, but they increase rapidly during the maximum growing period to the fruiting stage. During the later stages of maturity, water use decreases as the crops ripen (Schwab et al., 1995).

Crop consumptive water use is the amount of water transpired by the plants and the water evaporated from the soil plus the fraction of water held by the plant tissues. The amount of water retained by plant metabolic activity is about 1% of the overall water taken up by the plants. Thus, in practical terms crop water use corresponds to crop evapotranspiration (ET<sub>c</sub>). Potato ET<sub>c</sub> can be predictable by using weather data and is the amount of water to be replenished during the growing season in order to assure potential tuber yields at a given site. Potato ET<sub>c</sub> is important to consider in irrigation planning and its use in irrigation scheduling is a well-developed strategy to improve the effectiveness of irrigation. For high yields at a given site, the seasonal water requirements of a potato crop with a phenological cycle varying from 90 to 180 days ranged from 350 to 650 mm, depending on climate (Pasquale *et al.*, 2012).

The crop coefficient ( $k_c$ ) relating with maximum evapotranspiration (ET<sub>m</sub>) to reference evapotranspiration is: during the initial stage 0.4-0.5 (20 to 30 days), the development stage 0.7-0.8 (30 to 40 days), and the mid-season stage 1.05 -1.2 (30 to 60 days), the late season 0.85-0.95 (20 to 35 days) and at harvest 0.7-0.75 (Allen *et al.*, 2006). find out the K<sub>c</sub> of potato at Wondo Genet is fall in range of FAO document The K<sub>c</sub> values were determined on the basis of in-field observations of crop phonological stages and using this data. Following the (Allen *et al.*, 2006)

recommendation the Kc values was taken as 0.5, 1.15 and 0.75 respectively for the initial crop growth stages (up to the beginning of stem elongation), the crop development stage and mid-season (since stem elongation until flowering), the late season stage (maturity). Maximum root depth was fixed at 0.6 m. The period of potato maturity coincide with the period of less water demand because of drying of leaves and minimum leaf area available for transpiration (Kassam *et al.*, 1975)

CROPWAT model is a computer program for irrigation planning and management, developed based on the FAO Penman-Moneith method (Smith *et al.*, 1996). Calculation of water requirements utilizes inputs of climatic, crop and soil data, as well as irrigation and rainfall data. Its basic function includes the calculation of reference evapotranspiration, crop water requirement and crop and scheme requirement. Reference evapotranspiration can be calculated from the actual maximum and minimum temperatures, relative humidity, sunshine/radiation and wind speed data, According to Penman-Monteith method (Allen *et al.*, 1998), Crop water requirements (ETc) over the growing seasons are determined from ETo and estimates of crop evaporation rates, expressed as crop coefficient (Kc), are based on well-established procedures. The updated values of crop coefficients are determined from (Allen *et al.*, 1998).

### **2.5.3 Irrigation Scheduling**

According to Doorenbos and Kassam (1979), Irrigation scheduling is the process of determining when to irrigate and how much irrigation water to apply. In theory, water could be given daily. But, this would be very time and labour consuming; it is preferable to have a longer irrigation interval. The irrigation water will be stored in the root zone and gradually be used by the crop. The irrigation interval has to be chosen in such a way that the crop will not suffer from water shortage. To compute proper irrigation scheduling for crops, it is necessary to know the type of crop, growth stage, effective root zone, available water holding capacity of the soil and daily evapotranspiration rate (ETc) of the crop. The number of irrigation normally varies between one and six, depending on climatic condition and soil texture. The greatest water utilization efficiency will be obtained when these irrigations are well-timed in relation to the sensitivity of the crop to water deficit (Doorenbos and Kassam, 1979).

Scientific irrigation scheduling is a combined management and technical approach to ensure that crop water needs are met. This technique facilitates timely and accurate provision of water to crops, conserves water and energy, and improves irrigation performance, crop yield and quality (Tacker *et al.*, 1996) and sustainability of irrigated agriculture (Smith *et al.*, 1996). It is aimed at achieving an optimum water status for productivity by keeping soil moisture close to field capacity (Jones, 2004). Achieving optimum benefit from irrigation in a variable climate is dependent on regulating timing and quantity of water applied to provide continuously changing crop water requirements (Bailey and Spackman, 1996).

Among the benefits of proper irrigation scheduling is: improved crop yield and/or quality, water and energy conservation, and lower production costs (James, 1988). Normally farmers will use their own experience and indicators (wilting characteristics, soil dryness) to determine when to irrigate (Smith and Munoz, 2002). According to Smith and Munoz (2002) this method has proved not very accurate and a “scientific” advice to farmers on when to irrigate can lead to considerable water savings and to a more rational planning of water distribution (James, 1988).

According to Allen *et al.*, (1998) CROPWAT software is used to compute crop evapotranspiration and irrigation requirements by utilizing inputs of climatic, crop and soil data. Based on this program, reference evapotranspiration can be calculated from actual temperature, humidity, sunshine hours and wind speed data, according to FAO Penman Monteith method.

Based on water balance method the most convenient and reliable way to predict when to irrigate (Smith and Munoz, 2002). Soil based irrigation scheduling involves determining the current water contents of the soil, comparing it to a predetermined minimum water content and irrigation to maintain soil water contents above the minimum level. Soil indicators of when to irrigate also provide data for estimating the amount of water to apply per irrigation (Mishra and Ahmed 1990). for successful irrigation scheduling different considerations are requires which are, good understanding to the knowledge of soil water holding capacity, crop water use, and crop sensitivity to moisture stress at different growth stages. This requires consideration about the effective rainfall, and availability of irrigation water (Waskom, 1994).

Potato being a shallow rooted crop requires frequent irrigations of shallower depths rather than a few heavy irrigations. The irrigations interval depends mainly on soil types and the crop growth stages and a range of 6 to 10 days interval is used depending on soil type and temperature of the area. Therefore, irrigation intervals for sandy loam soils may be from 6 to 7 and 9 to 10 days for loam soils. However, the irrigation gaps might be longer in the early crop development stages and shorter with increased vegetative growth and stolonization and a little bit longer up to 15 days before harvesting (MOANRS, 2011). According to MOANRS, (2011) The irrigation scheduling for potato was determined on the basis of predetermined 6 days irrigation interval for all treatments, with 0 % yield loss.

## **2.6 Soil moisture content and its management**

Soil moisture is one of the most important soil ingredients and dynamic properties of soil. Water affects intensely many physical and chemical reactions of the soil as well as plant growth. Only part of the soil moisture or water stored in the root zone of a crop can be available and utilized by the crop for its transpiration and building up of plant tissues. The remaining soil moisture is lost either through leaching beyond the active root zone of crop plants and/or lost into the atmosphere in the form of evapotranspiration (MOANRS, 2011).

Soil water is important in agriculture because of its strong influence on plant growth and crop production. Different plants have different response to soil moisture stress. Potato tubers are very sensitive to moisture stress and it has a shallow and sparse root system: approximately 85% of the root length is concentrated in the top 0.3 - 0.4 m of the soil (Iwama, 2008; Wang et al. 2006). Moisture stress at any growth stage leads to a considerable negative impact on potato tuber yield and quality (Ahmadi et al. 2010; Shayannejad 2009). That is why a continuous moisture supply to meet the crop water demand at different growth stages is highly recommended for better growth from sprout development to maturity (Ierna and Mauromicale, 2006).

Effect of moisture stress is different at different growth stages of potatoes (Shock et al. 1993). Moisture stress during the vegetative growth stage decreases plant height and root expansion also it is more sensitive to moisture stress at tuber initiation and tuber bulking growth stages as compared to the sprout development, vegetative growth, and maturity stages (Miller and Martin 1987). Moisture deficit at tuber initiation growth stage causes reduction in number of tubers

produced per plant (MacKerron and Jefferies 1986), whereas moisture stress at tuber bulking stage even for a short period produce dumbbell-shaped, knobby or pointed-end tubers (Jefferies and MacKerron, 1993). If this stress persists for a longer period of time it leads to tuber defects such as internal brown spot (Haverkort et al., 1990).

Many researchers have studied the effect of moisture provide on potato yield and quality reported that different cultivars behave differently under moisture excess or stress conditions Hassanpanah (2010) reported that considerable decline in total and marketable tuber yields (tubers having fewer culls and knobs) to increased soil moisture stress. Potato is usually grown on sandy loam soil on Canadian prairies, especially in Manitoba. Potato plants are sensitive to the alteration in the soil moisture content because soil moisture is one of the important factors affecting the quantity and quality of tubers yield and any decline or un uniformity in irrigation (water stress), especially during initiation and growth phases of tubers resulted in significant damage to plants, and decrease the quantity and quality of tubers yield (Bao-Zhong *et al.*, 2003, Al-Aubiady, 2005).

Soil moisture status is expressed by percent available soil water (ASW) content or by soil water tension (SWT). Available soil water content is defined as being the amount of water that plants can extract from a given volume of soil, from the crop effective rooting zone. Available soil water is usually expressed as a percent between “field capacity” (100%) and “permanent wilting point” (0%). Soil water tension is the force necessary for roots to extract water from the soil (Curwen, 1993).

Monitoring soil water in the crop root zone would allow better management of water application to meet crop requirements. Soil moisture requirements differ with each crop and with each growth stage of crop. Soil moisture availability varies within the type of soil. Knowing the soil type is essential in planning for and in using an irrigation system. However, direct measurement of soil water in the field is tedious on large-scale production levels. Other approaches that are most accurate require an understanding of the soil-plant-atmosphere continuum as mechanistically as possible that is the Soil Water Balance (SWB) model is a mechanistic, real-time, soil water balance, irrigation scheduling model (Annandale *et al.*, 1999).

Hence, crop water use is best described by considering the supply of water from the soil root system and the demand from the canopy atmosphere. The atmospheric demand is best estimated by the Penman-Monteith reference that the effects of climate, crop characteristics and local agricultural conditions have to be taken into consideration when calculating  $ET_{crop}$  (Singh *et al.*, 1990). Growers need direct and unambiguous irrigation recommendations to deal with crops that have negative responses to small variations in irrigation management. The soil water tension irrigation criterion needed to optimize potato yield and quality can be determined by production region and generalized soil type (Shock, 2003).

## **2.7 Effect of water stress on Potato growth and yield components**

Sprout development, plant establishment, tuber initiation, tuber bulking, and tuber maturation are the growth stages of potato plant, in which plants pass different developmental stages. During sprout development, sprouts develop on seed tubers and grow upward to emerge from the soil; roots begin to develop at the base of emerging sprouts. Leaves and branches develop on emerged sprouts; roots and stolons develop below ground, and photosynthesis begins at plant establishment. When tuber initiation starts, tubers form at stolon tips and in most cultivars, the end of this stage coincides with early flowering with an average duration of roughly two weeks. At tuber bulking, tuber cells expand with the accumulation of water, nutrients, and carbohydrates. ", Finally," at maturity stage, photosynthesis gradually decreases, leaves turn yellow, tuber growth rate slows, and the vines die (INSAM, 2007).

Water stress is among several factors affecting plant growth, tuber yield and yield components when it occurs at different growth stages during the growing season. The greatest tuber yield reduction was obtained when potato cultivars were exposed to a moisture stress during early growth stage and tubers' specific gravity were decreased when the stress was applied in midseason growth stage (Lynch, 1995).

Reduction in leaf area, stem and root expansion, plant height and delays in canopy development are symptoms of water limitation at vegetative growth stage. This water limitation reduced total tuber yield due to production of fewer and larger tubers per plant at harvesting. According to Onder *et al.* (2005), for optimum yields in a potato, the total available soil water (ASW) during

the season should not be depleted by more than 30-50%. ",However," the ideal soil water tension irrigation criteria for a potato vary with factors such as soil type, irrigation system, and environment of the production (Thompson et. al 2008).

Water deficit affects plant growth stage significantly if the quantity of water supplied is insufficient to meet the basic needs of plants requires (Seki *et al.*, 2002). Drought induced changes in plants are mainly related to altered metabolic functions, such as reduced synthesis of photosynthetic pigments, accumulation of osmoprotectants like proline in the cell, reduced growth, loss of membrane stability and integrity and alterations in physiological parameters including plant height and leaf area (Baroowa and Gogoi, 2012). Water stress in the plant leads to stomatal closure, reduction of transpiration and water transport through the plant, resulting decrease in nutrient absorption rate (He and Dijkstra, 2014). It also affects nutrient transport to the root surface by inducing root shrinkage and subsequent loss of the soil-root contact (Ahmad *et al.*, 2013).

The effect of water stress on a potato and other plants range from morphological to biochemical, physiological such as seed germination, photosynthesis, respiration, membrane stability, and plant-water relations (Howarth, 2005; Siddiqui *et al.*, 2015), and evident at all phonological stages of plant growth. Water deficit is responsible for reduced number of leaves, low plant water potentials, reduced leaf area, plant dwarfing, limited ground cover, limited stem extension and tuber yield reduction (Hassanpanah, 2010, Lahlou *et al.*, 2003, Jose and Tad-Awan, 2008). The sustained soil moisture deficit produces small or cucumber-shaped tubers, while intermittent water stress produces knobby tubers or tubers with secondary growth. Water stress also makes the plants more susceptible to pest and diseases (Nolte *et al.*, 2003).

Responses of potatoes to soil moisture stress are assessed in survival, vegetative growth, tuber size or total tuber production (van Loon,1981, MacKerron and Jefferies, 1988). In most environments, yields are frequently constrained by water stress which can affect the development and growth of shoots, roots, and tubers (Lahlou *et al.*, 2003). Water stress before tuber initiation can reduce tuber set for certain varieties (van Loon, 1981). Water stress at the beginning of the tuberization stage induced a longer period of tuber formation but decreased tuber number, growth and yield (Cavagnaro *et al.*, 1971).

## 2.8 Yield

Tuber yield and stomatal conductance of potato showed differential responses to water stress forced during different growth stages (Pejic et al., 2015). Drought conditions both pre-flowering and post-flowering stages have the most adverse effect on crop yield. Water stress adversely affects various developmental stages and ultimately affects the yield (King et al. 2003). The highest recorded potato yield is 29.1 ton/ha under optimum conditions (progress report of Holetta Research Center. 2000–2006).

Average tuber yield for dry land potato is about a half that of irrigated potato. Cantore *et al.* (2014) with investigated the effect of dryness on the quantitative and qualitative characteristics and the indexes of growth for corn, potato and millet concluded that the investigated characteristics including the surface of the leaf, absolute growth rate, the yield of tuber, the yield of dry material, the percentage of tuber protein and the percentage of tuber starch is highly affected by the tension. Howell and Hiler (1975) reported that yield response of tuber potato was not strongly correlated to seasonal evapotranspiration but was highly dependent on timing of the evapotranspiration deficit.

In comparison with other species, potato is very sensitive to water stress because of its shallow root system: approximately 85% of the root length is concentrated in the upper 0.3-0.4 m of the soil (Wang et al., 2006; Iwama, 2008). It is also sensitive to the changes in the soil moisture content and the decrease of water (water stress), leading to a significant reduction in tubers quantity and quality. The requirement for water irrigation of potato plants vary in different plant growth stages such as; tubers initiation and tubers bulking are the more sensitive stages in the plant growth life (Abdallah et al., 1996).

King et al. (2003) reported that effect of various periods of water stress on irrigated potato tuber at vegetative stages. Their report indicated that when potato plants were exposed to water stress from moderate (10 days) to severe (14 days) did not affect tuber yield vegetative stages. Whereas the stress at tuber bulking stage might interfere with the process of starch (dry matter) accumulation and contributed to the yield losses from 7 to 14 % respectively. Fekadu (2009) investigated with Effect of Cutting Irrigation during different growth stages on agronomic Traits

in potato Varieties in Iran reported that cutting irrigation at reproductive stage reduced the yield than cutting irrigation at reproductive stage and cutting irrigation at vegetative stage.

## **2.9 Yield response factor**

Yield response to water depends on different factors and may vary from region to region. Yields are frequently forced by moisture stress in most environments. Moisture stress affecting the development and growth of shoots, roots and tubers (Lahlou *et al.*, 2003). The actual evaluation of moisture stress related to the yield due to soil water deficit during the potato growing season can be obtained by the estimation of the yield response factor ( $K_y$ ) that represents the relationship between a relative yield decrease ( $1 - Y_a/Y_m$ ) and a relative evaporation deficit ( $1 - ET_a / ET_m$ ) (Stewart *et al.*, 1977). For  $K_y \leq 1$  the crop is tolerant, for  $K_y \geq 1$ , the crop is sensitive to water stress.

Doorenbos *et al.*, (1986) estimated that the average value of  $K_y$  is 0.7 for a potato during the growing season. The upper limits for yield are set by soil fertility, climatic conditions and management practices (Bauder *et al.*, 1988). Where all of these are optimal throughout the growing season, yield reaches the maximum value as does evapotranspiration ( $ET_m$ ) water storage has an impact on water availability for a crop and, subsequently, on actual yield and actual evapotranspiration ( $ET_a$ ) (English, 1990).

Vaux and Pruitt (1983) suggest that it is highly significant to know not only the  $K_y$  values from the literature but also those determined for a particular crop species under specific climatic and soil moisture conditions. This is because  $K_y$  may be affected by other factors also soil water deficiency, namely soil properties, climate (environmental requirements in terms of evapotranspiration), growing season length and inappropriate growing technology, applied irrigation method. Water deficit effect on crops yield can be presented in two ways, for individual growth periods or for the total growing season of the crop.

Kobossi and Kaveh (2010) suggested  $K_y$  values for the whole growing period instead for individual growth stages as the decrease in yield due to water stress during specific periods, such as vegetative and ripening periods, is comparatively small compared with the yield formation period, which is relatively large. Potato is very sensitive to moisture stress particularly in the

stage of tuber formation. Even the decrease of 10% in the optimum water treatment in the growing period could have caused reduce in the yield of potato.

## **2.10 Water Productivity and Water use efficiency**

Water productivity is the amount of beneficial output per unit of water depleted. In its broadest sense, it reflects the objectives of producing more food and the associated income, livelihood and ecological benefits, at a lower social and environmental cost per unit of water used (Molden, 2007). Usually, water productivity can be defined with respect to the different sectors of production involving water (e.g. crop production, fishery, forestry, domestic and industrial water use). Water productivity with respect to crop production is referred to as crop water productivity (CWP), and is defined as the amount of crop produced per volume of water used. The unit of crop water productivity is  $\text{kg/m}^3$  (SWMRG, 2003; Kadigi *et al.*, 2004).

Increasing water productivity can be an important pathway for poverty reduction, especially in the developing countries, where the variability of water productivity of within and between fields is very high, according to specific condition under which the crop are grown (Hailelassie *et al.*, 2009). The crop water productivity is a vital parameter to assess the performance of irrigated and rain fed agriculture.

Water use efficiency and water productivity are often used in the same context of increasing agricultural outputs while using or degrading fewer resources. Although definitions vary, water use efficiency usually takes into account the water input, whereas water productivity uses the water consumption in its calculation. Improving agricultural water productivity is about increasing the production of rain-fed or irrigated crops. Crop water productivity has been the subject of many years of research and its assessment and means for improvement are well documented (Molden, 2007; Rockström and Barron, 2007). Opportunities for improving crop water productivity mainly lie in choosing adapted, water-efficient crops, reducing unproductive water losses and ensuring ideal agronomic conditions for crop production (Kijne *et al.*, 2003; Bouman, 2007).

### 3. METHODS AND MATERIALS

#### 3.1 Description of the experimental area

The study was conducted under irrigation condition during the 2017/18 season at Wondo Genet Yuwo districts, in Southern Regional State. The site was selected based on the fact that it represents potential potato production areas in the District. The town is 25 km far from Hawassa and 300 km from Addis Abeba and it is a resort town in Ethiopia Located southeast of Shashemene in the Sidama Zone of the SNNPRs. The site is located at latitude and longitude of 6°58' to 7°1' N 38°31 to 38°35' E respectively and an elevation of 1703 meters above sea level (see figure 1).

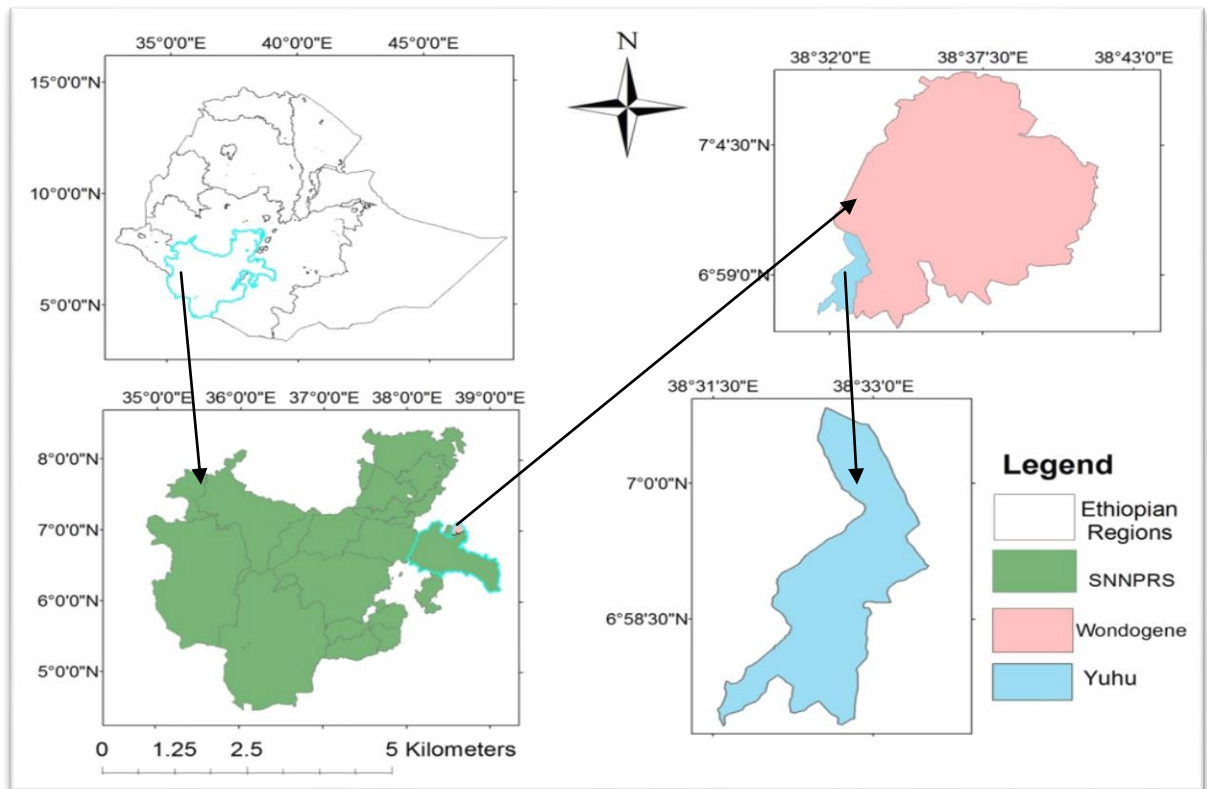


Figure 1: Location map of the study area

#### 3.2 Climate

The Climate of the area is semi-arid with total annual precipitation of 831.1 mm of rainfall expected in the rainy season which is characterized by bimodal rainfall pattern. The major season

is “*kremt*”, the long rainy season (July to September), while the short rainy season that extends from March to April is “*belg*” and mean temperature of 14.86 °C during the potato growing season was characterized by a long term meteorological data (see figure 2 and Table 1 of appendix). Long-term total rainfall exceeded Long-term mean temperatures in August, but in the remaining months, including July, Long-term mean temperatures exceeded Long-term total rainfall.

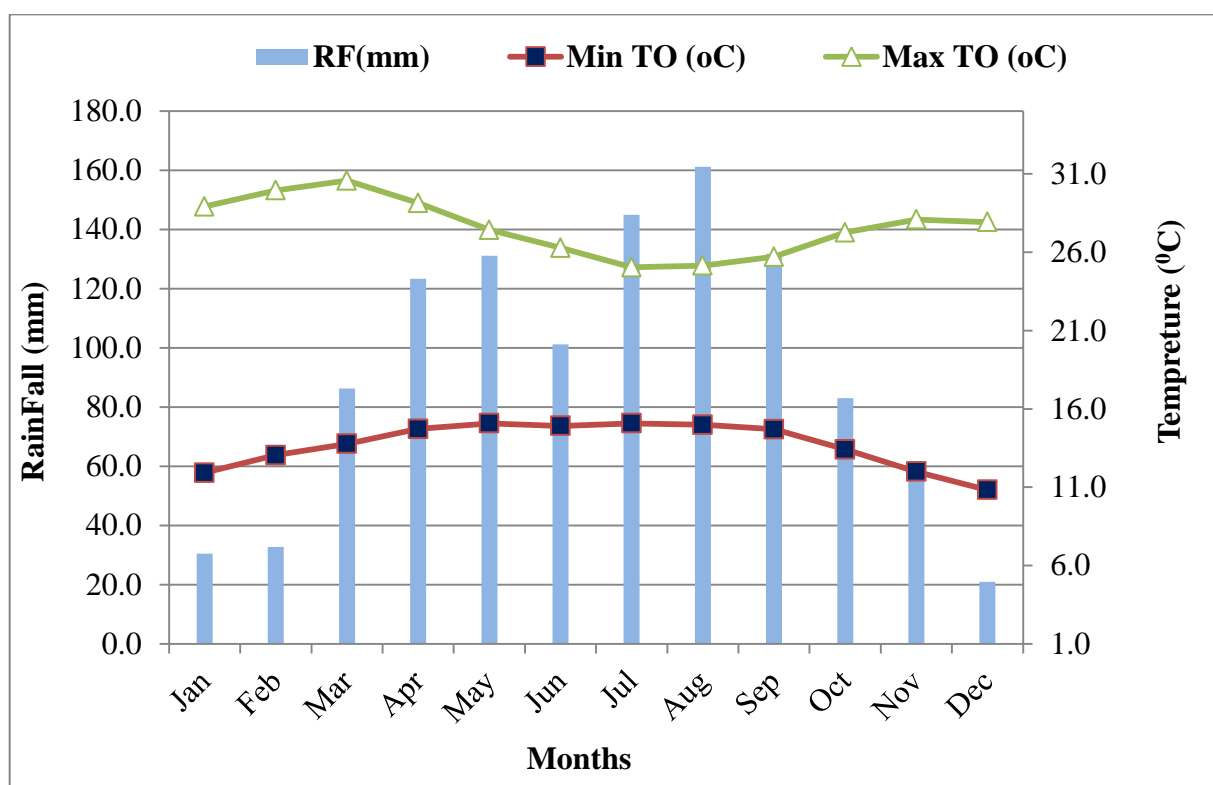


Figure 2: Long-term monthly rainfall, maximum ( $T_{max}$ ) and minimum temperature ( $T_{min}$ ) of the study area

(2007 – 2017) (Hawassa Meteorological Station, 2017)

### 3.3 Soil sampling and analysis

Soil samples were collected from 0-30 and 30-60 cm depth it is why because effective rooting depth of potato crop is 60 cm (MoA, 2015) the collected soil sample used to evaluate different soil physical properties (Table 2). Soil samples collected from the experimental field before

planting and were analyzed for textural class, pH, field capacity and permanent wilting point; Soil samples passed through 2 mm sieve were used for analyses. Determination of particle-size distribution was done by using hydrometer procedure as outlined by Sahlemedhin and Taye, (2000). The contents of sand, silt and clay were computed and the soil textural class was identified from textural triangle (Motsara and Roy, 2008). Moisture contents at FC and PWP measured using a pressure plate and membrane apparatus technique by applying pressures at -1/3 bar -15 bars respectively. Soil pH will be determined by using a pH meter where as total available water (TAW) was obtained by subtracting PWP from FC (Ryan *et al.*, 2001).

$$TAW = \frac{FC-PWP}{100} * BD * D_{rz} \dots\dots\dots 1$$

Where TAW = Total available water (mm/m), FC = Field capacity (% on weight basis), PWP = Permanent wilting point (% on weight basis), BD = Bulk density (g cm<sup>-3</sup>) and D<sub>rz</sub> = Depth of root zone (mm).

The soil bulk density is defined as the oven dry weight of undisturbed soil in a given volume, as it occurs in the field. It was determined by core sampler method. Soil bulk-density data was taken as cores in the field at two depths 0-30 cm and 30-60 cm, oven dried for 24 hrs at 105°C and weighed for dry density using the following formula (Ryan *et al.*, 2001).

$$BD = \frac{M_s}{V_s} \dots\dots\dots 2$$

Where M<sub>s</sub> is the weight of oven dry soil, and V<sub>s</sub> is the volume of the same soil in cm<sup>3</sup>.

### 3.4 Computation of Crop Water, irrigation water requirement and Scheduling

#### 3.4.1 Reference crop evapotranspiration

To calculate the reference evapotranspiration using the CROPWAT model, 10 years (2007 - 2017) of average monthly maximum and minimum temperature, relative humidity, sunshine hour and wind speed data that was collected from Hawassa meteorology station which was prepared in (Appendix Table 1).

Reference evapotranspiration (ET<sub>o</sub>) was determined based on the modified FAO Penman Monteith equation (Allen *et al.*, 1998)

$$ET_o = \frac{0.408\Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \dots\dots\dots 3$$

Where,  $ET_o$  = reference evapotranspiration [ $\text{mm day}^{-1}$ ],  $R_n$  = net radiation at the crop surface [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $G$  = soil heat flux density [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $T$  = mean daily air temperature at 2 m height [ $^{\circ}\text{C}$ ],  $u_2$  = wind speed at 2 m height [ $\text{m s}^{-1}$ ],  $e_s$  = saturation vapour pressure [kPa],  $e_a$  = actual vapour pressure [kPa],  $e_s - e_a$  = saturation vapour pressure deficit [kPa],  $\Delta$  = slope vapour pressure curve [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ],  $\gamma$  = psychrometric constant [ $\text{kPa } ^{\circ}\text{C}^{-1}$ ].

### 3.4.2 Crop water requirement

The crop water requirement ( $ET_c$ ) was determined for potato crop of the study area over the growing season requires the crop coefficient ( $K_c$ )-values at different crop development stages, planting dates, length of growing season, and length of each crop development stage. The  $K_c$  values were determined on the basis of in-field observations of crop phenological stages and using the (Richard *et al.*, 2006) data.  $K_c$  values were fixed at 0.5, 1.15 and 0.75 respectively for the initial crop growth stages (up to the beginning of stem elongation), mid-season (since stem elongation until flowering), and the late season stage (maturity). Maximum root depth was fixed at 0.6 m (MoA, 2015). The CWR was estimated based on the established procedure given by (Allen *et al.*, 1998).

$$ET_c = ET_o * K_c \dots\dots\dots 4$$

Where:  $ET_c$  is crop evapotranspiration,  $ET_o$  is reference evapotranspiration in mm/day and  $K_c$  is crop coefficient [dimensionless]

### 3.4.3 Irrigation Requirement (IR)

Computation of IR requires long-term rainfall data from the study sites. Long-term monthly rainfall data was obtained from the study sites. The values obtained were used during the computation of CWR. Generally, IR can be estimated from the expression:

$$IR = CWR - P_e \dots\dots\dots 5$$

Where, IR is irrigation requirement in mm, CWR is crop water requirement in mm and  $P_e$  is effective rainfall which is part of the rainfall that entered into the soil and made available for

crop production in mm. but, the experiments plot was covered with plastic so effective rainfall was taken as zero because it eliminates to see the effects of moisture stress at different crop growth stage.

Therefore  $IR = CWR$  .....6

### 3.4.4 Irrigation Scheduling

Considering the daily CWR, TAW and Drz the irrigation interval could be computed from the expression:

$$NIR = TAW * Z * P \dots\dots\dots 7$$

Where, NIR= Net irrigation required (mm), P = Allowable soil moisture depletion of crop TAW =Total available soil moisture (mm/m).

$$IRg = \frac{NIR}{Ea} \dots\dots\dots 8$$

Where  $IR_g$  is gross irrigation in mm, NIR= Net irrigation required (mm), and Ea is the Irrigation water application efficiency (take as 60%)

Method of irrigation was furrow irrigation with furrow spacing, width and depth respectively. And Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity. The irrigation scheduling for potato was determined on the basis of predetermined 6 days irrigation interval, 0 yield loss. Irrigation water was delivered to this experimental site by water pump from the shallow well which is near to the farm and the 3 inch standard rectangular shaped Parshal flume was set near the up-stream furrows to monitor the rate of inflowing irrigation water. Which is made at Melkasa Agricultural Research Center based on the calibrated depth and discharge (appendix table 6), the time required to irrigate each plot were calculated using the following formula (Allen *et al.*, 1998)

$$t = \frac{d * A}{60 * q} \dots\dots\dots 9$$

Where t = application time (min), d= gross depth of water applied (mm), A= net area of the plot (m<sup>2</sup>) and q= flow rate (discharge) (l/s).

In addition, rain gauge was installed at the field to measure the amount of rainfall during the growth season.

### 3.5 Experimental set up and treatment randomization

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. There were seven treatments made by varying two water regimes (0 and 100%  $ET_C$ ) and imposed at four growth stages of potato crop. The crop growing season was divided into four major growth periods: the initial stage, development stage, mid season stage, and late season stage. The treatments were: Treatment with full irrigation throughout the growing season (no stress), no irrigation application at initial stage only (I), no irrigation application at development stage only (D), no irrigation application at midseason stage only (M), no irrigation application at late season stage only (L), no irrigation application at initial and midseason stages (IM) and no irrigation application at initial and late season stages (IL), respectively.

Table 1: treatment combination

Treatments	Description
T1	Apply Irrigation at all stages(control)
T2	no irrigation application at initial stage only, but apply at all other stages
T3	no irrigation application at developmental stage only, but apply at all other stages
T4	no irrigation application at midseason stage only, but apply at all other stages
T5	no irrigation application at late season stage only, but apply at all other stages
T6	no irrigation application at initial and midseason stage only, but apply at both other stages
T7	no irrigation application at initial and late season stage only, but apply at both other stages

RCBD were selected to minimize the effect of slope difference on the treatment following the gradient of experimental site (Gomez and Gomez, 1984). Treatments were arranged in each of the three blocks randomly based on randomization.

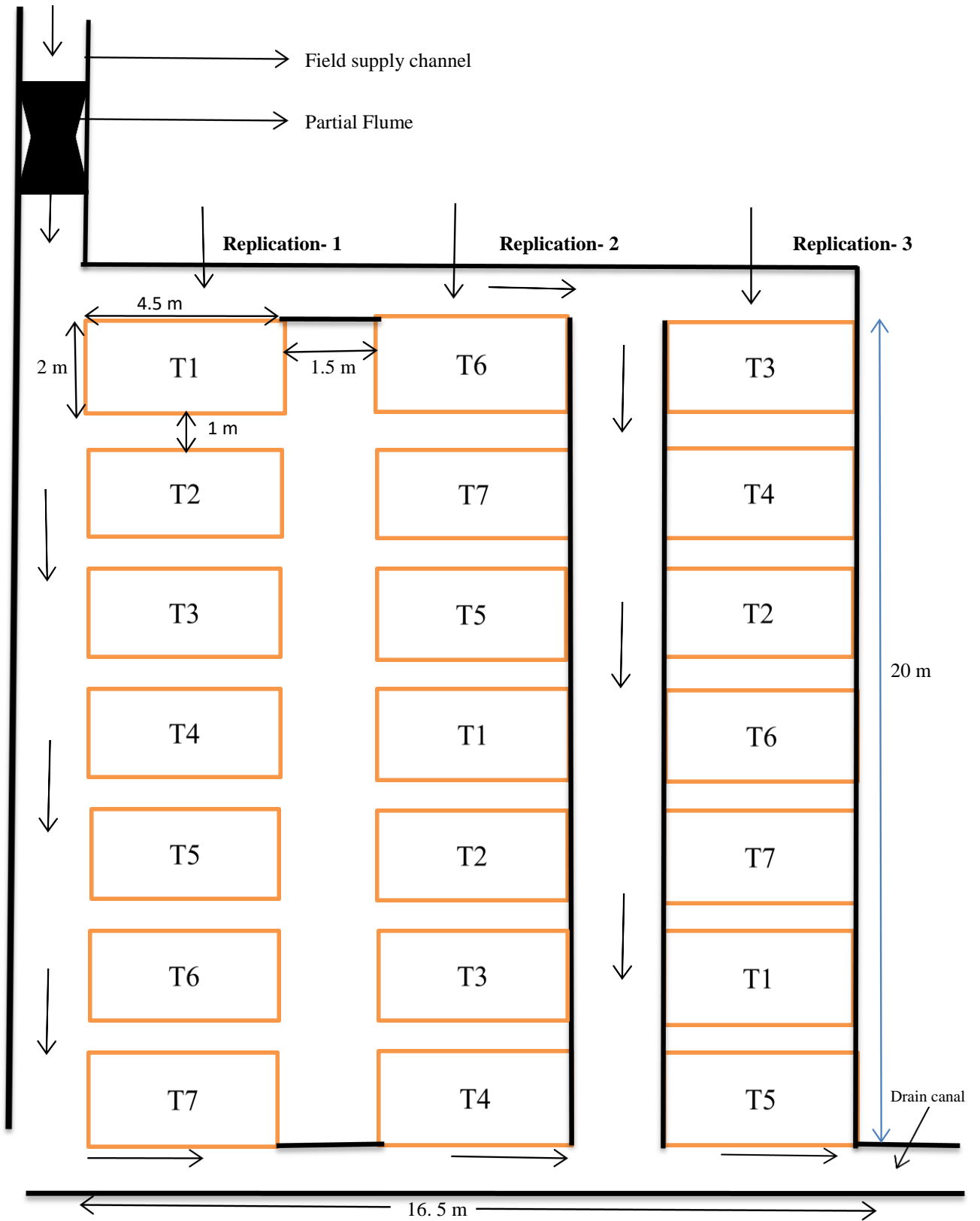


Figure 3: layout of the experiment

### 3.6 Land preparation and planting

Land preparation was carried out in February 2018. *Gudene*, an early maturing cultivar of potato Medium size and well sprouted tubers were used for planting. It was planted on 19 March 2018 G.C at a spacing of 75 cm between rows and 30 cm between plants. Each plot has five ridges and six end blocked furrows and having 7 plants in each row with a total of 35 plant population in each plot from this the harvested plot area was 3 x 2 m by avoiding the border furrows.

The furrow had a ‘V’ shape with an average depth of 15 cm at the top. Half of the N and the whole P fertilizer rate was applied during the time of planting; and the remaining half of the N dose was applied during the first earthing-up (35-45 days after planting) as side dressing. Weeds were managed by hoeing and hand weeding. Earthing-up was done two times before flowering to initiate tuber bulking and one time after flowering to prevent exposure of tubers to direct sunlight (MOANRS, 2011). All agronomic practices were done to all treatments in accordance to the recommendation made for the area. Potato was harvested manually using hand hoe after three months.

This experiment was done on farmer’s field land because of limited farm land and the cost of the shading material the plot size was adjusted and the plot size has a dimension of 4.5 m x 2 m and the spaces between plot and blocks was 1.0 m and 1.5 m respectively and in order to minimize the risk of water transfer from one plot the other plot and also shading was done to avoid the impact of crop water need from rainfall enter on the treatments (see appendix figure 1 and 2).

### 3.7 Water Productivity

Physical water productivity or water use efficiency (WUE) was determined by dividing the yield to seasonal evapotranspiration and calculated by the following equation (Barker *et al.*, 2003).

$$WUE = \frac{Yield}{ET_c} \dots\dots\dots 10$$

Where: WUE is water use efficiency (Kg/m<sup>3</sup>), Y is actual yield (Kg/ha), and ET<sub>c</sub> is seasonal crop evapotranspiration (m<sup>3</sup>/ha).

### 3.8 Growth and Yield Data Collection and Analysis

In the experiment the agronomic parameters was collected in the study site to know the effect of soil moisture stress on different crop growth stage in days. Five plants was chosen and marked from each plot randomly after 90 days from sowing. Parameters measured included:

**Plant height (cm):** five potato plants were randomly selected from the center three rows to avoid border effect then the height of these five plants was measured from the soil surface to the tip of the plant using tape meter. The mean value of the five plant height was recorded as plant height of each plot

**Number of branches per plant:** Number of branches was counted from randomly selected five plants per plant. The mean value of the five plant branches was recorded as plant branch number of each plot after 90 day from sowing.

**Number of tubers per plant:** Is the mean number of tuber produced by the sampled plants. Total number of tuber from each of the sampled plant were counted and divided by the number of plants and expressed as number per plant.

$$\text{No. of tubers /plant} = \frac{\text{No.of all tubers from sample (5 plants)}}{\text{No.of plant in sample (5 plants)}} \dots\dots\dots 11$$

**Tubers fresh weight (g):** Is the mean weight of tubers produced by the five randomly selected plants. The weight of all tubers from the sampled plants were taken and divided by the number of plants sampled and expressed in gram.

**Tuber length (cm):** refers to the length of randomly selected five plant tubers were measured using caliper in centimeter. Then, average tuber length was calculated.

**Tuber diameter (cm):** refers to the diameter of five sample randomly selected plant tuber measured at the widest point in the middle portion of the mature tuber using a caliper.

**Yield Components:** At harvest, the yield of tubers was classified according to sizes and the total marketable and non-marketable tubers were weighed separately and further computed to tons per hectare.

**a. Marketable yield:** Tubers classified under extra-large, big, medium and small were considered marketable yields.

**b. Non-marketable yield:** Tubers classified as marbles, diseased, physiologically disordered and putrid were considered non-marketable.

**Tuber yield (ton/ha):** Harvesting was done after 90 days from sowing and the tuber was recorded from net plot by weighed all tuber taken from central three rows and converted in to ton/ha calculated as:

$$\text{Yield (ton/ha)} = \frac{\text{wt.of tuber (g/m}^2\text{) x 10000 (ha)}}{1000 \text{ (ton) x1000 (kg)} \dots\dots\dots 12$$

**Water use efficiency (kg/m<sup>3</sup>):** was determined by dividing the tuber yield produced from each treatment to the total water applied for the respective treatments.

**Yield response factor (K<sub>y</sub>):** In order to quantify the effect of water stress it is necessary to derive the relationship between relative yield decrease and relative evapotranspiration deficit given by the empirically-derived yield response factor (k<sub>y</sub>) of Doorenbos and Kassam (1979)

$$\frac{Y_a}{Y_m} = 1 - k_y \left(1 - \frac{ET_a}{ET_m}\right) \dots\dots\dots 13$$

### 3.9 Statistical Analysis:

The collected data has been analyzed by using SAS software 9.0 window versions for analysis of the statistical effect of stress irrigation treatments (SAS Institute, 1996). The input data was plant height, branch number, tuber number per plant, tuber length, tuber diameter, tuber fresh weight, marketable yield, unmarketable yield, total tuber yield and water use efficiency. Whenever the treatment effects were found significant, at 5% was performed to assess any significant difference among treatments means.

## 4. RESULTS AND DISCUSSION

### 4.1 Soil of the study Area

The particle of the study soils possesses sand, silt and clay with 58, 26 and 16% distribution, respectively (Table 2). This could be named as sandy loam textural class based on (Sahlemedhin and Taye, 2000). The pH of the area is 6.35, which could be grouped as slightly acidic. The bulk density of the experimental plot is 1.32 g/cm<sup>3</sup> and 1.36 g/cm<sup>3</sup> at the depth of 0-30 cm and 30-60 cm respectively, and the average bulk density of the experimental area was 1.34 g/cm<sup>3</sup>, which is ideal for plant growth for aforementioned sandy loam soils according to USDA (2014).

The amount of water present in this soil during planting was 123.95 mm/m, which is found in the range of available water (110-150 mm/m) for sandy loam soils according to (Allen, 1998). Thus, the soils of the study area are suitable for potato crop production. This is in agreement with Lynn, (2015), who elaborated potato as a crop that requires well drained loam or sandy loam soils with slightly acidic pH. Some physical characteristics of soil, at the experimental site are presented in Table 2.

Table 2: Physical characteristics of soil at the experimental site

Depth (cm)	Bulk density (g/cm <sup>3</sup> )	PH	Field capacity (%)	Permanent Wilting Point (%)	Total Available Water (mm/m)	Particle size distribution (%)			Textural class
						Sand	silt	clay	
0-30	1.32	6.3	20.4	11.1	122.77	60	22	18	Sandy loam
30-60	1.36	6.4	21.5	12.3	125.13	58	26	16	Sandy loam
Total	1.34	6.35	20.95	11.7	123.95				

### 4.2 Irrigation Water Requirements and irrigation scheduling on potato

The amount of irrigation water applied to each treatment during the experimental period is shown in Table 3. The highest amount of irrigation water was applied on T1, which was irrigated at all stages while the lowest was applied on treatment (T6) which was irrigated at development and late season growth stages only. The total amount of water used by the crop was in the range

of previous report of FAO as 500 up to 700 mm (Doorenbos and kassam, 1979). Pejic *et al.* (2015) who reported that seasonal Evapotranspiration rate of potato in irrigated conditions ranged from 491.3 to 498.6 mm. Tolga *et al.* (2006) who found seasonal evapotranspiration of potato of 596 mm. While treatment T1 consumes higher than 500 mm. An ET value of the study was being slightly higher from the above two researchers. This may be attributed to differences in climatic conditions, planting date and total growing season irrigation depth. The irrigation scheduling was listed in appendix table 5.

Table 3: Rainfall, net irrigation water applied and total amount of water applied

<i>Treatment</i>	<i>Irrigation application stage</i>	<i>Effective rain fall (mm)</i>	<i>Net irrigation (mm)</i>	<i>Gross irrigation (mm)</i>
1	IDML	0	302.8	504.2
2	DML	0	276.1	459.8
3	IML	0	228.1	379.9
4	IDL	0	170.1	283.2
5	IDM	0	234.1	389.7
6	DL	0	143.4	238.8
7	DM	0	207.4	345.3

IDML= at initial, developmental, midseason and late season stage DML= at developmental, midseason and late season stage IML= at initial, midseason and late season stage IDL = at initial, developmental and late season stage IDM = at initial, developmental and midseason stage DL= at developmental and late season stage DM= at developmental and midseason stage

Table 4: Irrigation scheduling and amount of water applied for each treatment (mm)

<b>Date</b>	<b>Crop growth stage</b>	<b>IDML (T1)</b>	<b>DML (T2)</b>	<b>IML (T3)</b>	<b>IDL (T4)</b>	<b>IDM (T5)</b>	<b>DL (T6)</b>	<b>DM (T7)</b>
24-Mar	Init	22.3	-	22.3	22.3	22.3	-	-
30-Mar	Init	22.1	-	22.1	22.1	22.1	-	-
5-Apr	Dev	23.8	23.8	-	23.8	23.8	23.8	23.8
11-Apr	Dev	25.9	25.9	-	25.9	25.9	25.9	25.9
17-Apr	Dev	34.9	34.9	-	34.9	34.9	34.9	34.9
23-Apr	Dev	39.7	39.7	-	39.7	39.7	39.7	39.7
29-Apr	Mid	44.5	44.5	44.5	-	44.5	-	44.5
5-May	Mid	44.8	44.8	44.8	-	44.8	-	44.8
11-May	Mid	44.7	44.7	44.7	-	44.7	-	44.7
17-May	Mid	43.9	43.9	43.9	-	43.9	-	43.9
23-May	Mid	43.1	43.1	43.1	-	43.1	-	43.1
29-May	End	42.3	42.3	42.3	42.3	-	42.3	-
4-Jun	End	37.3	37.3	37.3	37.3	-	37.3	-
10-Jun	End	34.9	34.9	34.9	34.9	-	34.9	-
16-Jun	End							
<b>Total</b>		504.2	459.8	379.9	283.2	389.7	238.8	345.3

From table 4 as shown the above crop water requirement values were low at the beginning of the growing season, but increased gradually to reach a maximum during the plant growth stage of at development to midseason stage then decreased gradually the plant to reach at late season stage of the crop. This result indicates that, the maximum amount of water was applied around tuber formation of the potato crop which was lined with (Fekadu, 2009) who reported that water requirement of potato crop increase from planting to tuber formations stage then decrease at harvesting stage because photosynthesis gradually decreases, leaves turn yellow and the vines die.

### **4.3 Effect of moisture stress on Potato crop growth parameters**

#### **4.3.1 Plant height**

The statistical analysis showed that the plant height was significantly influenced at ( $p < 0.05$ ) due to soil moisture stress at different growth stage (appendix table 1). The maximum plant height of 92.67 cm and 85.16 cm were recorded from T1 and T5 (no stress and stressing only at late season) respectively while the minimum plant height of 47.433 cm and 55.53 cm were observed from T3 and T4 (stress only at development stage and stress at initial and midseason stage) respectively (Table 5). The data indicated that plant height for the treatment (T3) was inferior to other treatments. Water stress during the vegetative growth stage decreases plant height and root expansion (Haider and Ramana, 2015). This confirms that plant height was associated with the water applied at development stage.

#### **4.3.2 Number of branches per plant**

The number of branches per plant was different in different soil moisture stress periods (Table 5). There was a difference between treatments with control treatment. The treatment (T1) gave the highest number of branches but had no significant difference with treatments except with treatment T2, T3, T4, T6 and T7 while the lowest number of branches was recorded from treatment T3 (stress at development stages). The statistical analysis showed that there were a significant difference between the soil moisture stress at ( $p < 0.05$ ). The results was lined with Fekadu (2009) who reported that Water stress during development growth stage significantly reduced number of main stems produced per plant compared to stress during midseason stage.

Table 5: effect of moisture stress on plant height, and number of branch per plant at harvesting

<i>Treatment</i>	<i>Plant height</i> ( <i>cm</i> )	<i>Branch number</i>
1	92.67 <sup>a</sup>	8.66 <sup>a</sup>
2	69.66 <sup>b</sup>	6.66 <sup>b</sup>
3	47.433 <sup>e</sup>	3.33 <sup>d</sup>
4	55.53 <sup>de</sup>	4.66 <sup>c</sup>
5	85.16 <sup>a</sup>	8.66 <sup>a</sup>
6	57.467 <sup>cd</sup>	5.0 <sup>c</sup>
7	66.50 <sup>bc</sup>	6.33 <sup>b</sup>
LSD <sub>(0.05)</sub>	9.81	1.01
CV	8.14	9.21

Means followed by the same letter within a column are not significantly different at 5% level of significance. LSD = Least significant difference; CV% = Coefficient of variation.

#### 4.4 Effects of Moisture Stress on Yield and Yield Components of Potato crop

##### 4.4.1 The Numbers of Tuber per plant

Considering the table of analysis of variance, the attribute of number of tuber per plant of potato was significantly affected ( $P < 0.05$ ) by moisture stress applied at different growth stages (appendix Table 1). The highest number of tuber per plant was obtained from treatment T1 which received irrigation at all growth stages but had no significance differences with treatments T2 and T5.

Whereas the lowest number of tuber was recorded from treatment T6, which was stress in the combination of at initial and midseason stage but, it has no significant difference with treatment T3 and T4. In general, water stress at development and midseason growth stage causes a significant reduction in tuber number (Onder et al., 2005). Similarly water stress reduces seed yield in soybean and resulted fewer pods and seeds per unit area (Specht *et al.*, 2001). Avoiding soil moisture stress at developmental and mid-season growth stages of the crop leads to higher number of tuber yield. This is in line with that the number of tuber in plant decreases if irrigation

is cut at appearing the tuber initiation and beginning of elongation. Missing irrigation at the late season growth stage had no effect on number of tuber yield (Table 6).

#### **4.4.2 Tuber length and Tuber diameter**

Moisture stress at different potato growth stage had a significant influence at ( $p < 0.05$ ) on tuber length and tuber diameter (appendix Table1) . Treatment that irrigated at all stages was superior from the other treatments showed 7.76 cm and 5.53 cm on both tuber length and tuber diameter respectively in table 6. The minimum tuber length of 2.86 cm was recorded due to treatment that stressed only at midseason stage and minimum tuber diameter of 2.36 cm and 2.8 cm was recorded by treatment that moisture stresses occur at initial and midseason stages and only at midseason stage respectively. This revealed that when soil moisture stress occurred at development and midseason growth stage, tuber length and tuber diameters were highly affected which have a direct relation with tuber yield. Accordingly Eldredge et al. (1996) Extreme water stress conditions at critical growth stages influence the tuber yield, size, and external and internal quality of potato crop. Water stress during the tuber bulking stage causes dark stem-end fry colour

#### **4.4.3 Tuber fresh weight per plot**

The analysis of variance indicated that the Fresh weight of tuber was significantly difference ( $p < 0.05$ ) between the treatments (appendix Table 1). The effect of soil moisture stress showed a decrease in fresh weight of the tubers compared with the treatment which received irrigation at all growth stage. Treatment (T1, T2 and T5) gave the highest tuber fresh weight while treatment (T3) gave the lowest one. A statistical analysis of mean showed that high significant differences between treatments (Table 6). These results are in confirmation with those of Fekadu (2009) who reported that Water stress during vegetative and tuber bulking growth stages reduced tuber fresh weight in that, water stress fluctuation caused the highest yield reduction (40%) followed by the stress treatment which stayed for 15 days at vegetative or tuber bulking growth stages, both caused similar yield reduction (18%) from the zero water stress (control) treatment per plant. In general, tuber number per hill and tuber weight per hill appeared to be the yield component that are affected by deficit water during tuberization stage, which can decrease tuber yield up to 69% depending on period and strength of stress (Schafleitner *et al.*, 2007).

Table 6: effect of moisture stress at different growth stage on Potato yield components at harvesting

<i>Treatment</i>	<i>Tuber number per plant</i>	<i>Tuber length (cm)</i>	<i>Tuber Diameter (cm)</i>	<i>Tuber fresh we. per plant (g)</i>
1	11.33 <sup>a</sup>	7.76 <sup>a</sup>	5.53 <sup>a</sup>	756.67 <sup>a</sup>
2	10.00 <sup>b</sup>	6.83 <sup>b</sup>	4.73 <sup>b</sup>	693.33 <sup>b</sup>
3	5.33 <sup>d</sup>	3.36 <sup>d</sup>	3.26 <sup>d</sup>	216.67 <sup>e</sup>
4	4.33 <sup>e</sup>	2.86 <sup>e</sup>	2.8 <sup>de</sup>	306.67 <sup>d</sup>
5	10.66 <sup>ab</sup>	7.7 <sup>a</sup>	5.73 <sup>a</sup>	735.67 <sup>a</sup>
6	3.66 <sup>e</sup>	3.2 <sup>de</sup>	2.36 <sup>e</sup>	303.33 <sup>d</sup>
7	6.66 <sup>c</sup>	5.5 <sup>c</sup>	4.06 <sup>c</sup>	570 <sup>c</sup>
<i>LSD</i> ( <i>0.05</i> )	0.91	0.466	0.59	21.32
<i>CV</i> (%)	6.88	4.93	8.15	2.34

Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level and different letter are significant different at 5%, of probability level.

#### 4.4.4 Marketable and unmarketable tuber yield

**Marketable:** Temporary drought stress during different growth stages significantly ( $P < 0.05$ ) affected marketable yield of potato tuber (Table 7). The difference in total marketable potato tuber yield for the control and moisture stress occurred at different growth stage was found to be statistically significant (appendix Table 2). Treatment (T1) that receives irrigation at all growth stage was superior to the others showed 28.93 ton/ha with small significant difference between treatment (T5) which was moisture stress occurs only at late season growth stage recorded 27.83 ton/ha on marketable tuber yield and the minimum marketable tuber yield of 5.86 ton/ha was received by treatment (T6) that stressed at initial and midseason growth stage only with small significant difference of T4.

**Unmarketable:** The ANOVA result showed that un marketable tuber yield was significantly affected  $p < 0.05$  by moisture stress. The difference in unmarketable tuber yield for the control and moisture stress done at different growth stage was found to be statistically significant (appendix Table 2). The maximum tuber yield of 4.4 ton/ha was recorded from T3 which had

moisture stress occurs only at development stage and but had no significant difference with T6. While the minimum unmarketable tuber yield of 0.23 ton/ha was received by treatment (T1) which received irrigation at all growth stages but no significant difference with T2 and T5 tuber yield (Table 7).

These revealed that when moisture stress at development and midseason growth stage happen, marketable yield of tuber decrease whereas unmarketable tuber yield was increase and highly affected which have a direct relation with tuber yield. At final harvest, the size distribution of the marketable yield represents only a fraction of the harvestable yields. This is because marketable yields exclude tubers with physiological disorders like second growth, growth cracks, damage and diseases (Struik *et al.*, 1995). In addition unmarketable tuber yield, small tubers are also removed from the size distribution; for example tubers <10 g (Searle, 1999).

#### **4.4.5 Total Tuber Yield**

Data presented in Table 7 showed that missing irrigation at any of the studied growth stages significantly ( $P < 0.05$ ) decreased total tuber yield. The application of normal irrigation (14 irrigations) significantly produced the maximum total tuber yield ( $29.16 \text{ t ha}^{-1}$ ) there were no significant difference but there was simply in number difference with treatment (T5). While the lowest total tuber yield ( $10.20 \text{ t ha}^{-1}$ ) was obtained by applying water stress at the combination of initial and midseason growth stage.

These results are in agreement with those of (Badr *et al.*, 2012) they noticed that the treatment of applying irrigation at all growth stage gave the highest yield of tubers with a significant difference than the other treatments, and the average weight of the tuber was more affected by the lack of water than the number of tubers. (Mauromicale, 2006; Ierna *et al.* 2011) whose reported that water stress causes a significant reduction in total tuber yield and also Wang *et al.* (2006) studied that the effects of full irrigation and deficit soil moisture on yield of potato at tuber initiation stages was highly affected. They showed that potato tuber yield decreased significantly under deficit soil moisture relative to full irrigation. The present study also showed that yield reduction was greatly governed by the time of water stress. The total tuber yield was reduced by 13.4%, 12.1% and 10% when the plants were exposed to no irrigation application at

the combination of initial and midseason, midseason and development growth stages in comparison to the plants received normal irrigation respectively (see figure 4).

The average yield show increased potato yield production with additional water. Not only the amount of water applied important, but also the timing (Table 7), relative to the growth stage of the crop. The present result in line with Jaleel *et al*, (2009) tuber yield decreased with rising of drying in soil. As stated by Vijitha and Mahendra (2010), the final yield of the crop is the result of the combined effects of stress on growth, photosynthesis, respiration, metabolic processes, reproduction and other processes. Water stress can reduce photosynthesis by decrease in chlorophyll content, reduction in leaf area, closure of stomata, decrease in the efficiency of carbon fixation and reduced nutrient uptake by crops finally reduces yield.



Figure 4: Potato tuber yield at harvesting

Table 7: Effect of moisture stress at different growth stage on potato Marketable (Mky), Unmarketable yield (Umy), Tuber yield (Ty), and Water Use Efficiency (WUE)

<i>Treatment</i>	<i>Mky</i> (ton/ha)	<i>Umy</i> (ton/ha)	<i>Ty</i> (ton/ha)	<i>WUE</i> (kg/m <sup>3</sup> )
1	28.93 <sup>a</sup>	0.23 <sup>e</sup>	29.16 <sup>a</sup>	5.80 <sup>b</sup>
2	26.37 <sup>c</sup>	0.70 <sup>d</sup>	27.06 <sup>b</sup>	5.86 <sup>b</sup>
3	10.50 <sup>e</sup>	4.40 <sup>a</sup>	14.96 <sup>d</sup>	3.93 <sup>d</sup>
4	8.36 <sup>f</sup>	3.63 <sup>b</sup>	12.00 <sup>e</sup>	4.23 <sup>c</sup>
5	27.83 <sup>b</sup>	0.56 <sup>d</sup>	28.36 <sup>a</sup>	7.26 <sup>a</sup>
6	5.86 <sup>g</sup>	4.33 <sup>a</sup>	10.20 <sup>f</sup>	4.30 <sup>c</sup>
7	19.70 <sup>d</sup>	1.13 <sup>c</sup>	20.80 <sup>c</sup>	6.03 <sup>b</sup>
LSD <sub>(0.05)</sub>	0.84	0.24	0.88	0.23
CV (%)	2.81	6.51	2.43	2.45

Means followed by the same letter within a column are not significantly different at 5% level of significance.

#### 4.5 Water use efficiency or Water Productivity (WUE)

Moisture stress at different growth stage had a significant difference at ( $p < 0.05$ ) between the treatments (appendix table 4). The highest water use efficiency was recorded 7.26 kg/m<sup>3</sup> on treatment (T5). While the lowest water use efficiency due to moisture stress happens at development growth stage were measured 3.93 kg/m<sup>3</sup> (Table 8). Generally higher water use efficiency was associated with lower water application showing moisture stress at different growth stage enhance water productivity.

Numerous studies pointed out to the importance of water use efficiency (WUE) of crop and most of them on a tuber yield basis, but few on a photosynthesis and biomass basis. Potato requires from 0.35 to 0.8 m<sup>3</sup> of water to produce 1 kg of tuber dry matter. Under field conditions, this translates into a water requirement during the growing period of 350 to 650 mm, which is depending up on climate, cultivar, available moisture and growing season duration (Sood and Singh, 2003).

The result of this study is similar to what is repeated by Tolga *et al.* (2006) and they reported that maximum water use efficiency of a potato crop was 7.11 kg/m<sup>3</sup>. Erdem *et al.* (2006) reported that seasonal evapotranspiration of potato, drip irrigated, varied from 473 mm to 524 mm under semiarid conditions. King *et al.*, (2003) revealed that potato is highly sensitive to water stress during the vegetative and flowering stage. Better water use efficiency with significantly reducing the tuber yield was obtained due to treatments in which moisture stress happen the combination of both at initial and late season growth stage and treatment in which moisture stress happen only at late season stage.

Table 8: Component of water requirement and water productivity for treatments subject to moisture stress

Treatment	Tuber yield (kg/ha)	Amount of total irrigation(mm)	Water use efficiency (kg/m <sup>3</sup> )
T <sub>1</sub>	29185	504.2	5.80
T <sub>2</sub>	26148	459.8	5.86
T <sub>3</sub>	14963	379.9	3.93
T <sub>4</sub>	12000	283.2	4.23
T <sub>5</sub>	28370	389.7	7.26
T <sub>6</sub>	10222	238.8	4.30
T <sub>7</sub>	20815	345.3	6.03

#### 4.6 Effect of moisture stress on water productivity

As shown in Figure 5, below the lowest yield reductions were observed when moisture stress was occurred at the late season stage (815 Kg ha<sup>-1</sup>) and initial stages (3037 Kg ha<sup>-1</sup>), respectively. However, the yield reduction can be compensated by using the saved water to irrigate additional area. Here, it is observed that 529 and 1283 cubic meter of water per ha could be saved by, stressing during initial and last season growing stage of the potato crop growing season, respectively. And, using this saved water, an extra tuber yield of potato could be obtained by irrigating more irrigable area. The other irrigation regimes could not be economical from economic standpoint of water as the yield reduction from the optimum application is high, and the water saved could not compensate the yield reduction. Therefore it is better to apply the

stress at the initial and late season stages to save more water and to irrigate more areas under a limited water condition with minimum yield reduction compared to the full water application one.

In most situations, adopting measures to improve soil moisture availability and raise the capacity of crops to capture water are the lowest-cost and quickest ways to raise water productivity. In addition, overall water productivity can be raised by improved methods to reduce harvest and post-harvest losses, which may add up to 30–40 percent of the yield originally produced at the farm (Lundqvist, 2008).

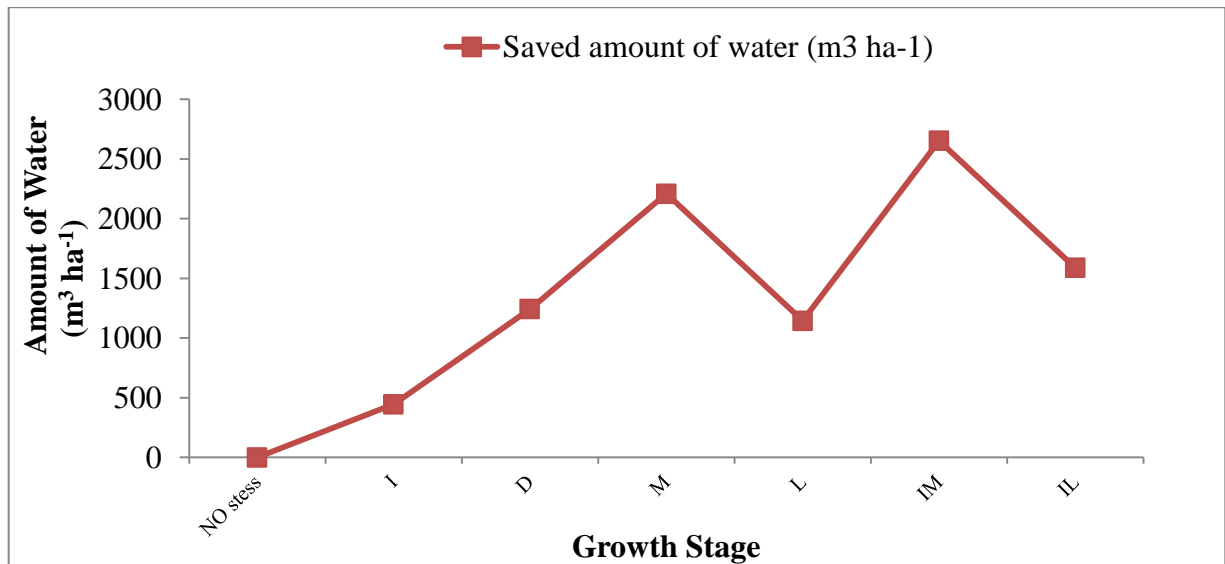


Figure 5: Amount of Water saved by stressing the crop at different growth stage

#### 4.7 Relative Yield Response Factor

The average crop yield response factor of each treatment is shown in (figure6). The reference relative yield decrease is expected to be 10% less than reference relative evapotranspiration deficit in potato tuber (Doorenbos and Kassam, 1979). But this study result T3, T4, and T6 showed higher relative yield response factor  $K_y$  than reference  $K_y$ . This is because very severe stress at some growth stages may alter yield production of potato tuber through reduction of plant growth significantly. T5 (no irrigation application at late season growth stage) shows the lowest  $k_y$  (0.12), which means no irrigation application at late season growth stage causes lowest

yield reduction while no irrigation application at development stage (T3) gave highest  $K_y$  (1.98) which means it showed relatively higher yield reduction than relative evapotranspiration.

The present study in line with Kobossi and Kaveh (2010) who suggested that  $K_y$  values are smaller at vegetative and ripening periods comparing with the yield formation period, which is relatively large. Potato is very sensitive to water stress particularly in the stage of tuber formation the study lined with Hassan et al. (2002) who reported that, potato is more sensitive to water stress at the stolonization and tuberization stages than the bulking and tuber enlargement stages.

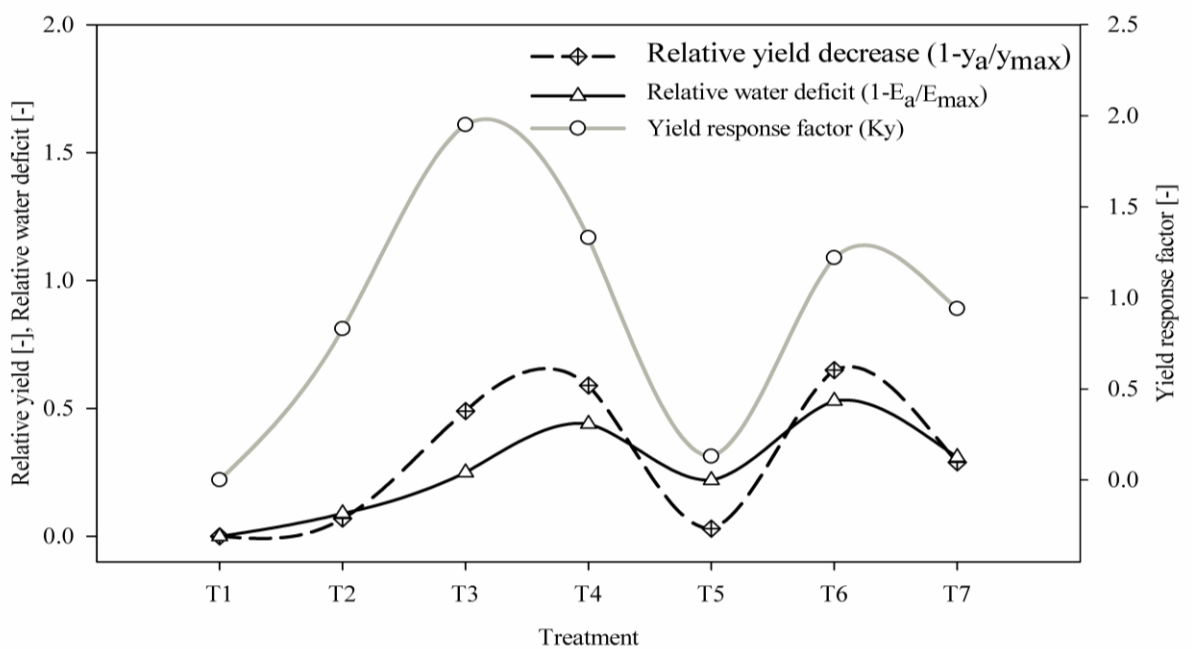


Figure 6: average yield response factor of potato tuber yield

$Y_a$ =actual yield of the treatment,  $Y_m$ =maximum yield from treatments,  $ET_a$ =the actual crop evapotranspiration of the treatment and  $ET_m$ = the maximum evapotranspiration from the treatments.

## 5. SUMMARY, CONCLUSION AND RECOMMENDATON

### 5.1 Summery and Conclusion

Uneven distribution and unreliable rain fall is one of the main causes for yield reduction of the potato crop in Ethiopia including central rift valley. Not only this but also the portion of fresh water currently available for agriculture is decreasing. So limited irrigation is an efficient strategy for sustainable crop production in this area hence, practicing of such irrigation requires precise knowledge about sensitive stages and response of crops to water stress at different growth stages. Therefore, this research was undertaken to observe crop growth stages sensitive to soil moisture stress, determine the critical time for irrigation application for a limited water resources and evaluate the effect of low soil moisture stress on crop productivity.

In view of this, an experiment was conducted during the 2017/2018 off-season at Wondo Genet, just 25 km south-west of Hawassa city and 300 km from Addis Ababa in the Central Rift Valley of Ethiopia. The experiment used the potato variety was *Gudene*. The treatments used in the study were two water regimes that were 0 and 100 ET<sub>c</sub> at different growth stages. The treatments were arranged in a randomized complete block design and each treatment was replicated three times.

The result showed that soil moisture stress at different growth stages of potato had significant effect on potato growth components like plant height, and number of branch per plant and on potato yield and yield components like tuber number per plant, tuber fresh weight per plant, marketable and unmarketable tuber yield, and total tuber yield and water use efficiency were also significantly affected by soil moisture stress at different growth stages of potato. The maximum plant height were recorded from T1 and T5, which were irrigated at all stage and irrigated at three consecutive growth stages (at initial, development and midseason stage) whereas the shortest was recorded from plants that were under soil moisture stress at development stages (T3).

The maximum tuber yield, number of tuber and tuber fresh weight was recorded from control treatment (T1) whereas the lowest was from T6 (grown under soil moisture stress at initial and midseason stages). Plants grown at soil moisture stress condition only at initial growth stages showed little yield reduction than the control treatment. Plants grown under soil moisture stress

condition at all growth stages except at developmental and midseason growth stage provided higher yield than plants grown under soil moisture stress condition only at developmental and midseason stage (T4). Applying irrigation water only at developmental and midseason stage provided higher tuber yield than applying irrigation water at initial and late season stages.

The maximum tuber yield was recorded from T1 while, the lowest was from T3 and T6 (grown under soil moisture stress at development and initial and midseason growth stages respectively). Missing irrigation at developmental and midseason growth stage reduced tuber yield significantly. Plants under soil moisture stress at late season growth stage were used the water in highest efficiency whereas plants grown under soil moisture stress at development stages utilized water in least efficient way. The highest yield response factor was recorded from plants grown under soil moisture stress condition only at development growth stage (T3) whereas the least was from plants grown under moisture condition only at late season growth stage (T5).

It can be concluded that the most sensitive stage of *Gudene* variety of potato to soil moisture stress is the developmental and midseason growth stage. Pre plant irrigations alone do not produce optimum yield. If irrigation is missed during development and midseason growth stage later irrigations was not increase yield substantially. If two in season irrigations are possible, developmental and midseason stage will produce the greatest yields. If three in season irrigations are possible, initial, developmental and midseason produce greater yields than developmental, midseason and late season stage. Irrigations at the late season stage failed to substantially increase yields. Four irrigations in addition to the pre plant watering produced the highest yields.

## **5.2 Recommendation**

From the study irrigate the crop at initial, development and mid season growth stages were gave more tuber yield than irrigating the crop at development, midseason and late season growth stages. However, this experiment was conducted at a given site (farm land) in one season. Therefore, conducting the same experiment for one more season, and initiating similar experiments at different environmental conditions and variety is recommended to develop reliable limited irrigation practice based on sensitive crop growth stages for the given potato crop.

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## 7. APPENDIXES

Appendix Table 1: long term meteorological data of the study area (2007 – 2017)

Month	Min Temp. °C	Max Temp. °C	RF mm	WRU m/s	RH %	Sun Shine (hours)
Jan	11.8	28.9	30.50	0.71	50.12	9.4
Feb	12.9	30.0	32.97	0.92	48.66	9.1
Mar	13.7	30.6	79.18	0.72	49.55	8.5
Apr	14.6	29.1	112.13	0.65	60.96	7.2
May	15.0	27.4	129.14	0.70	68.77	7.1
Jun	14.8	26.3	105.03	0.83	67.89	6.8
Jul	15.0	25.0	147.57	0.88	71.74	4.9
Aug	14.9	25.1	162.50	0.66	71.62	5.6
Sep	14.6	25.7	126.92	0.63	72.33	5.6
Oct	13.3	27.3	81.04	0.56	62.84	7.4
Nov	11.9	28.1	60.06	0.62	54.97	8.8
Dec	10.7	27.9	19.60	0.65	50.90	9.6

Appendix Table 2: ANOVA for plant height, Branch number, Tuber number, Tuber length and Tuber diameter under moisture stress condition

Source	Degree of freedom	Pht (cm)	Branch No	Tuber No	Tuber length	Tuber diameter
Treatment	6	798.586***	12.2063***	30.5238***	14.1509***	5.2538***
Replication	2	4.094762ns	0.0476 ns	0.42857ns	0.470476ns	0.1200ns
Error	12	30.4242	0.3254	0.26190	0.0688	0.1100
Total	20	833.1053	12.5783	31.21429	14.69024	5.48381

Ns, \*\*\* = none significant and highly significant at 5% probability levels, respectively

Appendix Table 3: ANOVA for Tuber fresh, Marketable yield and Unmarketable yield under moisture stress condition

Source	Degree of freedom	Tuber fresh weight (t/ha)	Marketable yield (t/ha)	Unmarketable yield (t/ha)
Treatment	6	34.8252***	285.78555***	10.673015***
Replication	2	0.0614286	0.241429	0.0300
Error	12	0.496428	0.226984	0.0194
Total	20	35.38306	286.2539	10.7224

Ns, \*\*\* = none significant and highly significant at 5% and 1% probability levels, respectively

Appendix Table 4: ANOVA for Total yield and WUE under moisture stress condition

Source	Degree of freedom	Total yield (t/ha)	WUE (kg/m <sup>3</sup> )
Treatment	6	188.83714 ***	2.88301***
Replication	2	0.209048	0.01433
Error	12	0.224048	0.00976
Total	20	189.270239	2.9071

Ns, \*\*\* = none significant and highly significant at 5% and 1% probability levels, respectively

Appendix Table 5: Irrigation schedule under different moisture stress, application time and Discharge (l/s) for Parshall flumes of 3inche throat width

<b>Date</b>	<b>Day</b>	<b>Growth Stage</b>	<b>Rain (mm)</b>	<b>Net Irr (mm)</b>	<b>Gr. Irr (mm)</b>	<b>Flow (l/s)</b>	<b>Area (m<sup>2</sup>)</b>	<b>Appli. Time (Min)</b>
24-Mar	6	Init	0.0	13.4	22.3	1.7	9	2
30-Mar	12	Init	0.0	13.3	22.1	1.7	9	2
5-Apr	18	Dev	0.0	14.3	23.8	1.7	9	2
11-Apr	24	Dev	0.0	15.6	25.9	1.7	9	2
17-Apr	30	Dev	0.0	21	34.9	1.7	9	3
23-Apr	36	Dev	0.0	23.8	39.7	1.7	9	4
29-Apr	42	Mid	0.0	26.7	44.5	1.7	9	4
5-May	48	Mid	0.0	26.9	44.8	1.7	9	4
11-May	54	Mid	0.0	26.8	44.7	1.7	9	4
17-May	60	Mid	0.0	26.4	43.9	1.7	9	4
23-May	66	Mid	0.0	25.9	43.1	1.7	9	4
29-May	72	End	0.0	25.4	42.3	1.7	9	4
4-Jun	78	End	0.0	22.4	37.3	1.7	9	3
10-Jun	84	End	0.0	20.9	34.9	1.7	9	3
16-Jun	End	End	0.0					

Appendix Table 6: Mean tuber yield, irrigation water needed, and saved water amount for each moisture stress of water for potato

Treatments	Tuber yield (Kgha <sup>-1</sup> )	Amount of irrigation water applied (m <sup>3</sup> ha <sup>-1</sup> )	Saved amount of water (m <sup>3</sup> ha <sup>-1</sup> )	Yield reduction(Kg ha <sup>-1</sup> )	Yield reduction (%)
1	29185 <sup>a</sup>	5042.0	0	0	0
2	27037 <sup>b</sup>	4598.0	444.0	2148	7
3	14963 <sup>d</sup>	3799.0	1243	14222	49
4	12000 <sup>e</sup>	2832.0	2210	17185	59
5	28370 <sup>a</sup>	3897.0	1145	815	3
6	10222 <sup>f</sup>	2388.0	2654	18963	65
7	20815 <sup>c</sup>	3453.0	1589	8370	29
CV	2.41				
LSD <sub>(0.05)</sub>	874.11				

**Appendix Table 7:** Discharge (l/s) for Parshall flumes of 7.5 cm (3inche) throat width

Head (cm)	Q (l/s)
3	0.77
4	1.2
5	1.7
6	2.2
7	2.9
8	3.5
9	4.2
10	5
11	5.7
12	6.6
13	7.5
14	8.4
15	9.4
16	10.3
17	11.4
18	12.4
19	13.5
20	14.6
21	15.8
22	16.9
23	18
24	19.4

Source: Kandiah (1981)

## Figure in the Appendix

Appendix Figure 1: The experimental area was shaded with plastics to minimized rainfall risk on the crop



Appendix Figure 2: The field water supply canal was covered by plastics to reduced deep percolation



Appendix Figure 3: a. At Initial growth stage of potato crop, b. At development growth stage of potato crop



Appendix Figure 4: a. Measuring tuber length and, b. Measuring tuber diameter by caliper

