# THE IMPACT OF ALTERNATE FURROW IRRIGATION ON WATER PRODUCTIVITY AND YIELD OF POTATO AT SMALL SCALE IRRIGATION, EJERE WEREDA, WEST SHOA, ETHIOPIA

**MSc THESIS**

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# The Impact of Alternate Furrow Irrigation on Water Productivity and Yield of Potato at Small Scale Irrigation, Ejere Wereda, West Shoa, Ethiopia

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## Post Graduate Program Directorate (PGPD)

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We hereby certify that we have read and evaluated this Thesis entitled ‘The Impact of Alternate Furrow Irrigation on Water Productivity and Yield of Potato at Small Scale Irrigation, Ejere Wereda, West Shoa, Ethiopia prepared, under our guidance, by Adisu Tadese Eba. We recommend that it be submitted as fulfilling the thesis requirement.

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As members of examining Board of the Final MSc Open Defense Examination, We certify that we have read and evaluated the thesis prepared by Adisu Tadese Eba and examined the candidate. We recommended that the Thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Irrigation Engineering.

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# DEDICATION

I dedicate this thesis manuscript to Tolasa Tadese, Ijigayehu Tadese and Chaltu Tashome.

# STATEMENT OF THE AUTHOR

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# BIOGRAPHICAL SKETCH

The author was born in Sibu Sire district, East Wollega zone in 1989. He attended elementary school at Sire Elementary School, East Wollega Zone. He completed his high school and preparatory study at Sire Secondary and Preparatory School in 2007. He joined Haramaya University, by then in 2008 to study for his B.Sc. degree and graduated with B.Sc. degree in Soil and Water engineering in 2011. Upon graduation, he was employed by Oromia Agricultural Research Institute to work at Bako Agricultural Research Center as soil and water conservation junior researcher. In September 2015, he joined the School of Graduate Studies at Haramya University to peruse his M.Sc. studies in Irrigation Engineering.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AE | Application Efficiency |
| AFI | Alternate Furrow Irrigation |
| ANOVA | Analysis of Variance |
| Bd | Bulk density |
| BRC | Cost Benefit Ratio |
| CEC | Cation Exchange Capacity |
| CFI | Conventional Furrow Irrigation |
| CU | Coefficient of Uniformity |
| CWP | Crop Water Productivity |
| CWU | Consumptive Water Use |
| DU | Distribution Uniformity |
| EC | Exchangeable Cations |
| EFI | Every Furrow Irrigation |
| EOFI | Every-Other Furrow Irrigation |
| ERZ | Effective Root Zone |
| ET | Evapotranspiration |
| $ET_O$ | Reference Evapotranspiration |
| FAO | Food and Agriculture Organization |
| FP | Farmer Practice |
| LSD | Least Significant Difference |
| MoWR | Ministry of Water Resources |
| NR | Net Return |
| OC, | Organic Carbon |
| PRD | Partial root-zone Drying |
| RCBD | Randomized Complete Block Design |
| USDA | United State Department of Agriculture |
| WP | Water Productivity |
| WUE | Water Use Efficiency |

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# The Impact of Alternate Furrow Irrigation on Water Productivity and Yield of Potato at Small Scale Irrigation, Ejere Wereda, West Shoa, Ethiopia

## ABSTRACT

*As a result of water resource shortage and the need for food self-sufficiency in Ethiopia, it has become essential to improve the productivity. In this study, an attempt was made to evaluate the impact of alternate furrow irrigation technique on yield and water productivity. Alternate furrow irrigation versus every furrow, fixed furrow and farmer practice (open-ended and unstructured furrow) were evaluated at full crop water requirement. The experimental design used was randomized complete block design with four treatment replicated five times. Results obtained revealed that average water application efficiency of alternate furrow irrigation was 85% which was high as compared to other irrigation methods at all irrigation events. Average application efficiencies of ever furrow irrigation, fixed furrow irrigation and farmer practice were 61.5%, 73.4% and 42% respectively. The average distribution uniformity of alternate furrow irrigation and every furrow irrigation methods were 89.3% and 85.3% respectively, which showed no significant difference between the two methods. However, average distribution uniformity of fixed furrow irrigation was 75.4%, which showed significant difference between alternate furrow and fixed furrow irrigation methods. Farmer practice showed poor water distribution uniformity of 63.8%. Alternate furrow irrigation method produced total tuber yield of 33198kg/ha which showed insignificant difference as compared with that obtained under every furrow irrigation ( 33369kg/ha). Total tuber yield harvested from fixed furrow irrigation and farmer practice were 30177kg/ha and 30098kg/ha respectively, which showed insignificant difference between the two methods. High marketable yield of 32667.8kg/ha was recorded from alternate furrow irrigation whereas, low marketable yield of 28266.7kg/ha was recorded from farmer practice. Water productivity of* $11.2 kg/m^3$*,*$10.7 kg/m^3$*,*$6.1 kg/m^3$ *and* $4.1 kg/m^3$ *were produced under alternate furrow, fixed furrow, and every furrow and farmer practice respectively. It was found that alternate furrow irrigation method saved 50% of water as compared with every furrow and 68.4% as compared with farmer practice. Therefore, it is recommended alternate furrow irrigation method with appropriate irrigation interval is suitable irrigation method; for humid climate where soil is dominated by clay soil and water is liming factor for potato crop production.*

# 1. INTRODUCTION

In almost all regions of the world, water supply is the main constraint to crop production due to water demand for rapid industrialization and high population growth. Water is increasingly recognized as a major component in economic development and poverty reduction. According to Rockstrom *et al.* (2009), holding the current rates of agricultural water use efficiency constant, an estimated additional amount of 5700 $km^3$ of fresh water will be required annually to meet the estimated food demand in 2050. The increasing competition on freshwater resources brought about by ever rising demand of water is of fundamental concern (FAO, 2008). Agriculture is the largest freshwater user on the planet, consuming more than two thirds of total withdrawals (Gan *et al*., 2013). Irrigation is an artificial application of water to soil for the purpose of supplying the moisture essential in plant root zone to prevent stress that may cause reduced yield or poor quality of crop at harvest. In Ethiopia, traditional irrigation schemes constitute large portion of the total irrigated land area.

Surface irrigation is the most common executed irrigation system in Ethiopia as well as Western Oromia. This wide spread implementation might be due to its low capital cost, no special technical experience regarding operation and maintenance and no specific equipment are required as a result of long practical background among local farmers regarding the implementation of this irrigation system. Furrow irrigation is most widely used among the surface irrigation methods. In this system water is applied by means of small channels or furrows, which follow a uniform longitudinal slope. Furrow irrigation has low application efficiency because of its high water loss due to surface runoff, evaporation from water in the furrow, evaporation from the soil surface and percolation below root zone. Alternate furrow irrigation (AFI) is a system of irrigating only one side of the plant, i.e., half of the root system, is irrigated at first irrigation event, while the other side receives water on the next irrigation.

Production of potato (*Solanum tuberosum L.*) takes a very important place in the world agriculture, with a production potential of about 381 million tons harvested and 19.3 million hectare planted area (FAO, 2014). In Ethiopia, potato is grown in four major areas: the central, the eastern, the northwestern and the southern. In the central area, potato production includes the highland areas surrounding the capital, i.e. Addis Abeba, within a 100–150 km radius.

In this area potato growing zones are West Shewa and North Shewa. About 10% of the potato farmers are located in this area (CSA, 2008/2009). Early studies have shown that water is the most important limiting factor for potato production and it is possible to increase production level by well-scheduled irrigation programs throughout the growing season (Yuldashev *et al*., 2014).

Almost all of the irrigation schemes of west Shoa zone, the western part of Ethiopia, are small scale and traditional. Farmers seem to have awareness about the benefits of irrigation and proven ability to organize themselves to manage small scale irrigation systems. However, it lacks scientific management; they either over or under irrigate their fields. At present situation water is a scarce resource due to use of water for different purposes. However, attention given to agricultural water management by the irrigators as well as the irrigation experts is very low. Therefore, efforts should be put in a place to develop water saving mechanisms which can minimize water lost during application of irrigation water (Haileslassie *et al*., 2016). If the amount of water lost due to poor water application method can be saved, irrigation command area of the scheme can be increased and accommodate the increased number of farmers. Saving unproductive losses creates opportunity for optimized use of a limited supply of irrigation water. Improved irrigation scheduling and water application methods are among the means of cutting losses and increasing efficiency.

The farmers of Ejere wereda West Shoa Zone are using surface irrigation system in which water is applied to the field without determining amount water required for the crop they are growing on that field and using indigenous knowledge for irrigation schedule. In this method water is applied to the field in excess amount and huge amount of water is lost in the form of surface runoff. On the other hand many farmers are left without irrigation water to produce crops during dry season due to shortage of irrigation water resulted from mismanagement of irrigation water by other farmers (Haileslassie *et al*., 2016). Potato crop one of the major crops farmers are producing under irrigation for home consumption and market in western Ethiopia particularly western Shoa. However, water resource is becoming scarce and limiting crop production during dry season in this area, whereas the number of farmers involved in crop production under irrigation is increasing from time to time.

Nevertheless, no study was conducted in this area to improve water productivity and water use efficiency of potato under surface irrigation system. Alternating furrow irrigation practice is one of the possible irrigation water management techniques that may help farmers to apply limited amount of water to their crops in time and amount vital for optimum crop water productivity.

In order to allocate the scarce water resources among competing users, identifying irrigation method which maximizes crop water productivity using available water is an obligatory work. The competition for freshwater often implies that, water for irrigation is not always available in the required quantity. Therefore, farmers often have to manage irrigation under moderate or severe water shortage. This experiment is, therefore proposed and executed with the hypothesis that irrigating alternate furrows, i.e., partial wetting of the root system alternatively could save water thereby increasing water productivity (WP) without causing a substantial drop in the yield of potato crop.

As a general objective; this research was planned and implemented to study the impact of alternate furrow irrigation (AFI) on potato yield and water productivity so as to get additional land and sustainable crop and water productivity. Therefore, this study specifically aims at (i) to evaluate the effects of different water application methods on yield and water productivity on farmers' field. (ii) To quantify the amount of water saved under each water application methods.

# 2. LITERATURE REVIEW

## 2.1. Importance of Irrigation in Agriculture

The World irrigated agriculture extends over 270 million hectares (Morison *et al.,* 2008). Although it represents only 17% of the world cultivated area, it provides 40% to 45% of the world food and fiber supply (Evans and Sadler, 2008). Nevertheless, irrigated agriculture is the major consumer of available fresh water worldwide and its consumption is estimated at ≈70% of the existing freshwater supplies. In addition, water for irrigation is becoming both scarce and expensive and necessitates to be utilized in a scientific manner. Early studies have shown that water is a very important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing period ( Hsiao *et al.,* 2007).

The competing uses of water for (domestic, industrial, and environmental) and the increasing demand for food due to a rapidly growing world population require an urgent improvement of productivity per unit of water consumed in agriculture. Irrigation is one means by which agricultural production can be increased to meet the growing demands in Ethiopia. In Ethiopia, under the prevalent rain fed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands coupled with climate variability have aggravated the incidence of poverty and food insecurity. Water resources management for agriculture includes both support for sustainable production in rain-fed agriculture and irrigation (Awulachew *et al*., 2008).

Currently, about 3% to 5% of the irrigable land is irrigated in Ethiopia while the irrigation potential has been estimated to be about 4.3 million hectares of arable land (Awulachew *et al*. 2007). Irrigated agriculture is becoming increasingly important in meeting the demands of food security, employment, rural transformation and poverty reduction. For Ethiopia, increasing agricultural productivity, enabling households to generate more income, increasing their resilience as well as transforming their livelihoods stands out as the most pressing agenda now and for the coming decades.

Small scale irrigation is a policy priority in Ethiopia for rural poverty alleviation, climate change adaptation and growth. Small scale irrigation in the Ethiopian context refers to smallholder farms with the size of scheme amounting to less than 200 ha (MOWR, 2007).

Modern irrigation is started in the early 1950's by the bilateral agreement between the government of Ethiopia and the Dutch company jointly known as HVA-Ethiopia sugar cane plantation (MOA, 2011a). Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources, while ground water uses has just been started on a pilot basis in the East Amhara region (MOA, 2011a). Surface irrigation methods predominantly furrow irrigation and basin irrigation methods were practiced for productions of fruit crops and some commercial crops. Irrigation in Ethiopia is considered as a basic strategy to alleviate poverty and hence food security. It is useful to transform the rain-fed agricultural system which depends on rainfall into the combined rain-fed and irrigation agricultural system. This is believed to be the most prominent way of sustainable development in the country. Ethiopia is one of the few African countries endowed with relatively abundant water resources, favorable climate and potentially huge irrigable land. According to the database developed by (Awulachew, 2007), the total estimated area of irrigated agriculture in the country is 107,265.65 hectares out of which 20,038.39 hectares are from small-scale, 30,291.26 hectares is from medium-scale and 56,936 hectares is from large scale.

Irrigation contributes to the national economy in several ways. Irrigation leads to an increase in yield per hectare and subsequent increases in income, consumption and food security. Irrigation enables smallholders to diversify cropping patterns, and to switch from low-value subsistence production to high-value market-oriented production. Irrigation can benefit the poor people specifically through higher production, higher yields, lower risks of crop failure, and higher and all year round farm and non-farm employment (Samson *et al*., 2010)

## 2.2. Furrow Irrigation

The most commonly used and most ancient type is surface irrigation methods (FAO, 2002) through using gravity forces. Furrow irrigation system is the most popular surface irrigation, as it requires a smaller initial investment compared to pressured irrigation systems like sprinkler and drip irrigation systems. For furrow irrigation systems, the important hydraulic variables are inflow rate, length of water run over the field, time of irrigation water cut-off, surface resistance of water flow, field slope and the infiltration characteristics of the soil. The combination of these variables may result in non-uniformity from varying intake opportunity time and infiltration rate throughout the irrigated field. Furrow irrigation method is the most widely used in Ethiopia in almost all large and small irrigation schemes. In Ethiopia, surface irrigation methods predominantly furrow irrigation and basin irrigation methods were practiced for crop production in Ethiopia (Michael *et al.,* 2007).

Furrow irrigation, reported to be one of the least efficient methods compared with other irrigation methods (Burt *et a*l., 1997) is still one of the most widely used forms of surface irrigation. Despite its application efficiency remaining relatively low (Ampas and Baltas, 2009) not enough effort is being made to keep improving its management and efficiency. Because furrow irrigation is a well-known, simple and economical method of irrigation, farmers are likely to be ready to adopt new approaches that are practical improvements of their current practices and that result in improved water productivity.

Furrow irrigation is considered as one of the main types of surface irrigation method. A furrow irrigation system consists of furrows and ridges. The water is applied by means of small channels or furrows, which follow a uniform longitudinal slope. The method is best suited to row crops such as maize, potatoes, onions, tomatoes, etc. The principal advantage of furrow irrigation is the less irrigated area comparing with the other surface irrigation methods, especially basin irrigation which irrigates total cultivated area. Furrow irrigation method is the irrigation method which has the lowest application efficiency among irrigation methods as a result of water losses in the form of runoff, evaporation from water in the furrow, evaporation from the soil surface, and percolation below the root zone. Losses due to runoff can be significant if tail water is not recovered and reused.

When furrows are too long, deep percolation can occur at the upstream end of the furrow by the time the downstream end is adequately watered. Most surface irrigation systems have inherent inefficiencies due to deep percolation on the upper end and runoff at the lower end of the field. In a study conducted by (Kassa and Fekadu, 2003) at Melka Werer, Middle Aish Valley, with a furrow length of 200m and different water inflow rates, the maximum attainable application efficiency of furrow irrigation is 62 to 64%.

## 2.3. Advantage of Furrow Irrigation over Other Surface Irrigation Methods

Furrow irrigation method is best suited to deep, moderately permeable soils with uniform relatively flat slopes and for crops that are cultivated in rows (vegetables, maize, cotton and potatoes, etc). Furrows are particularly well adapted to irrigating crops, which are susceptible to fungal root rot since water ponding and contact with plant parts can be avoided (Michael, 1997). Furrow irrigation may be adapted on a wide range of natural slopes without causing erosion by designing the furrows across the slope rather than down the slope. The method reduces labor requirements in the land preparation and irrigation. Compared to check basin method, there is no wastage of land in field ditches. Most crops can be irrigated by furrow method except those grown in ponded water such as rice. The furrow method is particularly suitable for irrigating crops subject to injury if water covers the crown or stem of the plants, as the crops may be planted on beds between furrows (Michael, 1997).

Moderate to high application efficiency can be obtained if good water management practices are followed and the land is properly prepared. Many different kinds of crops can be grown in sequence without major changes in design layout or operating procedures. The initial capital investment is relatively low on lands not requiring extensive land forming as the furrow are constructed by common farm implements. Soils, which form surface crusts when flooded, can readily be irrigated, because water moves laterally under the surface. This irrigation method is best suited to medium and moderately fine textured soils with relatively high available water holding capacity and hydraulic conductivity, which allow significant water movement in both the horizontal and vertical directions. The method is also suited to fine textured soils on level sites, where it permits water impoundment (Jensen, 1983).

Using furrows for irrigation necessitates the wetting of only part of the surface (20 % to 50%), thus reducing evaporation losses, lessening the puddling of heavy soils, and making it possible to cultivate the soil sooner after irrigation.

Nearly all row crops are irrigated using furrow method rather than flooding. Furrow irrigation is advantageous when the available irrigation streams are small, and for land of uneven topography. Furrow irrigation is adaptable to a great variation in slope (Jensen, 1983).

Furrow irrigation avoids flooding the entire field surface by channeling the flow along the primary direction of the field using furrows, creases, or corrugations. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir. Furrows are often employed in basins and borders to reduce the effects of topographical variation and crusting. The distinctive feature of furrow irrigation is that the flow into each furrow is independently set and controlled as opposed to furrowed borders and basins where the flow is set and controlled on a border-by-border or basin-by-basin basis (Walker, 1989). Furrows provide better on-farm water management flexibility under many surface irrigation conditions. The discharge per unit width of the field is substantially reduced and topographical variations can be more severe. Furrows provide the irrigator more opportunity to manage irrigations towards higher efficiencies as field conditions change during each irrigation time throughout the growing season (Walker, 1989).

## 2.4. Alternate Furrow Irrigation (AFI)

Alternate furrow irrigation (AFI) meant one of the two neighboring furrows alternatively irrigated during consecutive watering. It offers opportunity for reducing size of irrigation and permits irrigating the field in a shorter time with a given water supply. The reduced size of irrigation may not reduce yields appreciably and thus increase irrigation- water use efficiency. Besides this, alternate furrow irrigation (AFI) system is adopted where salt is a problem. This system save quite a good amount of water and is very useful and crucial in areas of water scarcity and salt problems. Alternate furrow irrigation system may supply water in a manner that greatly reduces the amount of surface wetted leading to less evapotranspiration and less deep percolation (Hsiao *et al*., 2007). Deep percolation can be reduced because the lower wetted surface with alternate furrow results in lower infiltration.

It has been suggested that the reduced evapotranspiration in the alternate furrow irrigation method is due to a reduction wet soil surface and continuous regulation on stomatal opening by plant hormone (ABA) Absisic Acid (ABA) produced in roots in drying soil and transported by water to shoot (Farre and Faci, 2009). According to (Luis, 2012), alternate furrow irrigation method uses less irrigation water but can maintain the same grain yield production as that of conventional furrow irrigation.

Alternate furrow irrigation (AFI) or Partial root-zone drying (PRD) is a modified form of deficit irrigation (DI) which involves irrigating only one part of the root zone in each irrigation event, leaving another part to dry to certain soil water content before rewetting by shifting irrigation to the dry side. Therefore, alternate furrow irrigation is a novel irrigation technique that half of the root is placed in drying soil and the other half is growing in irrigated soil (Ahmadi *et al*., 2010a). Absisic Acid (ABA) is a plant hormone that is produced in the roots in drying soils and is transported by water flow in xylem to the shoot for regulating the shoot physiology. Therefore, in alternate furrow irrigation, roots sense the soil drying and induce ABA that reduce leaf expansion and stomatal conductance and simultaneously the roots in wet soil absorb sufficient water to maintain a high water status in the shoot. Roots in drying soil produce more ABA than under normal conditions and it is moved as an anti- stress root chemical signal to shoot through transpiration stream and limits the stomatal conductance (Kang and Zhang, 2004).

The studies of (Du *et al*., 2010) have been suggested efficiency of conventional furrow irrigation (CFI) or every furrow irrigation method can be improved by converting it to alternate furrow irrigation (AFI). The AFI method is essentially the same as CFI, except that instead of irrigating every furrow, irrigation is applied to alternate furrows. This means each ridge receives water from only one side, and the side receiving irrigation water could be changed with each irrigation event if the field set up is facilitating this change. Irrigating just one side of the ridge means there is significant potential to save irrigation water compared to CFI. However, there is potential in some cases for a reduction in crop yield (Mashori, 2013). Alternate furrow irrigation (AFI) is considered to be one of the most effective tools to minimize irrigation water application and irrigation costs without yield reduction.

The alternate furrow irrigation (AFI) method is a way to save irrigation water, improve irrigation efficiency and increase yield (Shayannejad and Moharreri, 2009). Excessive soil moisture following planting can promote seed piece decay and an erratic emergence.

Early studies have shown that irrigation water saving technique is very important in crop production under irrigation water. Considering the importance of water saving mechanisms in surface irrigation method in the sustainable use of irrigation water, the studies were conducted in different parts of Ethiopi like effect of deficit irrigation on yield and water use efficiency of potato (*Solanum tuberosum L.)* (Mulubrehan and Gebretsadikan, 2016), dearth of irrigation planning for potato production (Kelem, 2013) and effect of drip and surface irrigation on yield and water use efficiency of Onion (*Allium Cepa L.*) (Teferi, 2015) in the Northern parts of the country. Similarly, many studies were conducted in different parts of the county in terms of water saving mechanism in surface irrigation method like effect of irrigation regimes on yield and water use efficiencies of potato (*Solanum tuberosum L.)* (Kassu *et al*., 2017) and yield and water use efficiency of deficit-irrigated maize (Yenesew and Tilahun, 2009) in southeastern and eastern parts the country.

## 2.5. Fixed Furrow Irrigation (FFI)

Deficit irrigation has been used as a water saving method in agricultural production to increase benefit and water use efficiency (Behboudian, 1997). Deficit irrigation, under furrow irrigation, can be induced via different irrigation techniques such as fixed-furrow. Fixed furrow irrigation (FFI) is a way to save water and showed a small improvement over the alternate furrow irrigation (Slatni, 2011). For economic and environmental benefit of using every-other furrow irrigation method is higher than any other irrigation methods, because less water is applied and a greater economic return can be obtained (Nelson, 2011). Fixed furrow irrigation (FFI) means that irrigation is fixed to one of the two neighboring furrows. Irrigating every other furrow (fixed furrow irrigation) means supplying water to one side of each furrow ridge throughout crop growing season. If water has been applied to every furrow, the entire root zone may have been refilled prior to rainfall.

Irrigating fixed furrow and applying less water per irrigation may provide more storage space within the root zone for potential rainfall. Usually, this technique applies water to more area in a given amount of time than does irrigating conventional furrow irrigation. Benefit of irrigating every other furrow is the ability to store rainfall in a recently irrigated soil. Fixed furrow irrigation (FFI) should not be used on steep slopes or on soils with low intake rates. Research indicates that fixed furrow irrigation results in yields comparable to those achieved when every furrow is irrigated. Irrigation water application may be reduced 20 to 30 percent by implementing fixed furrow irrigation (FFI) (Yonts *et al.,* 2007). Fixed furrow irrigation may reduce the volume of water used up to 50 percent and induce a decrease in growth and yield due to the water stress caused by the smaller amount of applied irrigation in same furrow (Masoud, 2012)

## 2.6. Every Furrow Irrigation (EFI)

Conventional furrow irrigation (CFI) means irrigating all furrows during consecutive watering. The significant quantities of irrigation water losses by infiltration and surface runoff (about 40% of total water supply) and decreased the efficiency of agricultural production as well as the reliability of drainage systems. This irrigation system has speed up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, brought to soil fertility losses (Karajeh *et al.,* 2000). Conventional furrow irrigation (CFI) system, where every furrow is irrigated during consecutive watering, is known to be less efficient particularly where there is shortage of irrigation water. It usually causes excessive deep percolation at the upper part of the furrow, insufficient irrigation at the lower part and considerable runoff, resulting in low application efficiencies and distribution uniformities. Therefore, proper furrow irrigation practices have to be devised to minimize water application and irrigation costs and to save water at the same time maintaining higher crop yields.

## 2.7. Crop Water Requirements

Crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop growing in a large field under a non restricting soil condition, soil water and fertility achieving full production potential under given growing environment (Allen *et al.,* 1998). As the primary objective of irrigation scheduling is to supply plants with water when they need it, monitoring plants is the most direct method of determining when to irrigate. The depth of water plants consume is equal to their evapotranspiration, which is used to determine quantity of irrigation water the farmer should apply. According to (Pereira and Shock, 2006), for maximum yields, the crop water requirement (CWR) of potato for a 120 to 150 day crop is 500 to 700 mm, depending on climate.

Water supply and scheduling are important in terms of potato yield quality. Yield of potato under irrigation in the temperate and subtropical climates are 25 to 35 $tha^{-1}$ and 15 to $25tha^{-1}$ respectively if good water management system is applied with proper agronomic practice.
The water utilization of harvested yield for tubers containing 70 to 75 % moisture is 4 to 7 $kgm^{-3}$ (Pereira and Shock, 2006).

## 2.8. Water Productivity

Crop water productivity (CWP) and water use efficiency (WUE) are the key terms in the evaluation of alternate furrow irrigation technique. Water productivity with dimensions of kg $m^{-3}$ is defined as the ratio of the mass of yield (Y) to the volume of water applied (Michael, 2008). Water Productivity is the major yield limiting factor in agricultural system. In the present era of climate change and colossal population pressure, the drought is becoming a critical problem, thus making the water a scarce resource in the world (Hussain *et al.,* 2009). In areas where water is the most limiting resource to production, maximizing water productivity may be more profitable to the farmer than maximizing crop yield. Using alternate furrow irrigation or deficit irrigation system, irrigation water can be saved and becomes available to irrigate more land (Luis, 2012).

It is widely believed that an increase in agricultural water productivity is the key approach to mitigate water shortage and to reduce environmental problems. Maximization of yield per unit of water (WP), and not yield per unit of land (land productivity), is, therefore, a better strategy for limited amount of water is available (Ali *et al*., 2007). So, enhancement of water productivity (WP) in irrigated agriculture is very important (Haileslassie *et al.,* 2016).

In crop production system, WP is used to define the relationship between crops produced and the amount of water involved in crop production, expressed as crop production per unit volume of water. The common unit that is emerging to measure water productivity is kilograms of yield produced per meter cube of water. Yield can be quantified in terms of wet or dry yield, nutritional value or economic return. When dealing with different crops, yield may be transformed into monetary units.

Crop water productivity (CWP) with dimensions of kg/m$^3$ is defined by (Kassam and Smith, 2001) as the ratio of the mass of yield (Y) in kilograms to the volume of water consumed by the crop (ET) in m$^3$. Research results confirmed that deficit irrigation (DI) is successful in increasing water productivity for various crops without causing severe yield reductions. Nevertheless, a certain minimum amount of seasonal moisture must be guaranteed (Geerts *et al.,* 2008). In agriculture, we are interested to produce more with less water because water is a limiting factor in many parts of the world. The pressure on the availability of water is likely to increase significantly as the requirement for food production and domestic animas use in couple with rapidly growing of the population is at increasing rate. Subsequently, improper on-farm irrigation management practices may lead to erosion, poor water distribution, non-uniform crop growth, and water logging all of which decrease the yield per unit of land area and per unit of water applied (Eyasu, 2005). The purpose of increasing efficiency is beyond optimizing yield from the target field it also addresses the issues of equity and environmental sustainability. Excess soil water at planting promotes seed piece decay and delays emergence due to decreased soil temperature.

Potatoes that are over-irrigated during vegetative growth and tuber initiation have a greater potential for developing brown center and hollow heart, and are generally more susceptible to early die problems and also nutrient loss by leaching (Shock *et al.*, 2013).

## 2.9. Evapotranspiration

The term evapotranspiration (ET) is commonly used to describe two processes of water loss from land surface to atmosphere, evaporation and transpiration. Evaporation is the process where liquid water is converted to water vapor (vaporization) and removed from sources such as soil surface, wet vegetation, pavement, water bodies, etc. Transpiration consists of the vaporization of liquid water within a plant and subsequent loss of water as vapor through leaf stomata. Reference evapotranspiration ($ET_o$) is defined as the rate at which readily available soil water is vaporized from specified vegetated surfaces (Allen *et al.*, 2005). A large number of empirical methods have been developed to estimate evapotranspiration from different climatic variables. Methods used for calculation of Evapotranspiration include tanks and Lysimeter experiments, Field experimental plots, Installation of sunken (Colarado) tanks and evapotranspiration equations. Evaporation equations are developed by Lowry-Johnson, Penman, Thornthwaite, and Blaney-Criddle. Evapotranspiration can be also determined by Evaporation index method that is from pan evaporation data as developed by Hargreaves and Christiansen. The Penman_Monteith equation (Monteith, 1965) is generally considered to be able to represent the evapotranspiration from any vegetated surface. Penman equation to determine evaporation from open water, bare soil, and grass based on a combination of an energy balance and an aerodynamic formula, given as:

$$\Delta \mathrm{E} = \frac{[\nabla(\mathrm{R_n} - \mathrm{G})] + (\gamma\lambda \mathrm{E_a})}{(\Delta + \lambda)} \qquad 1$$

where $\lambda E$= evaporative latent heat flux (MJ $m^{-2}$ $d^{-1}$), $\Delta$= slope of the saturated vapor pressure curve [$\delta e_o / \delta T$, where $e_o$ = saturated vapor pressure (kPa) and $T_{mean}$ = daily mean temperature (°C)]; Rn = net radiation flux (MJ $m^{-2}$ $d^{-1}$), $G$ = sensible heat flux into the soil (MJ $m^{-2}d^{-1}$), $\gamma$ = psychrometric constant (kPa $°C^{-1}$), and $E_a$ = vapor transport of flux (mm $d^{-1}$).

Various derivation of the Penman equation included a bulk surface resistance term (Monteith, 1965), and the resulting equation is now called the Penman-Monteith equation, which may be expressed for daily values as:

$$\lambda ET_o = \frac{\nabla(R_n - G) + [86400\frac{\rho_a C_p(e^o{}_s - e_a)}{r_{av}}]}{\nabla + \gamma(\frac{r_s}{r_{av}})} \qquad 2$$

where $\rho_a$ = air density (kg $m^{-3}$), $C_p$ = specific heat of dry air, $e_s^o$ = mean saturated vapor pressure (kPa) computed as the mean $e^o$ at the daily minimum and maximum air temperature (°C), $r_{av}$ = bulk surface aerodynamic resistance for water vapor (s $m^{-1}$), $e_a$ = mean daily ambient vapor pressure (kPa), and $r_s$ = the canopy surface resistance (s $m^{-1}$). An updated equation is recommended by (Allen*,* 1998) with the FAO-56 Penman-Monteith Equation, simplifying equation (2) by utilizing some assumed constant parameters for a clipped grass reference crop.

$$ET_o = \frac{0.408\nabla(R_n - G) + \gamma\frac{900}{T + 273}u_{2(e_s - e_a)}}{\nabla + \gamma(1 + 0.34u_2)} \qquad 3$$

where, $ET_o$ = reference evapotranspiration rate (mm $d^{-1}$), T= mean air temperature (°C), and $u_2$ = wind speed (m $s^{-1}$) at 2 m above the ground. The reference evapotranspiration estimation method is based on climatic data, which can be obtained from a local weather station.

The equation uses standard climatologically records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water (Allen *et al*., 2005).

## 2.10. Response of Potato to Over Irrigation

Potato is one of the root crops having an important role in human and animal nutrition. The natural environment in Ethiopia is very suitable for year round production of potato using rain-fed and irrigated systems.

The main production season for potato in Ethiopia in areas with altitude higher than 2500 m runs from June to September while the off-season slot starts in April and ends in August. The altitude between 1800 and 2200 m is suitable for growing seed and table potatoes in Ethiopia and 70% of the agricultural land is located at that elevation. The favorable climate at higher elevations, fertile soils and availability of irrigation in many areas such as the South-Central Rift Valley provide suitable conditions for potato (Asrat, 2014). The demand for potato food products is increasing from time to time because of significant increase in the numbers of urban consumers willing to diversify their potato consumption pattern including branded and packed fresh potatoes in super markets, chips and crisps (Haverkort *et al.*, 2012). Potato is a horticultural crop which requires good irrigation water management for a normal growth and better yield. Yield is considerably affected by storage quality, disease resistance, and the time, depth and frequency of irrigation. Improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers. Widely fluctuating soil water contents create the greatest opportunity for developing these tubers defect. Growth cracks are also associated with wide fluctuations in soil water availability and corresponding changes in tuber turgidity and volume of internal tissues (Serhat and Abdurrahim, 2010).

The purpose of irrigation management is to maximize potato yield and quality by maintaining soil water content within specified limits throughout the growing season through timely and controlled water application to the crop. The optimal range for water content at planting is about 70 to 80 % available soil moisture. This soil water level will provide ideal conditions for planting and early sprout development (Shock *et al.,* 2013). Excessive wet soil is conducive to many tubers rotting, encouraging the incidence of blights, rots, and wilts that can limit yield, tuber yield, tuber size, dry matter content, and crop marketability at harvest or from storage. Dense canopy growth, long periods of leaf wetness and high relative humidity creates microenvironments that favor infection. Improperly managed irrigation often keeps the vines wet for long periods of time, exacerbating the risk of infection (Shock *et al*., 2013). Too much water prevents oxygen from reaching underground parts of the potato plant resulting in poor root development and rotting of the newly formed tubers. Seed tubers are especially susceptible to tuber rot. Over-irrigation shortly after planting may reduce emergence because of excessive growth of lenticels which allows entrance of parasites.

# 3. MATERIALS AND METHODS

## 3.1. General Description of the Study Area

The experiment was conducted in Giche small scale irrigation of Ejere Wereda during 2016/17 dry season. Giche small scale irrigation is a traditional irrigation system which was developed by farmers' association of Andode kebele. The site is located at (10°01'N and 43°33'E), 8 kms from Ejere town and 55 kms to West of Addis Ababa, in West Shoa Zone of Oromia Regional State. The altitude of the area is about 2400m above mean sea level and the area is prominent with undulated land feature. The area is characterized by uni-modal rainfall pattern, which extends from late June to September. The mean annual rainfall vary from 560 to 1200 mm and mean annual minimum and maximum temperature vary between $6^oC$ to $8^oC$ and $22^oC$ to $25^oC$, respectively. The area is classified as humid climate and it is characterized by land degradation due to runoff from rainfall during rainy season. The soil is well drained, light to dark brown in color, and very shallow to shallow in depth, clay loam to clay in texture and continuously cultivated.

The experiment was carried out at farmer field located in Giche small irrigation of Andode kebele. The total area of Giche small scale irrigation is about 20 ha. The land in this area is mostly dominated by clay soil. Source of water for Giche small scale irrigation is river flows close to the site and diverted by pump to the farmers field. The major crops farmers are producing in this area by irrigation water are mostly horticultural crops like potato, onion and garlic.

Table 1 Mean monthly Climate data at Ejere district (1985-2015)

| Month | Rainfall (mm) | Min Temp °C | Max Temp °C | Relative humidity (%) | Wind speed km/day | Sunshine Hours |
|---|---|---|---|---|---|---|
| January | 50.9 | 3.4 | 23.4 | 51 | 130 | 8.0 |
| February | 49.9 | 5.0 | 23.9 | 50 | 147 | 7.6 |
| March | 51.4 | 6.7 | 24.4 | 51 | 147 | 7.1 |
| April | 56.1 | 7.9 | 23.9 | 56 | 138 | 7.0 |
| May | 55.5 | 6.8 | 24.4 | 56 | 130 | 6.3 |
| June | 66.1 | 7.7 | 22.4 | 66 | 95 | 5.1 |
| July | 77.6 | 9.1 | 20.0 | 78 | 104 | 3.4 |
| August | 80.2 | 9.1 | 19.6 | 80 | 95 | 8.1 |
| September | 73.8 | 7.8 | 20.3 | 74 | 104 | 5.0 |
| October | 57.0 | 4.9 | 21.9 | 57 | 156 | 7.6 |
| November | 51.9 | 2.3 | 22.4 | 52 | 147 | 8.7 |
| December | 51.0 | 1.9 | 22.8 | 51 | 147 | 8.6 |
| Average | 60.1 | 6 | 22.5 | 60.2 | 128.3 | 6.9 |

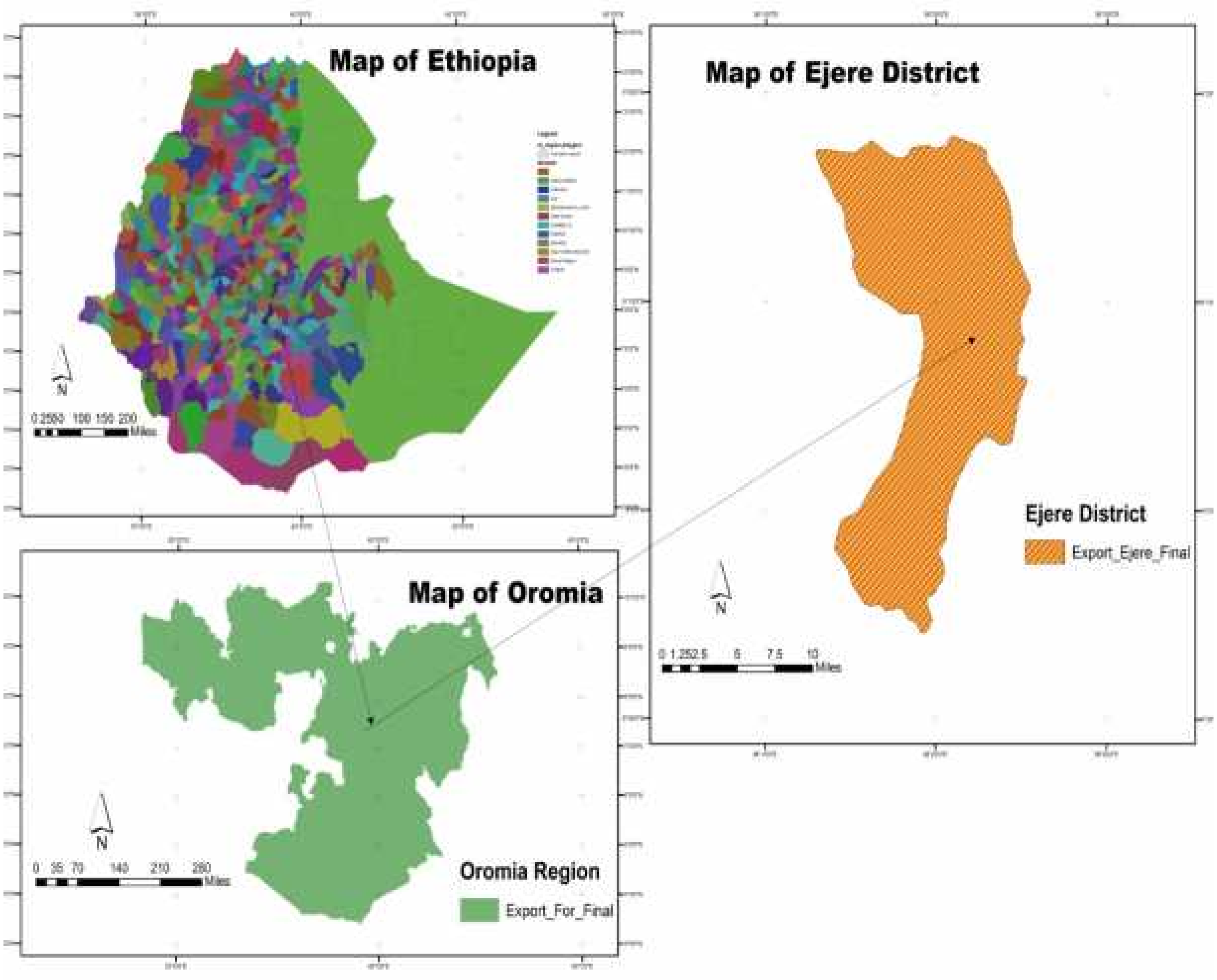

Figure 1 Location map of the study area

## 3.2. Treatments and Experimental Design

The experiment included three irrigation methods: alternate (AFI), every furrow (EFI) and fixed furrow irrigation (FFI) irrigation methods all were block-ended furrow and farmer practice (making furrow with opened). Farmers around the study area are using irrigation water during dry season for crop production especially horticultural crops such as potato, onion and garlic etc. After land was prepared potatoes are planted on the ridge of furrow with open-ended. Every furrow irrigation (EFI) in which water was applied to every furrow, fixed furrow irrigation (FFI) in which water was applied as fixed every-other furrow throughout the growth season, alternate furrow irrigation (AFI) which is similar to fixed furrow irrigation (FFI), but water was applied to the furrow which was dry in the previous irrigation cycle.

Farmer's practice (FP) (Farmer made every furrow irrigation with open-ended furrows) and irrigated with farmer irrigation interval. Farmers are used fixed irrigation interval system. every furrow irrigation method is in which every furrow has been irrigated throughout growing season with determined irrigation interval.

In alternate furrow irrigation (AFI) odd furrows (1, 3, 5 and 7) received water at first irrigation event and even furrows received water at next irrigation (2, 4, 6 and 8) throughout growing season with determined irrigation interval. In fixed furrow irrigation (FFI) water was applied to odd furrows (1,3,5,and 7) throughout the growth season with determined irrigation interval and farmer practice which is similar to every furrow irrigation (EFI) but furrows were made by farmer, not tide at the end and was irrigated with farmers irrigation interval.

Table 2 List of treatments

| Treatment No | Treatment name |
|---|---|
| 1 | Every Furrow Irrigation (EFI) block- ended |
| 2 | Alternate furrow irrigation (AFI) block- ended |
| 3 | Fixed furrow irrigation (FFI) block- ended |
| 4 | Farmer practice (FP) with open-ended furrows |

These treatments were assigned in Randomized Complete Block Design (RCBD) with five replications. The size of each experimental plot was 6 m x 10 m. The experimental field was 27m by 54m and occupied a total area of 1458m$^2$. A spacing of 75cm between rows (furrows) and 30 cm between plants was used based on recommendation provided by Chindi *et al.,* (2016) and Gebremedhin *et al*., (2008). Each experimental plot consists of eight furrows and seven ridges with furrow length of 10 m each. A spacing of 1 m was used between blocks and plots within a block respectively. The net area covered by the experiment was 1200m$^2$ from the total experimental area of 1458m$^2$.

| | | | | |
|---|---|---|---|---|
| REP V | 17FP | 18<br>FFI | 19<br>AFI | 20<br>EFI |
| REP IV | 16<br>FFI | 15<br>FP | 14<br>EFI | 13<br>AFI |
| REP III | 9<br>FP | 10<br>EFI | 11<br>AFI | 12<br>FFI |
| REP II | 8<br>EFI | 7<br>FP | 6<br>FFI | 5<br>AFI |
| REP I | 1<br>EFI | 2<br>AFI | 3<br>FFI | 4<br>FP |

Figure 2 Randomization of treatments with five replications

## 3.3. Site Selection and Agronomic practice

From Giche small scale irrigation one farmers’ field had been selected for the implementation of designed water application methods based on suitability of the land for execution of the treatments. Uniform flat or gentle slope was preferred for furrow irrigation. These should not exceed 0.5%.

In general terms, furrow irrigation should be implemented on land slope less than 0.5%.This is because the flow is confined to a small channel (the furrow), which could result in erosion. The slope of the land selected for the execution of the experiment is 1%. Based on this furrows are made with slope of 0.3%. The experimental field was prepared to create suitable condition for crop growth and furrow irrigation application as per the recommendation of the agronomic requirement of potato crop. Before plowing, the field was irrigated with little irrigation to keep the soil moist but not wet. This ensures a uniformity of moist soil and makes good condition for the preparation of furrows.

Potato (Gudane variety) was planted on 29 November 2016/2017 growing season. One tuber was planted per hole with a plant spacing of 0.30 m. prior to planting all plots were irrigated with similar amount of water to make soil moist for planting (planting irrigation). For this study Gudane improved potato variety was used because of its palatability and high yielding varity around study area. The crop was planted at spacing of 75cm between rows. Inorganic fertilizers of DAP with rate of 150 kg ha$^{-1}$ and urea with rate of 117 kg ha$^{-1}$ (MOARD, 2009), were applied during planting and after planting as split application.

The amount of fertilizers used in this study was applied using band method. Nitrogen fertilizer was applied in two splits. Half of the nitrogen fertilizers and entire phosphorus requirement was applied as basal while the remaining amount was applied at 45 days after planting .All of the other cultural practices used throughout the growing season were similar to those that were practiced by regular farmers.

## 3.4. Crop Characterization

The test crop used in this study was potato (*Solanum tuberosum* L.) crop. Gudane improved variety was used as test crop having growing period of 120 days. Potato tubers were planted by hand in plot sizes of 6 m by 10 m. Hence, there were a total of 8 rows within a plot and 33 potato tubers within a single row. The spacing of 1m between plots within a block and 1m between blocks were used.

The spacing used between within a single row and between rows within a single plot were collected from Holeta Agricultural Research Center, Horticultural crop research team and other references (eg. Chindi *et al*., 2016; Gebremedhin *et al*., 2008). In addition, plant parameters such as rooting depth and stages of growth were taken from Holeta Agricultural Research Center, Horticultural crop research team. The other crop characteristics such as maximum rooting depth, crop coefficient and maximum allowed depletion level and yield response factor were taken from Food and Agriculture Organization (FAO) Irrigation and Drainage paper 66, (FAO, 2012).

According to FAO Irrigation and Drainage paper maximum root depth of 60cm, crop coefficient of 1.15, allowed depletion level value of 0.70 and total yield response factor of 1.10 were used in determination of crop water requirement. The maximum potato yield from farmers experience in the area is up to 30 t/hectares.

## 3.5. Furrow Parameters

The most important factors for furrow irrigation are furrow distance, length and slope, and ridge uniformity. Furrow design is an iterative process that should consider the shape of the furrow, the spacing between furrows and furrow length with other factors such as the stream size to be applied and its application time, the soil type and the slope.

### 3.5.1. Furrow distance

In potato, the distance between irrigation furrows varies from 60 to 90 cm depending on soil texture. In sandy soil, water leaks away rapid and does not reach far; distance between rows should be smaller than in clay soils. In coarse sandy soils the distance between the furrows should preferably be around 60 -65 cm, and in heavier clay soils around 70-80cm (Anton, 1982). The spacing between furrows depends on the water movement in the soil type of soil texture and agronomic requirements. In addition, spacing of furrow depends on the type of equipment used in the construction of furrows (Zamil, 2010). Since the textural class of the soil on the study area is clay, spacing of 0.75m ridges of furrow had been used based on soil texture and agronomic recommendations.

### 3.5.2. Furrow length

Maximum furrow length depends on slope of the furrows, soil type and depth of water in the furrow. Water should not exceed half ridge height to avoid excess moisture in tuber region. Furrow slope should be not exceeding 0.5% to control erosion. Beyond this there is a major risk of soil erosion following a breach in the furrow system. Soil type also affects furrow length .In sandy soils water infiltrates rapidly, whereas in clay water infiltrates slowly.

In sandy soil furrows should be short, so that water can reach the downstream end without excessive percolation losses. In clay soils, furrow can be long as a result of low infiltration rate that results low percolation loss at upper part of the furrow.

Under mechanized agriculture, furrows should preferably be as long as possible in order to reduce labor requirements and system costs. However, they also should be short enough to retain a reasonable application efficiency and uniformity. Application efficiency and uniformity normally increase as the furrow length decreases. Maximum furrow length on clay soil of slope less than 0.5% can be extending up to 300m. Based on the above information 10m furrow length was used for this study to increase irrigation efficiencies. Heights of ridges vary between 15 cm and 40 cm and the range of spacing commonly used for furrow irrigation is 0.3 to 1.8 m and furrows are generally V-shaped or U-shaped in cross section with depth of 15-30 cm and 25-40 cm wide at the top ( Anton, 1982).

The shape of the furrow depends on the soil type and the stream size. Soils with low infiltration rates have usually shallow wide parabolic or U-shaped furrows to reduce water velocity and to obtain a large wetted perimeter to encourage infiltration. Clay soils use a wide, shallow furrow to achieve a large wetted area so as to promote infiltrations (Kay, 1986). On the other hand, soil with a high infiltration rate requires more or less V-shaped furrows to reduce the wetted perimeter through which water infiltrates.

U-shaped furrow is widely practiced in the study area because of the nature of the soil found in this area was clay soil with low infiltration rate and it is easy to construct.

## 3.6. Crop Water Requirement

Crop consumptive water use is the amount of water transpired by plants, water evaporated from the soil and fraction of water held by plant tissues. There are three methods for matching irrigation with crop water requirements. The first method is that measure how much of water is contained in soil. The second is by monitoring some attributes of plant that are related to water deficiency; such as canopy temperature, xylem water potential and visible wilting. The third method that calculate amount of water the atmosphere can extract from a well watered crop by using model.

CROPWAT version 8.0 was used for this study to determine reference evapotranspiration, crop water requirements and irrigation schedule by utilizing metrological data as an input. For estimation of water irrigation requirements, climatic, crop and soil data have been utilized as an input. The climatic data such as maximum and minimum temperature, humidity and sunshine hours were used by the model to calculate reference evapotranspiration on monthly basis. This calculation has been done by using FAO Penman- Monteith method (Allen *et al.*, 1998). The reference evapotranspiration ETo was calculated by FAO Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO.
The Penman–Monteith equation integrated in the CROPWAT program is expressed by:

$$ET_O = \frac{0.408\nabla(R_n - G) + \gamma\frac{900}{T+273}u_{2(e_s-e_a)}}{\nabla + \gamma(1 + 0.34u_2)} \qquad 4$$

Where $ET_o$ = reference evapotranspiration rate (mm $d^{-1}$), T= mean air temperature (°C), and $u_2$ = wind speed (m $s^{-1}$) at 2 m above the ground. The crop parameters used for estimation of crop water requirement by the model were crop coefficient ($K_c$), length of the growing season, maximum crop rooting depth, critical depletion level (p) and yield response factor ($K_y$) collected from FAO irrigation and drainage paper 66 and Holeta Agricultural Research Center In the estimation procedure, effective rainfall can be computed by the CROPWAT program and deduced from the subsequent irrigation. Therefore, irrigation was the sole source of water for the crop throughout the whole growth period. The net irrigation water requirement has been equal to $ET_c$. The gross water requirement was computed by CROPWAT program adopting field application efficiency of 70%. When using properly designed row slopes, row lengths, set times, stream sizes, and tail water is reused furrow irrigation efficiency can be 60-80% (Irmak et al., 2011).

CROPWAT program was used to calculate $ET_{c,}$ by multiplying Evaotranspiration ($ET_o$) by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration ($ET_c$), as indicated by ( Allen, 1998).

$$ET_c = K_c\, ET_o \qquad 5$$

where $ET_c$ is a crop evapotranspiration; $K_c$ is a crop coefficient; $ET_o$ is a reference crop evapotranspiration. Crop coefficient is defined as the ratio of the crop $ET_c$ to the reference crop evapotranspiration and calculated by single crop and dual crop coefficient methods. In this study, single crop coefficient was calculated by CROPWAT model using calculated evapotranspiration (ET) and reference crop evapotranspiration ($ET_o$) as follow:

$$K_c = \frac{ET_c}{ET_o} \tag{6}$$

At pre-plant irrigation water was applied to every furrow in each plot, two days before planting with minimum water. The purpose of this irrigation was to bring the upper 30 cm soil depth to field capacity and create good soil to encourage a full and even plant stand.

In this experiment, the reference evapotranspiration (ETo) and crop water requirement (ETc) was estimated from long years climatic data collected from Metrological station of Holeta Agricultural Research Center.

Table 3 Climatic data Used for $ET_o$ calculation (1985-2015)

| Month | Min Temp °C | Max Temp °C | Humidity % | Wind speed km/day | Sunshine Hours |
|---|---|---|---|---|---|
| January | 3.4 | 23.4 | 51 | 130 | 8.0 |
| February | 5.0 | 23.9 | 50 | 147 | 7.6 |
| March | 6.7 | 24.4 | 51 | 147 | 7.1 |
| April | 7.9 | 23.9 | 56 | 138 | 7.0 |
| May | 6.8 | 24.4 | 56 | 130 | 6.3 |
| June | 7.7 | 22.4 | 66 | 95 | 5.1 |
| July | 9.1 | 20.0 | 78 | 104 | 3.4 |
| August | 9.1 | 19.6 | 80 | 95 | 8.1 |
| September | 7.8 | 20.3 | 74 | 104 | 5.0 |
| October | 4.9 | 21.9 | 57 | 156 | 7.6 |
| November | 2.3 | 22.4 | 52 | 147 | 8.7 |
| December | 1.9 | 22.8 | 51 | 147 | 8.6 |
| Average | 6.0 | 22.4 | 60 | 128.3 | 6.9 |

Climatic data displayed on the above table were collected from Holeta Agricultural Research Center starting from 1985 to 2015 for thirty one years.

## 3.7. Irrigation Schedule

Irrigation scheduling involves determining both the timing of irrigation and quantity of water to apply. Several methods are available for estimating crop water use. Methods for scheduling irrigation can be classified as observational (personal experience, plant and soil condition), determining soil moisture and calculating evapotranspiration losses. These methods can vary in complexity and some may require the use of technology. In this study irrigation interval in days and depth of application which is expressed in millimeter has been calculated by using CROPWAT version 8.0. Depth of water application was determined by the model and gave gross water required at experimental field by multiplying with each plot area. The root depth is assumed to increase linearly as a function of time, so it is important to consider the root depth at each stage of growth. The adjustment of depth of application at each stage was done by the model itself.

## 3.8. Water Conveyance and Measurement

The irrigation water source was located in the nearby water channel which is a natural channel convey water from the origin to the farmers field. The water had been brought to the experimental field by pressure generated by pump located near the channel. The earthen channel which was made of soil material by natural phenomenon was used to convey water from distant water source to around the experimental field. And then, the water had been pumped through the pipe connected to the pump which conveyed water to the earthen canal prepared between pipe and experimental field. Water movement in conveyance system requires pressure because of the difference in elevation between water surface in the channel and the field. Pipe was used to supply water from channel to the experimental field by pressure created pump located near the channel. The water had been applied carefully to every experimental unit through Parshall Flume by measuring depth of water flowing in the flume to ensure application at desired level of water for each treatment and to avoid over flow of water. For discharge measurement flume was extensively used in irrigation schemes because it can be used under almost any flow condition, have smaller head-losses than weirs and relatively less susceptible to sediment and debris transport.

The flow through Parshall Flume can be either under free flow or under submerged flow conditions. In this case, flow through parshall Flume was occurring under free flow condition. Before using, flumes were calibrated as per guidelines of (Skogerboe *et al.,* 1967) and relevant equation was used under free flow condition. Depth of water flowing in the Parshall Flume was measured using gage located at the throat section of the Parshall Flume and related with discharge given by Parshall Flume flow table.

Figure 3 indicated un-irrigated and furrow under irrigation

## 3.9. Water Productivity

Water productivity was determined by dividing tuber yield by total applied irrigation water and is expressed as follows (Ali *et al.,* 2007):

$$\mathrm{WP}\left(\frac{\mathrm{kg}}{\mathrm{m}^3}\right) = \frac{\mathrm{Yield}\left(\frac{\mathrm{kg}}{\mathrm{ha}}\right)}{\mathrm{total\ water\ received}\left(\frac{\mathrm{m}^3}{\mathrm{ha}}\right)} \qquad 7$$

where WP water productivity (kg/$m^3$), Yield (kg/ha) and total water received ($m^3$/ha) from planting to harvest and water applied before planting is not included in the total.

## 3.10. Irrigation Performance Indicators

Surface irrigation systems were designed and operated to satisfy the irrigation water requirements of each field. The performance of the system is determined by the efficiency of water conveyed to the field from the channel and distributed within the experimental plot. Irrigation performance mainly determined by using conjunctively various parameters because one is not capable to describe whether the irrigation is satisfied the plant water requirements or not. In this case, two parameters were used to estimate irrigation performance: application efficiency and distribution uniformity.

### 3.10.1. Field application efficiency (AE)

Field application efficiency is the ratio of water directly available to the crop to water received at the field inlet. It is affected by the rate of supply, infiltration rate of soil, storage capacity of the root zone, land leveling, etc. For furrow and border strip irrigation, water is mostly lost through deep percolation at the head end and through runoff at the tail end, while for basin irrigation it is mostly through deep percolation and evaporation, since the basin is closed. Application efficiency was calculated based on, water application efficiency (AE) as the ratio between the volume of water held in the root zone of the soil profile after the irrigation and the total volume of water applied during the irrigation process (Zerihun *et al.,*2001).

$$\mathrm{AE}(\%) = \frac{\mathrm{D_{sz}}}{\mathrm{D_a}} * 100 \qquad 8$$

Where $D_{sz}$ depth of water stored in root zone (mm), $D_a$ total depth of water applied to the plot (mm).

Pre and post irrigation soil moisture analysis method was employed for calculating water stored in the crop root zone. The soil samples for moisture content before and after irrigation were taken at three randomly selected points in each plot. The samples were collected at three depths i.e. 0-20, 20-40 and 40-60 cm. The potato crop has maximum root depth of 60 cm; therefore, soil samples were collected down to 60 cm depth. Moisture content of samples was measured on dry weight basis.

The depth of water stored in the root zone was calculated by equation given in the procedure adopted by (Imark *et al.,* 2011).

$$D_s(\mathrm{mm}) = \mathrm{M.C} * \mathrm{Sp.G} * R_Z \qquad 9$$

where: Ds depth of water stored in root zone (mm), M.C moisture content of soil (%), Sp.G specific gravity of soil, Rz depth of root zone of crop (cm).

### 3.10.2. Distribution uniformity (DU)

Distribution Uniformity is the measure of how uniformly the water is applied. Distribution uniformity (DU) shows how evenly water is applied throughout the field and it is important in managing water efficiently. Poor uniformity causes excessive deep percolation, where water percolates below the root zone and is lost to crop use. An irrigation uniformity of 100% would mean that every point within the irrigated area received the same amount of water as every other point. Typically, distribution uniformity (DU) is based on the post-irrigation measurement of water depth that infiltrates to the soil because it can be more easily measured and better represents the water available to the crop.

However, using post-irrigation measurements of infiltrated water to evaluate DU ignores any water intercepted by the crop and evaporated, and any soil water evaporation that occurs before the measurement. Any water that percolates below the root zone or the sampling depth is also ignored. A low distribution uniformity (DU) ($\leq$60%) indicates that the irrigation water is unevenly distributed, while a high distribution (DU)$\geq$80 indicates that the application is relatively uniform over the entire field (Irmak, 2011). The Christiansen Uniformity Coefficient is given as: -

$$CU = \left(1 - \frac{\sum|X_i - X|}{nX}\right)100 \qquad 10$$

where CU is Christiansen uniformity coefficient %, $X_i$ the recorded depth of water stored in root zone (mm) at i$^{th}$ point (from gravimetric moisture determination). It is the moisture content after oven dry of each of the soil samples from a plot.

Soil samples prior to the commencement of the irrigation and two days after irrigation at three points from a plot. N is number of points where samples were taken. X is the mean water depth (mm) of water stored in root zone and is determined by:

$$X = \frac{\sum_{xk=0}^{n} X_i}{N} \qquad 11$$

Distribution uniformity at low quarter (or simply distribution uniformity) ($DU_{lq}$) is defined as the average water applied in 25% of the area received the least amount of water, regardless of location, divided by the average water applied over the total area (Merriam and Keller, 1978).

$$DU_{lq} = 100 * \frac{LQ}{M} \qquad 12$$

where $DU_{lq}$ distribution uniformity at low quarter (or simply distribution uniformity, DU), LQ average low-quarter depth infiltrated (mm) M average depth infiltrated (mm). The moisture content of the soil is taken from each plot at 2m, 5m and 8m starting from the upper end to the lower end for calculations of irrigation uniformity. Soil samples were taken before and after each irrigation events i.e. one day before irrigation and two days after irrigation.

## 3.11. Data Collection

Data collection was performed before the implementation of the experiment, during the implementation of the experiment and after the implementation of the experiment. Data collected before implementation of the experiment and after harvest were climatic data, soil data and yield and yield component data.

### 3.11.1. Climatic data

Long term climatic data was used for estimation of crop water requirement to get actual estimation of reference evapotranspiration ETo and crop evapotranspiration ($ET_c$). Thirty years climatic data of (maximum and minimum temperature, humidity, wind speed and sunshine hour) on monthly base had been collected from Holeta Meteorological Station of Holeta Agricultural Research Center.

The daily minimum ($T_{min}$) and maximum air temperature ($T_{max}$) are, respectively the minimum and maximum air temperature observed during the 24-hour and converted to months for thirty years. The daily humidity of the air and daily wind speed at 2m were observed during the 24-hour by the observers of meteorological station for thirty years were converted to monthly base data. Rainfall and Sunshine hours, which was observed by observers during the 24-hours for thirty years was converted to monthly base data. The climatic data were collected based on monthly bases (air temperature, humidity, wind speed, rain fall and sun shine) to use as in put for CROPWAT program for estimation of $ET_o$.

### 3.11.2. Soil data

The soil samples were collected from experimental site to determine bulk density, soil moisture, field capacity, permanent wilting point, soil texture, pH, OC, OM, CEC, total nitrogen, available phosphorus and exchangeable potassium in laboratory. To determine the bulk density, undisturbed soil samples were taken by core sampler of known volume (100cm$^3$) that was driven into the soil of up to desired depth. Since bulk density varies considerably spatially, the samples were taken at two different soil depths (0-30cm and 30-60cm) of the soil profile and from three locations across the experimental plot. The samples were dried in an oven to determine the dry weight fraction. Then the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (Hillel, 2004).

$$\rho_b = \frac{M_s}{V_t} \qquad 13$$

where $\rho_b$ is bulk density gcm$^{-3}$, $M_s$ mass of solid (gm) and $V_t$ total volume cm$^3$.

Gravimetric method was used to determine the initial moisture content and moisture content before and after irrigation events. Soil samples were collected from each plot at depths of 0-20cm, 20-40cm and 40-60cm of the soil profile. These samples were collected from each plot along the furrow length at 2m, 5m and 8m to get representative soil moisture content of the plot. After weighing the soil sample, it was placed in an oven at 105$^o$C until the constant weight was obtained. After drying, the soil sample was weighed again.

The gravimetric method was used to determine the soil moisture content and calculated as a dry weighed fraction (Michael, 2008).

$$\emptyset m = \frac{Mw - Ms}{Ms} \qquad 14$$

where $\emptyset m$ is soil moisture, Mw is weight of wet soil sample (g) and Ms is weight of dry sample soil (g).

Soil texture of the field was determined in the laboratory using hydrometer method and soil pH was determined from saturation pest extract using pH meter. Double-Ring infiltrometer of 30cm diameter and 60cm diameter was used to measure the infiltration capacity of experimental soil at field level. The infiltration rate is the velocity or speed at which water enters into the soil and expressed as depth (mm) of the water layer that can enter in to the soil in one hour had been calculated from ring infiltromter data.

The water content at field capacity was determined in the laboratory by using a pressure plate apparatus applying -1/3 bar to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture was taken as field capacity. Permanent wilting point was also determined using pressure membrane apparatus by applying -15 bars to a saturated soil. All soil data were analyzed in soil laboratory of Holeta and Bako Agricultural Research Center.

Soil samples were also analyzed for soil chemical properties such as available phosphorus (P), organic matter (OM) and organic Carbon (OC), exchangeable potassium (K), total Nitrogen and Cation exchange capacity (CEC) in soil laboratory of Holeta Agricultural Research Center. Cation exchange capacity (CEC) was determined after saturation of samples with 1M ammonium acetate solution by using the modified Kjeldhal method as described by (Okalebo, *et al*., 2002). Total nitrogen was determined by treating the sample with a mixture of concentrated sulfuric acid and digestion catalysis following the modified Kjeldhal method (Okalebo *et al*., 2002). Available phosphorus was determined using sodium bicarbonate as extraction solution according to the Olsen method.

### 3.11.3. Yield and yield components

Yield data were recorded on plot basis and extrapolated to hectare basis. All parameters were determined and calculated from the middle 6 rows. That is, the gross size of 6 m x 10 m (60 $m^2$) and the net (harvestable) plot area was 4.5 m x 10 m (45 $m^2$). Marketable tuber yield and unmarketable were differentiated based on the fact that marketable tuber yield was tuber yield which was not affected by disease, not deformed and damaged tubers during harvesting. The number of tubers per plant was recorded from 10 plants randomly selected and averaged to get number of tuber per plant at harvest. Maturity of the potato crop was observed when 50% of the plant haulms (vines) showed yellowed or in each plot they show senescence. Diseased, misshaped, damaged tubers during harvest were recorded as unmarketable tuber yield from the middle rows. Total tuber yield ($Kgha^{-1}$) was recorded as the sum of marketable tuber yield and unmarketable tuber yield and calculated as kg per hectare.

## 3.12. Statistical Analyses.

Analysis was performed on yield, water productivity, and application efficiency and distribution uniformity using SAS statistical software. The data of the experiment was analyzed in randomized complete block design (RCBD), and the mean difference was estimated using the least significant difference (LSD) comparison.

## 3.13. Benefit-Cost Ratio (BCR) and Net Return (NR)

The total cost mainly includes labor cost, input cost and fuel costs. Labor cost included costs for land preparation, weeding and watering and estimated based on the study area. Input costs included costs for purchasing of seed and fertilizer. The indigenous irrigation farmers in the study area do not pay for water for their farms. Therefore, they only bear the costs of labor for land preparation, weeding and watering (estimated the man-day labor cost of 70 Ethiopian Birr) as well as the price of seed, fertilizer and fuel to run a pump to withdraw water from the channel. Therefore, labor cost, input cost and fuel costs of the three irrigation method and farmer practice were estimated at plot level based on the observed costs and converted to hectare.

In the study area majority of the farmers are using pumps to convey water from the river channels to their farm land. Based on this fact fuel cost was estimated at plot level and converted to hectare. Gross revenue had been calculated by multiplying total yield in kg $ha^{-1}$ and potato market price per kilogram. The farm-gate price for potato tubers in this study was 3 Ethiopian Birr per kilogram (local price). Net return (NR) and benefit-cost ratio (BCR) due to irrigation were calculated according to Li *et al*., 2005 as follows:

$$NR = GR - TC \qquad 15$$

$$BCR = NR/\text{Total costs} \qquad 16$$

where NR Net return (ETB), GR Gross revenue (ETB), TC Total costs (ETB) and BCR Benefit-Cost ratio.

# 4. RESULTS AND DISCUSSION

## 4.1. Soil Parameters and Soil Water Relation

Soil sample taken from the experimental plots before planting was analyzed for soil texture and other parameters such as Soil PH, Organic matter (OM&OC),Total nitrogen (N) and phosphorus (P). The result of texture analysis using Hydrometer method of the soil from the experiment site showed that the composition of clay, silt and sand percentage were 52, 21 and 27, respectively. Thus as per the USDA texture triangle classification, the soil was classified as clay loam soil. The field capacity and permanent wilting point of the soil were determined to be 42 and 29 percent, respectively. The infiltration rate determined from Ring infltrometer data was 10 mm/hr. The volumetric soil moisture content remained at field capacity was about 42% for this soil. The volumetric soil moisture content at the wilting point had been dropped to 29%. The above information showed that the soil was categorized under clay soil with good water holding capacity with low infiltration rate The soil types with higher total available water content are generally more conducive to high water productivity because they can supply adequate moisture to plants.

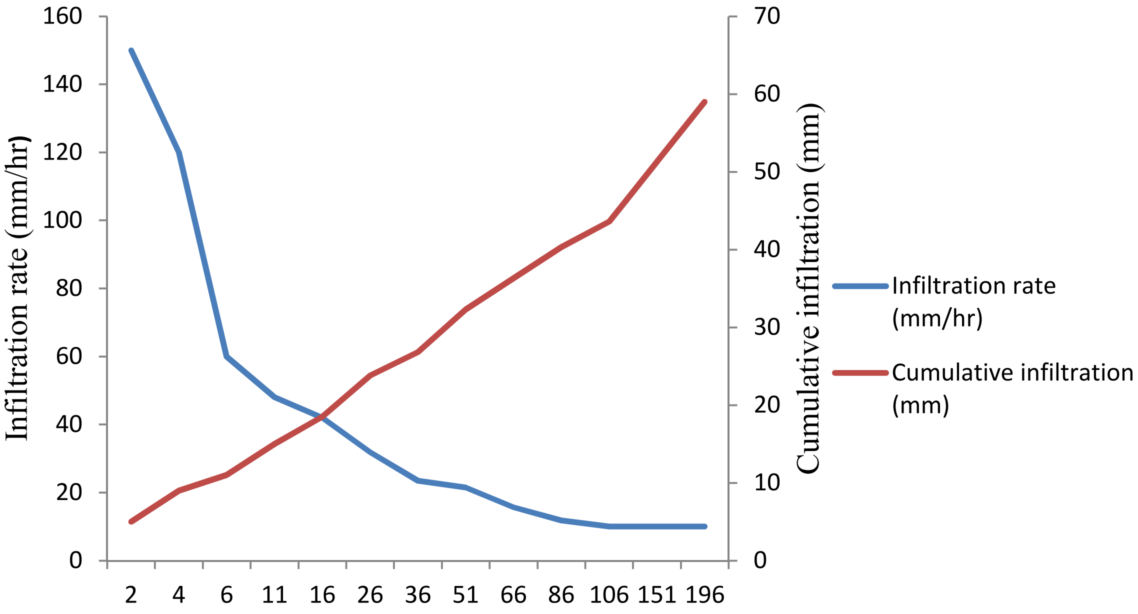

Figure 4 Infiltration rate (mmhr$^{-1}$ and Cumulative Infiltration (mm) curves

Soil pH is a measure of the acidity or basicity of a soil. The analyzed data for soil PH before planting showed the soil was slightly acidic for all treatments. This showed the acidity range of the soil had no impact on plant growth, nutrient and water availability. Potassium (K) is an essential nutrient for plant growth and is classified as a macronutrient due to large quantities of K being taken up by plants during their life cycle. From the soil data analyzed before planting for exchangeable potassium that held on the exchange sites on clay particles (exchangeable K) for all treatment showed that potassium was readily available for plant growth. Bulk density reflects the soils ability to function for structural support, water and solute movement, and soil aeration. The bulk density recorded from collected soil sample before planting for all treatments was in the range that not restricts root growth. Soil sample analyzed for available phosphorus showed that P content of the soil was with the range of available for plant growth for all treatments. Analyzed soil data before planting showed that enough organic matter content was found in soil for all treatments. The cation exchangeable capacity (CEC) of soils varies according the clay %, the type of clay, soil pH and amount of organic matter. Based on this information CEC of the experimental soil was showed that soils dominated by clays with variable surface charge are typically strongly weathered. Nitrate-nitrogen (NO3-N) measures the amount of available nitrogen in the soil that can be absorbed immediately by plants. From the analyzed soil data collected before planting total nitrogen availability of the soil was within the range of available for plant growth.

Table 4 Soil parameters of experimental plots before planting

| Treatment | PH | Available p ppm | Organic Carbon (%OC) | Organic Matter (%OM) | Total Nitrogen (%N) | Execahngable (K) K(cmol(+)/Kg soil | CEC | Bulk density |
|---|---|---|---|---|---|---|---|---|
| Every furrow irrigation | 6.37 | 7.4 | 1.45 | 2.53 | 0.12 | 0.76 | 26.5 | 1.35 |
| Alternate furrow irrigation | 6.49 | 7 | 1.54 | 2.78 | 0.13 | 0.76 | 26.3 | 1.36 |
| Fixed furrow irrigation | 6.60 | 7.6 | 1.7 | 2.88 | 0.14 | 0.85 | 21.4 | 1.36 |
| Farmer practice | 6.46 | 7.2 | 1.78 | 2.7 | 0.13 | 0.74 | 24.5 | 1.35 |

Soil data analyzed for PH from soil sample collected after planting showed that slight reduction of soil PH for all treatments. However, no change was observed on the PH range as compared to that obtained before planting. This showed the applied treatments had no impact on soil PH. After planting Exchangeable Potassium (K) content of all experimental plots was increased relatively compared to that obtained before planting. This implied that some amount of K was become at exchangeable site after planting due to the implementation of the experiment. Analyzed result for bulk density form soil sample collected after planting for all treatments showed that bulk density value decreased after planting. This reflected that bulk density of the experimental soil was decreased due to the disturbance of soil while plowing and other agronomic practice. Phosphorus content of the experimental soil was increased after planting as a result of addition of inorganic fertilizers. Analyzed soil data after planting also showed that organic matter content and cation exchange capacity (CEC) of the experimental soil were increased. This may be related to the increment of the microbial activity that in turn increases the organic matter content and CEC of the soil. The analyzed soil data collected after planting showed that nitrogen content of the experimental soil was increased du e to addition of inorganic fertilizer at planting and after planting.

Table 5 Soil parameters of experimental plots after planting

| Treatment | PH | Available P (Ppm) | Organic Carbon (%OC) | Organic Matter (%OM) | Total Nitrogen (%N) | Execahngable (K) K(cmol(+)/Kg soil | CEC | Bulk density |
|---|---|---|---|---|---|---|---|---|
| Every furrow | 6.28 | 11.4 | 2.23 | 3.21 | 0.17 | 0.88 | 28.90 | 1.30 |
| Alternate furrow | 6.39 | 13.20 | 2.17 | 3.81 | 0.18 | 0.88 | 28.73 | 1.31 |
| Fixed furrow | 6.50 | 12.80 | 2.20 | 3.65 | 0.18 | 0.92 | 23.4 | 1.31 |
| Farmer practice | 6.36 | 11.8 | 2.55 | 4.10 | 0.22 | 0.83 | 27.4 | 1.30 |

## 4.2. Amount of Water Applied Under Each Treatment

In order to study the impact of alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and every furrow irrigation (EFI) methods, on yield, water productivity and water use efficiency parameters had been measured. These included computation of crop water requirement using the CROPWAT model (Computer program), soil infiltration rate, irrigation efficiencies and yield assessment. The CROPWAT software was used to determine the amount of water required for the potato crop throughout the growing season. The model also gave optimum irrigation schedule.

As per the output of the model, the optimum seasonal irrigation requirement was found to be 584.3 mm (5843m$^3$/ha) for every furrow irrigation method. For the alternate furrow irrigation (AFI) and fixed furrow irrigation (FFI), 292.2mm (2922m$^3$/ha) of water was needed throughout the growing season of potato crop. Application of irrigation water according to CROPWAT model was started after twelve days i.e. after the crop is fully geminated. Before germination all experimental plots were irrigated with the same amount of water. Totally eight irrigation events were considered in the experimental site for determination of application efficiency, distribution uniformity, water productivity and water use efficiency excluding irrigation events prior to planting and before germination.

Table 6 Details of irrigation during the growing season in the potato grown experiment

| Treatment | Number of irrigation (number) | Depth of Water Applied ($W_d$ (mm) |
|---|---|---|
| Every furrow irrigation (EFI) | 8 | 584.3 |
| Alternate furrow irrigation (AFI) | 8 | 292.2 |
| Fixed furrow irrigation (FFI) | 8 | 292.2 |
| Farmer practice (FP) | 12 | 925.6 |

The number of irrigation events and depth of water applied ($W_d$) for each treatment are shown in the above table. The alternate furrow and fixed furrow irrigation treatment consumed less water as compared with every furrow irrigation method. The treatment considered as farmer practice was irrigated by farmer himself with twelve number irrigation events. The amount of water consumed by treatment implemented by farmer (Farmer practice) was calculated from depth of water flowing in the parshall flume located at the entrance of the plot and the time of irrigation.

The seasonal amount of water consumed by the alternate furrow irrigation and every furrow irrigation were amounted to 292.2mm (2922m$^3$ m$^3$ ha$^{-1}$), and 584.3 mm (5843m$^3$ ha$^{-1}$) respectively. According to (Pereira and Shock, 2006) for maximum yields, the crop water requirement (CWR) of potato for a 120 to 150 day crop growth is 500 to 700 mm depending on climate. Amount of water applied for every furrow irrigation treatment was agreed with the range of water requirement stated previously.

Based on the fact that alternate furrow and fixed furrow irrigation reduces number of furrow under irrigation and the amount of water applied to these treatments was reduced by half as compared with every furrow irrigation method. Alternate furrow irrigation technique has been fundamentally based on alternatively wetting and drying opposite parts of the ridge of furrows under which the plant root system is thought to be located. Amount of water applied under alternate furrow irrigation was also agrees with conclusion says alternate furrow irrigation is commonly applied as part of a deficit irrigation program because it does not require the application of more than 50–70% of the water used in a fully irrigated furrow (every furrow irrigation method) ( Webber *et al*., 2006). On the other hand, alternate furrow irrigation technique recorded lower values of total evapotranspiration as compared with every furrow irrigation technique. This may be due to less evaporation from the dry furrow that was reflected on decreasing total evapotranspiration (Eduardo *et al*., 2010).

The above table indicates that alternate furrow and fixed furrow irrigation techniques saved 50% of irrigation water as compared with every furrow irrigation technique and 68.4% as compared with farmer practice, whereas every furrow irrigation method saved 37% of irrigation water as compared with farmer practice. The lowest depth of water applied ($W_d$) under alternate furrow irrigation method as compared to every furrow irrigation is as a result of great reduction of wetted surface in alternate furrow irrigation; almost half of the soil surface is wetted in alternate furrow irrigation. This result supports the outcome obtained by (Shayannejad and Moharreri, 2009) that conclude alternate furrow irrigation method which can supply water in a way greatly reduces the amount of wetted surface, which leads to less evapotranspiration and less deep percolation.

## 4.3. Field application efficiency (AE)

The determination of the water application efficiency by soil moisture measurements require two components of water balance, i.e. volume of water applied and volume of water stored in the root zone. The stored volume was measured in terms of soil moisture status and can either be measured by taking soil samples before and after irrigation. Soil samples from different depths were randomly taken before and after irrigation. Test statistics was applied to determine the efficient method at the significance level of 5%.

The results shown in table 7 are the average values of water application efficiency calculated separately for each irrigation events. A total of eight irrigation events were considered during observations. Irrigation application efficiencies under every furrow irrigation method where found between 60 to 67% with average of 61.6% for all irrigation events, whereas values under alternate furrow irrigation method were found between 82 to 88% with average of 85 % for all irrigation events. The result depicted there is significant ($p < 0.05$) difference between every furrow and alternate furrow irrigation.

The results showed in table 7 were application efficiency under alternate furrow irrigation method was higher by 23.4% as compared to every furrow irrigation method under clay loam soil. The wetted perimeter of alternate furrow irrigation is less as compared to every furrow irrigation method. Hence, alternate furrow irrigation method saves a considerable volume of irrigation water. The results of this study are in close agreement with (Rogers and Lamm, 1997) concluded that furrow irrigation method have wider range of 60-90%. On overall basis, the values of water application efficiency of every furrow irrigation method are within acceptable ranges as described by (Martin, 2006).

As shown in table 7 application efficiencies under fixed furrow irrigation method where found between 65 to 77% with average of 73.4% for all irrigation events, whereas under alternate furrow irrigation method the average value is 85 %. The result shows that there is a significant ($p < 0.05$) difference between alternate furrow and fixed furrow irrigation methods. From the obtained results, one can clearly see that water application efficiency of alternate furrow irrigation method was higher than fixed furrow irrigation by 11.6%.

The results of this study are in close agreement with (Ebrahimian *et al.*, 2011) conclude that the mean value of application efficiency of alternate furrow irrigation is higher than that of fixed-every furrow in which the drier furrow remains dry throughout the growing season, due to low lateral and more downward water flow is expected in fixed furrow method. As indicated in table 7 application efficiencies under farmer practice where found between 38 to 48% with average of 42% for all irrigation events, whereas the average values of 61.6, 85 and 73.4% where observed under every furrow, alternate furrow and fixed furrow irrigation respectively. According to the results of table 7, there was high significance ($p < 0.05$) difference between framer practice and other methods. The result indicated that farmer practice resulted low application efficiency of 42% that is lower by 19.6% as compared to that obtained under every furrow irrigation method. In addition, results obtained under farmer practice shows low application efficiency that is lower by 43% as compared to alternate furrow irrigation. This shows that there was high significance difference between farmer practice and alternate furrow irrigation method.

As showed in table 7, alternate furrow irrigation (AFI) is the most effective tools to minimize water application by half as compared with full furrow irrigation and increase irrigation water application efficiency. This result supports the outcome obtained by (Shayannejad and Moharreri, 2009) conclude that alternate furrow irrigation method is a way to save irrigation water and improve irrigation efficiency.

Table 7 Application efficiency of all irrigation events

| Treatment | AE first irrigation % | AE second irrigation % | AE third irrigation % | AE fourth irrigation % | AE fifth irrigation % | AE Sixth irrigation % | AE seventh irrigation % | AE eighth irrigation % | Overall mean |
|---|---|---|---|---|---|---|---|---|---|
| EFI | $67^{a}\pm3$ | $65^{b}\pm3$ | $60^{b}\pm3$ | $60^{c}\pm1$ | $60^{b}\pm3$ | $60^{b}\pm3$ | $60^{b}\pm2.4$ | $61^{b}\pm3$ | 61.6 |
| AFI | $81^{a}\pm3$ | $82^{a}\pm3$ | $84^{a}\pm3$ | $87^{a}\pm1$ | $88^{a}\pm3$ | $84^{a}\pm3$ | $83^{a}\pm2.4$ | $87^{a}\pm3$ | 85 |
| FFI | $75^{a}\pm3$ | $77^{ab}+3$ | $73^{ab}\pm3$ | $74^{b}\pm1$ | $75^{a}\pm3$ | $75^{ab}\pm3$ | $65^{b}\pm2.4$ | $73^{ab}\pm3$ | 73.4 |
| FP | $48^{b}\pm3$ | $43^{c}+3$ | $38^{c}\pm3$ | $40^{d}\pm1$ | $41^{c}\pm3$ | $43^{c}\pm3$ | $42^{c}\pm2.4$ | $41^{c}\pm3$ | 42 |
| LSD (0.05) | 16.5 | 14.7 | 14 | 10.2 | 14.3 | 16.9 | 15.8 | 14.8 | |
| CV | 15.4 | 11.7 | 17.2 | 12.2 | 16.3 | 18.4 | 15.7 | 17.2 | |

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

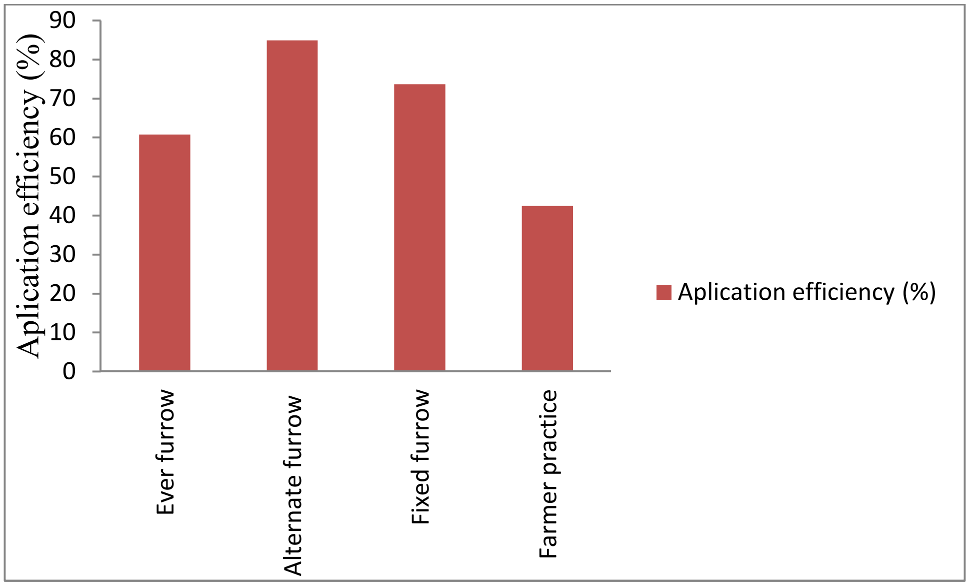

Figure 5 Application efficiency vs irrigation methods

The above figure shows that application efficiency recorded under each irrigation methods. A lternate furrow and fixed furrow irrigation techniques used small amount of water as compared with every furrow irrigation and farmer practice. However the highest application efficiency was recorded under alternate furrow irrigation.

## 4.4. Distribution uniformity

Comparison between the irrigation methods was made on basis of the distribution uniformity. The tools used to evaluate distribution uniformity of irrigation methods were the Christiansen Uniformity Coefficient and distribution uniformity at low quarter (or simply distribution uniformity, DU) as given in the table 8 and 9.

The results shown in the table 8 are the average values of coefficient of uniformity (CU) calculated separately for each irrigation events. As indicated in table 8 the highest coefficient of uniformity (CU) was recorded under every furrow irrigation method which is not significantly ($p < 0.05$) different from that recorded under alternate furrow irrigation.

However, significant ($p < 0.05$) difference is observed between alternate furrow and fixed furrow irrigation methods.

This may be due to low lateral movement of water in fixed furrow irrigation as compared to alternate furrow irrigation. Low coefficient of uniformity was recorded under farmer practice which shows high significance ($p < 0.05$) difference as compared with other methods.

Table 8 Coefficient of uniformity (CU)

| Treatments | CU for the first irrigation | CU for the second irrigation | CU for the third irrigation | CU for the fourth Irrigation | CU for the fifth Irrigation | CU for sixth irrigation | CU for seventh irrigation | CU for Eight irrigation | Overall mean |
|---|---|---|---|---|---|---|---|---|---|
| EFI | $87^{a}\pm3$ | $87^{a}\pm3$ | $89^{a}\pm2$ | $88^{a}\pm3$ | $87^{a}\pm2$ | $89^{a}\pm1$ | $86^{a}\pm3$ | $88^{a}\pm2$ | 87.6 |
| AFI | $89^{a}\pm3$ | $92^{a}\pm3$ | $91^{a}\pm2$ | $90^{a}\pm3$ | $90^{a}\pm2$ | $92^{a}\pm1$ | $88^{a}\pm3$ | $92^{a}\pm2$ | 90.5 |
| FFI | $80^{b}\pm3$ | $78^{b}\pm3$ | $84^{b}\pm2$ | $80^{b}\pm3$ | $81^{b}\pm2$ | $80^{b}\pm1$ | $79^{b}\pm3$ | $84^{b}\pm2$ | 80.8 |
| FP | $76^{c}\pm3$ | $70^{c}\pm3$ | $74^{c}\pm2$ | $74^{c}\pm3$ | $75^{c}\pm2$ | $73^{c}\pm1$ | $70^{c}\pm3$ | $73^{c}\pm2$ | 73.1 |
| LSD (0.05) | 4.7 | 6.4 | 3.2 | 5.4 | 3.6 | 4.3 | 6.2 | 3.2 | |
| CV | 17.5 | 10.7 | 17 | 15.6 | 12.6 | 31.2 | 10.5 | 15.4 | |

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

The output of statistical analysis revealed that there was no significant ($p < 0.05$) difference between every furrow irrigation and alternate furrow irrigation in terms of water distribution uniformity (DU) as indicated in table 9, whereas significant difference is observed between alternate furrow and fixed furrow irrigation methods. The average value of distribution uniformity obtained under fixed furrow irrigation for all irrigation events was 75.4%, which is lowered 13.9% as compared with alternate furrow irrigation. This supports the outcome obtained by Rodrigues *et al.* (2008) concludes that the soil water in the irrigated side of alternate furrow irrigation is depleted more effectively than corresponding side in fixed furrow. This indicated that the root system can partially compensate for the increasing limited water availability on the non-irrigated side of alternate furrow irrigation due to an increase in root hydraulic conductivity. This increases distribution uniformity of irrigation water under furrow irrigation.

The movement of water between ridges of alternate furrow irrigation is increased to compensate limited water availability on the non-irrigated side that increases distribution uniformity of irrigation water under this method. This also agrees with the outcome obtained by Liu *et al*. (2006a) concludes that larger hydraulic gradient in the soil-root interface was observed under alternate furrow irrigation than under fixed furrow irrigation. This explained that the greater rate of water extraction from soil in alternate furrow irrigation is obtained.

As indicated in the table 9, there was high significance ($p < 0.05$) difference between farmer practice and other irrigation methods. Low distribution uniformity (DU) is recorded under farmer practice as compared with other irrigation methods. This is based on the fact that, in farmer practice water is applied by farmer without determination of crop water requirement and using fixed irrigation schedule system which reduces the irrigation efficiency and distribution uniformity.

Table 9 Distribution uniformity (DU)

| Treatments | DU for the first irrigation | DU for the second irrigation | DU for the third irrigation | DU for the fourth Irrigation | DU for the fifth Irrigation | DU for sixth irrigation | DU for seventh irrigation | DU for Eight irrigation | Overall mean |
|---|---|---|---|---|---|---|---|---|---|
| EFI | $85^a \pm 3$ | $85^a \pm 2$ | $86^a \pm 3$ | $84^a \pm 2$ | $87a \pm 3$ | $86a \pm 2$ | $85^a \pm 3$ | $84^a \pm 2$ | 85.3 |
| AFI | $86^a \pm 3$ | $92^a \pm 2$ | $93^a \pm 3$ | $87^a \pm 2$ | $90^a \pm 3$ | $93^a \pm 2$ | $86^a \pm 3$ | $87^a \pm 2$ | 89.3 |
| FFI | $74^b \pm 3$ | $75^b \pm 2$ | $76^b \pm 3$ | $75^b \pm 2$ | $74^b \pm 3$ | $75^b \pm 2$ | $78^b \pm 3$ | $76^b \pm 2$ | 75.4 |
| FP | $64^c \pm 3$ | $63^c \pm 2$ | $64^c \pm 3$ | $64^c \pm 2$ | $65^c \pm 3$ | $64^c \pm 2$ | $56^c \pm 3$ | $59^c \pm 2$ | 62.4 |
| LSD (0.05) | 6.4 | 8.5 | 9.3 | 8.2 | 7.6 | 9.4 | 5.6 | 6.2 | |
| CV | 15.5 | 14.7 | 16.5 | 15.6 | 13.6 | 12.3 | 10.8 | 15.4 | |

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

## 4.5. Yield and Yield Components

### 4.5.1. Number tubers per plant

Potato yield and yield parameters recorded from each irrigation methods including farmer practice were indicted in the following tables. Table 10 shows that average number of tuber per plant i.e. total number of tubers. Irrigation methods significantly influenced total number of tubers (marketable and unmarketable tubers) collected from each plot. The highest number of tubers (16) was produced under every furrow irrigation method, whereas the lowest number of tubers (6) was produced under famer practice.

As shown in the table 10 no significant ($p <0.05$) different was observed between every furrow and alternate furrow irrigation methods in terms of number of tubers, whereas significant difference was observed between alternate furrow and fixed furrow irrigation methods. The highest number of tubers (16 per plant) was harvested from every furrow irrigation method which showed insignificant difference compared to that obtained from alternate furrow irrigation (14 per plant). This implies that, under alternate furrow irrigation method more number of tubers was harvested as compared with that obtained under fixed furrow irrigation method (19 per plant) due to uniform water distribution in alternate furrow irrigation than fixed furrow irrigation which in turn increased the tuber yield harvested from alternate furrow irrigation.

Table 10 Effect of irrigation methods on number of tubers per plant

| Treatment | Water applied (mm) | Average tuber number per plant |
|---|---|---|
| Every furrow irrigation | 584.3 | $16^{a}\pm1.1$ |
| Alternate furrow irrigation | 292.2 | $14^{a}\pm1.1$ |
| Fixed furrow irrigation | 292.2 | $9^{b}\pm1.1$ |
| Farmer practice | 925.6 | $6^{c}\pm1.1$ |
| LSD | | 3.4 |
| CV | | 17.2 |

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

### 4.5.2. Potato tuber yields

To determine the impact of irrigation methods on yield, tuber yield was differentiated as total yield, marketable yield and unmarketable yield. This is because; the whole purpose of doing the experiment was to assess how much water could be saved by alternate irrigation method with minimum or no yield reduction as compared with other methods (every furrow irrigation , fixed furrow irrigation and farmer practice).

With the intention of comparing the yield performance each irrigation methods, tuber yield from six central rows for all treatments was collected, weighed and yield per hectare was extrapolated. The yield collected from each treatment was further differentiated to total yield, marketable yield and unmarketable yields. Table 11 shows average tuber yield in terms of total tuber yield, marketable and unmarketable yield collected from each irrigation methods including farmer practice.

As indicated in the table 11 the difference observed between every furrow and alternate furrow irrigation methods in terms of total tuber yield was statically insignificant at 5% significant level. This shows that, the total tuber yield was nearly the same in both (EFI and AFI) irrigation methods; whereas total depth of water applied under every furrow irrigation was almost double as compared with that of applied under alternate furrow irrigation. Minor yield reduction (171 kg/ha) was observed under alternate furrow irrigation as compared with every furrow irrigation which is less than 1%. This implies that, applying alternate furrow irrigation will not produce significant yield reduction as compared with every furrow irrigation method in terms of total tuber yield. Therefore, by implementing alternative furrow irrigation technique, almost the same tuber yield was obtained comparing with the every furrow irrigation method. This result agreed with outcome obtained by Ahmadi *et al*.(2010b) conclude that alternate furrow irrigation (AFI) or partial root-zone drying (PDI) can increase water productivity with no or minor yield loss. The result also agreed with the outcome obtained by Jovanovic *et al*.(2010) reported that alternate furrow irrigation or partial root-zone drying (PDI) saved irrigation water compared to every furrow irrigation while maintaining similar yield with every furrow irrigation.

As indicated in table 11 total tuber yield was decreased significantly under fixed furrow irrigation compared to every furrow and alternate furrow irrigation techniques. The total tuber yield under fixed furrow irrigation was lowered by 3192kg/ha (9.5%) and 3021 kg/ha (9.1%) as compared with every furrow and alternate furrow irrigation respectively. The difference in total tuber yield between alternate furrow irrigation and fixed furrow irrigation is due to low moisture availability in fixed furrow irrigation technique as result of only even furrows were received water throughout the growing season. On the other hand, reduction in tubers yield under fixed furrow irrigation may be attributed due to little lateral movement of water and high downward movement of water and drying of un-watered furrows throughout the growing period of the crop. This result supports the outcome obtained by (Sepaskhah and Parand, 2006) stated that yield is decreased significantly in fixed furrow irrigation as compared with alternate furrow and every furrow irrigation techniques.

By comparing total tuber yield observed under farmer with every furrow and alternate furrow irrigation, high significant difference was observed at 5% significant level. The yield reduction obtained under farmers practice were 3271kg/ha (9.8%), 3100kg/ha (9.3%), as compared with every furrow and alternate furrow irrigation techniques respectively. This implies that the extra amount of water added under farmer practice shows adverse effect on potato tuber yield. Farmers in the study area commonly uses fixed irrigation scheduling system because of the scarcity of water and high competition to use available water for crop production. However, fixed irrigation scheduling is not appropriate method to meet crop water requirement as per growth stage the crop. This indicates that the amount of water applied under farmer practice is not agreed with crop water requirement needed at each growth stage. As indicated in table 11 no significant difference was observed between fixed furrow irrigation and farmer practice.

The farmers generally lack knowledge on aspects of soil-water-plant relationship and they apply water to the crop regardless of the plant needs. They seem to relate irrigation occurrence to number of days after planting with fixed intervals rather than crop growth stage progress. This result agrees with outcome obtained by Shock *et al*. (2013) conclude that improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers.

As indicated in table 11 differences observed in marketable tuber yield between every furrow and alternate furrow irrigation methods was not significant at 5% significant level. In addition to this, there was no statistically significant difference in marketable tuber yield between fixed furrow and farmer practice. However, there was statistically significant difference in marketable tuber yield between alternate furrow and fixed furrow irrigation. The lowest marketable yield was observed under framer practice which shows insignificant difference as compared with fixed furrow irrigation. The difference observed in marketable tuber yield between fixed furrow and farmer practice was only 1320.9kg/ha that shows insignificant difference between the two methods.

The difference observed between alternate furrow and fixed furrow irrigation in terms of marketable yield may be related to; under fixed furrow irrigation technique only little amount of water was moved laterally towards the un-watered furrows and large portion of water moves down ward due to watering of furrows that received water at all irrigation events and remain dry un-watered furrow throughout the growing season. This affects the size and quality of potato tubers which agrees with the suggestion given by (Kaman *et al*., 2006) fixed furrow irrigation lowers quality of tubers as a result of limitation of water to only one side of furrow.

Table 11 also indicates that, fixed furrow irrigation and farmer practice were resulted low marketable yield of 29587.6kg/ha and 28266.7kg/ha respectively as compared to that obtained under alternate furrow irrigation and every furrow irrigation. Therefore, the study indicated that low marketable yield was recorded at farmer practice this was due to poor water application method that affects the marketability of the tubers. Improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers that reduce the quality of potato for marketability (Shock *et al*., 2013). In addition, high unmarketable yield (1831.1 kg/ha) was recorded under farmer practice as a result of poor irrigation water management.

Table 11 Effects of irrigation method on tuber yield

| Treatment | Total. Yield (kg/ha) | Marketable Yield (kg/ha) | Unmarketable yield (kg/ha) |
|---|---|---|---|
| Every furrow irrigation | 33369$^{a}$±811 | 31839.2$^{a}$±516.5 | 1482.9$^{a}$±29.7 |
| Alternate furrow irrigation | 33198$^{a}$±811 | 32667.8$^{a}$±516.5 | 534.2$^{b}$±29.7 |
| Fixed furrow irrigation | 30177$^{b}$±811 | 29587.6$^{b}$±516.5 | 821.3$^{b}$±29.7 |
| Farmer practice | 30098$^{b\pm}$811 | 28266.7$^{b}$±516.5 | 1831.1$^{a}$±29.7 |
| LSD | 2499.5 | 1591.4 | 497.35 |
| CV | 14 | 12.3 | 15.7 |

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

## 4.6. Water Productivity (WP), Irrigation Water saved and Additional Area Gained

### 4.6.1. Water productivity (WP)

The amounts of water applied for the potato from planting to harvest over the growing season are given in table 6. Water productivity (WP) based on fresh tuber production was expressed as the ratio of tuber yield at harvest to the water applied is given in the table 12. The WP values obtained in this study were similar to those reported for potato by others and were affected by irrigation techniques. It is clear that by increasing irrigation water application, a decreasing in crop water productivity could be obtained and vise versa.

As indicated in table 12 there was significant difference at 5% significant level in water productivity (WP) values between irrigation techniques. The highest water productivity value was 11.2 kgm$^{-3}$ obtained from the alternate furrow irrigation treatment followed by 10.7 and 6.1kgm$^{-3}$ obtained from fixed furrow and every furrow irrigation methods respectively whereas, the lowest value of 4.1kgm$^{-3}$ was obtained from farmer practice. This finding agreed with result obtained by (Ibrahim and Emara, 2010) reported that an adverse relationship was found between the amounts of water applied and water productivity of the crop.

The applied water was used more efficiently in the alternate furrow irrigation treatment in which the lower amount of water applied produces higher water productivity value.

The higher mean value of water productivity obtained under alternate furrow irrigation was related to lower amount of water applied with uniform lateral movement in crop root zone and minor tuber yield reduction obtained under this method. The reason of having more water productivity (WP) and minor yield reduction for alternate furrow irrigation could be related to better distribution of water in root zone in both sides of the ridge that increases water and fertilizer uptakes by plant. This result indicated that alternate furrow irrigation is appropriate to increase water productivity by allow applying less irrigation water for potato production which supports the outcome obtained by Saeed *et al*.(2008) using alternate furrow irrigation or partial root zone drying (PDI) higher water productivity (WP) and even better fruit quality can be produced.

As indicated in table 12 the difference observed in water productivity between alternate and fixed furrow irrigations was statistically significant at 5% significant level. The same amount of irrigation water was applied for alternate furrow and fixed furrow irrigation techniques. However, alternative drying of root zone under alternate furrow irrigation method showed higher water productivity than fixed drying of root zone under fixed furrow irrigation method. This is due to uniform water distribution between ridges in alternate furrow than fixed furrow irrigation. Uniform water distribution between ridges in alternate furrow irrigation method enhanced root growth and improved nutrient uptake of crop which increases the yield than fixed furrow irrigation method. The results of this study are in close agreement with Wang *et al.* (2009) conclude that alternative furrow irrigation enhanced root growth and increased nutrient uptake of the crop.

The difference observed in total water productivity (WP) between farmer practice and other irrigation techniques was statistically highly significant. The reduction of water productivity in farmer practice was related with more volume of water added in farmer practice without yield advantage. This indicates that extra amount of water is added to farmer practice plot as a result of improper irrigation depth and fixed schedule system.

Table 12 Effects of irrigation methods on water productivity and water use efficiency

| Treatment | Water productivity (kg/m$^3$) |
|---|---|
| Every furrow irrigation | 6.1$^c$±0.13 |
| Alternate furrow irrigation | 11.2$^a$±0.13 |
| Fixed furrow irrigation | 10.7$^b$+0.13 |
| Farmer practice | 4.1$^d$±0.13 |
| LSD | 0.41 |
| CV | 10.3 |

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

### 4.6.2. Irrigation water saved and additional area gained

Table 13 indicated that amount of water saved under each irrigation methods comparing with each other. This table also indicated that additional area can be irrigated by amount of water saved under each irrigation methods. Every furrow irrigation method saved 341.3mm of water applied under farmer practice. This amount of water can be used to irrigate 0.58ha of additional land using every furrow irrigation method for potato production. Similarly, alternate furrow irrigation and fixed furrow irrigation methods saved 633.4mm of water applied under farmer practice which can be used to irrigate 2.17ha of additional land using alternate furrow or every furrow irrigation method for potato production. Alternate furrow and fixed furrow irrigation received the same amount of irrigation water, whereas low water productivity was obtained under fixed furrow irrigation compared to alternate furrow irrigation method. This result is in close agreement with Jovanovic *et al*. (2010) conclude that alternate furrow irrigation increase water productivity as compared with fixed furrow irrigation techniques by saving irrigation water.

Alternate furrow irrigation and fixed furrow irrigation saved 292.1mm of water applied under every furrow irrigation method which can be used to irrigate 1ha of additional land using alternate furrow or fixed furrow irrigation method for potato production. Moreover, applying alternate furrow irrigation method increased water productivity 45.5% and saved 292.1mm (50%) of water consumed under every furrow irrigation method. This amount of water was sufficient to irrigate one hectare of potato cropped area using alternate furrow irrigation technique that can earn better economic returns as compared to every furrow irrigation method.

Similarly, applying alternate furrow irrigation technique increased water productivity by 63.4% and saved 633.4 mm (68.4%) of water consumed under farmer practice. This amount of water is sufficient to irrigate 2.17ha of potato cropped area using alternate furrow irrigation technique that can earn better economic returns as compared to that of farmer practice. In addition, fixed furrow irrigation saved 633.4mm (68.4%) of water as compared with farmer practice but less in water productivity as compared to alternate furrow irrigation as indicated in table 13. Generally, alternate furrow system increased water productivity (WP) with minor or no yield reduction as compared to every furrow irrigation system. This finding agrees with results obtained by (Nouri and Nasab, 2011) concluded that alternate furrow irrigation increases water productivity with minor or no yield reduction and save substantial quantity of irrigation water.

Table 13 Irrigation water saved and additional area gained under each treatments

| Treatment | Irrigation water saved ( mm) Comparing three irrigation method with FP | Additional irrigated can be irrigated (ha) | Irrigation water saved ( mm) Comparing AFI and FFI methods with EFI method | Additional irrigated can be irrigated (ha) |
|---|---|---|---|---|
| EFI | 341.3 | 0.58 | 0 | 0 |
| AFI | 633.4 | 2.17 | 292.1 | 1 |
| FFI | 633.4 | 2.17 | 292.1 | 1 |
| FP | 0 | 0 | 0 | 0 |

## 4.7. Benefit-Cost Ratio (BCR) and Net Return (NR)

Table 14 Expenses involved in the implementation of irrigation treatments

| Treatments | Labor cost (ETB) | | Input cost (ETB) | | Fuel cost (ETB) | Total cost (ETB) |
|---|---|---|---|---|---|---|
| | Land preparation and Weeding | Watering | fertilizer | seed | | |
| EFI | 950 | 1550 | 5780 | 2720 | 3966 | 14966 |
| AFI | 570 | 930 | 5780 | 2720 | 1983 | 11983 |
| FFI | 570 | 930 | 5780 | 2720 | 1983 | 11983 |
| FP | 1520 | 2480 | 5780 | 2720 | 5950 | 18450 |

Table 15 Revenues gained from the implementation of irrigation treatments

| Treatments | Marketable tuber yield kgha-$^{1}$ | Unit price (Per Kg) | Total price |
|---|---|---|---|
| EFI | 31967.1 | 3 | 95901.3 |
| AFI | 32682.7 | 3 | 98048.1 |
| FFI | 29465.6 | 3 | 88396.8 |
| FP | 28333.3 | 3 | 84999.9 |

Table 16 Benefit-cost ratio (BCR) and net return (NR) associated with the adopted irrigation treatments

| Treatments | Applied water m$^{3}$ha$^{-1}$ | Fuel cost ETB | Labor cost ETBha$^{-1}$ | In put cost TBha$^{-1}$ | Total cost ETB | Marketable tuber yield kgha-$^{1}$ | Gross Revenue ETB | Net revenue ETB | Benefit-cost ratio |
|---|---|---|---|---|---|---|---|---|---|
| Ever furrow | 5843 | 3966 | 2500 | 8500 | 14966 | 31967.1 | 95901.3 | 80935.3 | 5.4 |
| Alternate furrow | 2922 | 1983 | 1500 | 8500 | 11983 | 32682.7 | 98048.1 | 86065.1 | 7.2 |
| Fixed furrow | 2922 | 1983 | 1500 | 8500 | 11983 | 29465.6 | 88396.8 | 76413.8 | 6.48 |
| Farmer practice | 9256 | 5950 | 4000 | 8500 | 18450 | 28333.3 | 84999.9 | 66549.9 | 3.6 |

Estimation of cost and revenue earned was done based on the expenses involved to produce potato around study area and revenues can be gained from production potato in the study area. Estimated benefit-cost ratio (BCR) and net return (NR) were affected by the irrigation techniques. Maximum benefit-cost ratio (BCR) was 7.2 obtained from alternate furrow irrigation followed by 6.5 from fixed furrow irrigation and 5.4 from every furrow irrigation technique, whereas minimum benefit-cost ratio was 3.6 observed from farmer practice. The total cost mainly includes labor, input and fuel costs. Labor costs (labor cost for land preparation, weeding and watering) were estimated based on the study area. Low labor cost was estimated for alternate furrow and fixed furrow irrigation as a result of cost used to irrigate the two techniques is low as compared with every furrow irrigation and farmer practice.

However, net revenue gained from fixed furrow irrigation was low as a result of low marketable yield collected from this treatment as compared with alternate furrow irrigation. From the results of this study, alternate furrow irrigation was the best method to improve water productivity, water use efficiency and economic return from potato production. The result benefit-cost ratio indicated in table 16 showed that all irrigation methods are feasible. However by comparing alternate furrow irrigation with other methods, farmers can get more benefit from alternate furrow irrigation compared to other irrigation methods.

# 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 5. 1. Summary

At present situation, the depth of rainfall is low or its distribution is uneven, and highly erratic to meet the daily crop evapotranspiration requirement. Under this condition, the need to use the available water economically and efficiently is unquestionable. Based on the actual crop need, irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving high yield. Alternate furrow irrigation is one of the irrigation management practices that can save irrigation water. This experiment was conducted to study the effect of alternate furrow irrigation system by comparing with others irrigation techeniques on yield, water productivity and water use efficiency of potato (*Solanum tuberosum L.*). This study emphasized on comparison of irrigation methods to identify the irrigation management strategies which could contribute for water saving, increase water productivity and water use efficiency with no or minimum yield reduction in the humid climate of Western Ethiopia particularly West Shoa zone of Oromia region. Results confirmed that irrigation treatments significantly influenced yield, water productivity and water use efficiencies of potato.

In order to compare irrigation methods some parameters such as application efficiency, distribution uniformity, tuber yield and water productivity were measured for all irrigation treatments. Highest value of irrigation performance indicators (coefficient of uniformity and distribution uniformity) were obtained under alternate furrow irrigation. From the investigation the highest total tuber yield was observed under every furrow irrigation method which showed little difference as compared with alternate furrow irrigation. The yield reduction observed under alternate furrow irrigation is less than 1 % as compared with every furrow irrigation method, which has no significant impact on marketable yield of the potato crop. The highest marketable yield (32682.7kgha$^{-}$1) was obtained from alternate furrow irrigation, whereas the lowest marketable yield (28333.3kgha$^{-}$1) was obtained from farmer practice.

Comparing the results of the irrigation methods from the point of crop water productivity, it clearly confirmed that, alternate furrow irrigation method had more beneficial use of water followed by fixed furrow irrigation and every furrow irrigation methods respectively. The highest water productivity (WP) value (11.2kg $m^{-3}$) was obtained under alternate furrow irrigation (AFI), whereas the lowest value (4.1kg $m^{-3}$) was obtained under famer practice. Alternate furrow and fixed furrow irrigation methods saved 50% of water applied under of every furrow irrigation method .However; under fixed furrow irrigation method low water productivity was recorded as compared with alternate furrow irrigation method. This study advocates that alternate furrow irrigation was substantially saved water than every furrow irrigation method without significant yield reduction which is sufficient to irrigate additional area of potato cropped land. Moreover, alternate furrow irrigation method increased the benefit-cost ratio (BCR), net return (NR) in addition to saving water.

## 5.2. Conclusions

The results demonstrated conclusively that alternate furrow irrigation method is more effective in enhancing water productivity (WP) and water use efficiency (WUE) as compared with other methods. The study results confirmed that with alternate irrigation strategy it is possible to increase water productivity and save significant depth of water for irrigation without significant yield reduction**.** From this result, one can conclude that applying alternate furrow irrigation method improved water efficiency by saving 50% of water applied under every furrow irrigation method which is sufficient to irrigate one hectare potato cropped land.. Similarly, applying alternate furrow irrigation method improved water use efficiency by saving 68.4% of water applied under farmer practice which is sufficient to irrigate two hectare of potato cropped land. These results indicated that alternate furrow irrigation (AFI) is appropriate to increase water productivity (WP) and water use efficiency (WUE) by allowing application of less irrigation water with minor or no yield reduction as compared to every furrow irrigation method.

Therefore applying alternate-furrow irrigation with appropriate irrigation intervals is efficient method in the study area where soil is mainly dominated by clay soil and water become limiting factor in potato production.

It can be conclude that using alternate irrigation is a good water management technique to save irrigation water without reducing the yield of potato crop. The preference between alternate furrow irrigation method and other methods depends on the value of water in relation to crop returns. This water application technique is much important for highlands of western Ethiopia like the West Shoa zone of Oromia region and other similar agro-ecology elsewhere in the Ethiopia where limited amount of water is available for irrigation and irrigation water management is very poor.

## 5.3. Recommendations

Generally this study would like to recommend farmers, water managers, water use associations and decision makers to use water efficiently using alternate furrow irrigation and increase their agricultural production by expand irrigable land with existing amount of water in a given irrigation scheme. Therefore, alternate furrow irrigation method with appropriate irrigation interval is suitable irrigation method; for humid climate where soil is dominated by clay soil and water is liming factor for potato crop production. Similarly, alternate furrow irrigation with appropriate intervals will essentially be the best choice under similar conditions of the study area. Thus, it is recommended that all possible efforts should be made to introduce the technology to the farming community since the use of alternate furrow irrigation method saves reasonable amount of water without affecting the production in humid area using appropriate varieties of potato crop.

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# 7. APPENDIX

Appendix Table 1 Maximum Temperature collected from Holeta Agricultural Research Center Metrological Station (1985-2015)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 23.64 | 24.22 | 24.59 | 22.68 | 23.27 | 23.42 | 19.01 | 18.98 | 20.07 | 20.22 | 22.49 | 22.65 |
| 1986 | 23.73 | 23.93 | 23.40 | 22.16 | 23.56 | 21.80 | 20.14 | 19.51 | 20.40 | 21.84 | 22.81 | 23.66 |
| 1987 | 22.94 | 23.55 | 22.54 | 22.63 | 22.59 | 21.98 | 20.95 | 19.97 | 21.45 | 22.61 | 23.34 | 23.46 |
| 1988 | 23.63 | 23.70 | 26.04 | 24.42 | 25.54 | 22.14 | 18.72 | 19.38 | 19.87 | 21.18 | 21.99 | 22.25 |
| 1989 | 22.38 | 22.24 | 23.20 | 21.63 | 24.14 | 22.61 | 19.37 | 19.66 | 19.95 | 21.29 | 22.50 | 22.11 |
| 1990 | 23.03 | 21.91 | 22.77 | 23.02 | 24.56 | 22.17 | 19.79 | 19.55 | 20.09 | 21.90 | 22.80 | 23.13 |
| 1991 | 24.18 | 23.85 | 23.28 | 24.37 | 25.93 | 23.81 | 19.49 | 19.81 | 20.94 | 22.17 | 22.52 | 22.73 |
| 1992 | 22.42 | 22.58 | 24.79 | 24.55 | 24.29 | 22.46 | 19.37 | 18.66 | 19.68 | 20.98 | 21.81 | 22.50 |
| 1993 | 22.39 | 22.00 | 25.11 | 22.39 | 22.86 | 21.61 | 19.62 | 19.40 | 19.33 | 21.50 | 22.42 | 30.13 |
| 1994 | 24.09 | 25.14 | 24.43 | 24.05 | 25.07 | 21.42 | 18.95 | 19.32 | 20.64 | 22.35 | 22.43 | 23.13 |
| 1995 | 24.02 | 24.28 | 24.48 | 22.55 | 23.99 | 23.57 | 19.37 | 19.66 | 20.59 | 22.58 | 23.36 | 23.16 |
| 1996 | 21.78 | 24.90 | 24.23 | 23.20 | 23.13 | 20.64 | 19.90 | 19.51 | 20.35 | 22.32 | 22.52 | 22.63 |
| 1997 | 22.92 | 24.65 | 25.56 | 23.82 | 25.34 | 23.42 | 20.13 | 20.25 | 22.14 | 22.47 | 22.46 | 23.56 |
| 1998 | 23.75 | 24.40 | 24.80 | 25.68 | 24.33 | 23.21 | 25.92 | 19.69 | 20.64 | 21.52 | 22.36 | 22.43 |
| 1999 | 23.19 | 25.13 | 23.91 | 25.57 | 24.56 | 23.02 | 19.05 | 19.46 | 20.52 | 20.58 | 21.89 | 22.27 |
| 2000 | 23.29 | 24.51 | 25.70 | 23.81 | 29.85 | 21.09 | 20.18 | 19.00 | 20.06 | 21.54 | 22.24 | 22.82 |
| 2001 | 22.97 | 24.78 | 22.37 | 24.26 | 30.49 | 21.20 | 19.91 | 19.48 | 20.62 | 22.75 | 22.98 | 23.44 |
| 2002 | 23.08 | 24.88 | 24.03 | 25.32 | 25.67 | 22.91 | 20.98 | 20.27 | 21.21 | 23.29 | 23.91 | 23.29 |
| 2003 | 23.43 | 25.32 | 23.48 | 23.31 | 23.39 | 21.57 | 18.06 | 18.65 | 19.77 | 21.96 | 22.42 | 22.20 |
| 2004 | 23.55 | 23.91 | 24.48 | 22.22 | 24.19 | 21.18 | 19.39 | 19.06 | 19.83 | 20.87 | 22.49 | 22.97 |
| 2005 | 22.92 | 25.32 | 24.46 | 23.80 | 21.96 | 21.06 | 19.48 | 19.69 | 20.08 | 21.40 | 22.00 | 22.94 |
| 2006 | 23.51 | 24.42 | 23.24 | 22.56 | 22.79 | 21.27 | 19.51 | 18.18 | 19.37 | 21.56 | 21.56 | 21.63 |
| 2007 | 23.48 | 23.52 | 24.01 | 23.00 | 23.97 | 21.15 | 18.97 | 19.10 | 19.63 | 20.98 | 22.27 | 24.60 |
| 2008 | 26.67 | 23.35 | 26.77 | 24.55 | 24.70 | 21.39 | 20.58 | 19.92 | 21.03 | 22.50 | 21.08 | 22.85 |
| 2009 | 23.26 | 24.68 | 26.06 | 25.93 | 26.61 | 25.50 | 21.37 | 20.89 | 22.04 | 23.19 | 24.43 | 23.05 |
| 2010 | 23.72 | 21.66 | 24.99 | 23.41 | 24.31 | 22.99 | 21.65 | 20.89 | 20.35 | 23.87 | 22.21 | 22.87 |
| 2011 | 24.52 | 22.94 | 24.02 | 24.97 | 24.85 | 22.52 | 21.02 | 20.27 | 19.99 | 23.49 | 23.22 | 23.47 |
| 2012 | 24.84 | 25.92 | 26.56 | 25.05 | 25.89 | 24.73 | 16.58 | 20.29 | 21.21 | 23.43 | 25.62 | 25.91 |
| 2013 | 27.09 | 28.37 | 28.82 | 26.43 | 25.89 | 25.73 | 19.75 | 22.88 | 21.55 | 25.23 | 23.94 | 19.33 |
| 2014 | 19.59 | 19.34 | 21.17 | 24.42 | 25.32 | 24.86 | 21.38 | 20.87 | 21.39 | 19.90 | 18.90 | 18.70 |
| 2015 | 26.09 | 26.07 | 25.00 | 25.00 | 25.00 | 25.00 | 24.00 | 24.30 | 20.10 | 24.30 | 23.60 | 22.80 |
| Sum | 730.19 | 745.46 | 758.31 | 740.74 | 768.05 | 701.44 | 622.59 | 616.56 | 634.89 | 685.80 | 700.58 | 712.66 |
| Mean | 23.55 | 26.62 | 25.28 | 24.69 | 24.78 | 24.19 | 20.08 | 19.89 | 22.67 | 22.12 | 23.35 | 22.99 |

Appendix Table 2 Minimum Temperature collected from Holeta Agricultural Research Center Metrological Station (1985-2015)

| Year | Jan | Feb | Mar | April | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 2.45 | 3.29 | 6.97 | 8.98 | 7.73 | 6.76 | 8.31 | 8.93 | 7.34 | 4.54 | 1.41 | 1.08 |
| 1986 | 0.24 | 6.32 | 6.19 | 9.15 | 8.20 | 8.52 | 8.56 | 8.10 | 6.97 | 3.40 | 1.32 | 2.13 |
| 1987 | 2.33 | 6.10 | 10.07 | 8.24 | 8.79 | 7.80 | 8.83 | 9.68 | 7.79 | 5.69 | 2.18 | 3.02 |
| 1988 | 4.68 | 8.49 | 5.58 | 8.79 | 6.92 | 8.27 | 10.41 | 9.86 | 8.94 | 5.03 | 0.19 | 0.27 |
| 1989 | 3.57 | 7.13 | 6.55 | 8.56 | 7.06 | 7.66 | 9.74 | 9.42 | 8.30 | 4.90 | 1.23 | 3.01 |
| 1990 | 2.68 | 9.92 | 7.02 | 8.50 | 7.69 | 7.29 | 9.25 | 9.24 | 8.47 | 4.29 | 3.52 | 0.68 |
| 1991 | 4.63 | 10.31 | 8.53 | 7.92 | 7.65 | 8.49 | 10.11 | 9.68 | 7.95 | 3.38 | 1.54 | 2.64 |
| 1992 | 4.00 | 4.22 | 6.80 | 7.95 | 7.54 | 7.46 | 9.03 | 8.76 | 6.98 | 4.83 | 2.13 | 1.47 |
| 1993 | 5.60 | 7.41 | 4.55 | 9.59 | 8.26 | 8.29 | 9.12 | 8.61 | 7.74 | 5.76 | 1.80 | 0.97 |
| 1994 | 1.64 | 3.90 | 8.01 | 7.87 | 7.35 | 8.09 | 9.92 | 9.10 | 6.62 | 2.46 | 2.65 | 0.54 |
| 1995 | 1.39 | 5.72 | 6.95 | 9.83 | 7.58 | 6.54 | 8.59 | 9.10 | 6.29 | 3.39 | 1.68 | 3.28 |
| 1996 | 5.42 | 3.56 | 7.75 | 7.45 | 7.28 | 8.19 | 8.65 | 8.29 | 7.12 | 3.16 | 2.46 | 1.65 |
| 1997 | 5.57 | 1.08 | 7.25 | 8.07 | 6.59 | 8.40 | 8.26 | 8.43 | 7.17 | 6.34 | 5.55 | 2.49 |
| 1998 | 6.38 | 7.77 | 8.77 | 8.87 | 9.07 | 7.82 | 12.23 | 9.32 | 7.86 | 6.57 | 0.68 | -1.55 |
| 1999 | 1.77 | 0.98 | 6.11 | 5.74 | 6.64 | 6.73 | 8.38 | 8.10 | 6.44 | 5.83 | 0.10 | 0.35 |
| 2000 | 0.32 | 0.63 | 3.47 | 7.09 | 6.91 | 6.48 | 7.72 | 7.60 | 6.58 | 4.69 | 2.31 | 1.03 |
| 2001 | 2.79 | 2.42 | 7.35 | 6.42 | 7.00 | 6.75 | 7.98 | 8.28 | 5.22 | 3.55 | 1.20 | 3.16 |
| 2002 | 4.75 | 4.75 | 8.14 | 8.32 | 8.95 | 8.01 | 9.11 | 8.27 | 6.84 | 4.24 | 2.41 | 6.47 |
| 2003 | 5.02 | 5.83 | 6.98 | 9.41 | 8.37 | 7.94 | 9.29 | 9.05 | 7.83 | 3.76 | 2.23 | 2.22 |
| 2004 | 5.32 | 4.47 | 6.68 | 9.57 | 7.02 | 8.08 | 8.71 | 8.70 | 7.72 | 4.33 | 2.47 | 3.74 |
| 2005 | 3.44 | 4.48 | 7.26 | 8.01 | 9.44 | 6.99 | 8.70 | 8.81 | 8.33 | 4.31 | 1.90 | -0.28 |
| 2006 | 3.56 | 6.52 | 6.91 | 9.22 | 7.37 | 7.79 | 9.53 | 9.49 | 7.79 | 6.20 | 4.32 | 4.99 |
| 2007 | 4.62 | 6.43 | 6.21 | 8.82 | 8.49 | 8.30 | 10.03 | 9.37 | 8.32 | 4.29 | 1.91 | 0.02 |
| 2008 | 3.90 | 3.90 | 3.55 | 7.96 | 8.92 | 8.99 | 9.64 | 9.76 | 7.97 | 6.20 | 4.05 | 1.98 |
| 2009 | 5.11 | 4.72 | 6.61 | 8.07 | 9.83 | 8.34 | 10.43 | 10.41 | 8.50 | 6.63 | 2.22 | 7.16 |
| 2010 | 5.34 | 7.95 | 8.95 | 10.11 | 10.77 | 9.51 | 10.54 | 10.34 | 8.54 | 5.74 | 3.37 | 4.06 |
| 2011 | 3.83 | 2.14 | 6.12 | 6.82 | 8.34 | 7.59 | 7.78 | 8.79 | 6.74 | 1.02 | 3.04 | 0.35 |
| 2012 | 0.86 | 0.65 | 3.83 | 8.32 | 8.88 | 8.50 | 9.41 | 9.05 | 7.96 | 3.56 | 2.32 | 0.40 |
| 2013 | -0.59 | 1.90 | 2.40 | 5.73 | 8.88 | 10.68 | 10.55 | 9.81 | 8.50 | 6.77 | 6.41 | 4.10 |
| 2014 | 5.05 | 8.70 | 6.74 | 6.30 | 6.96 | 7.20 | 8.96 | 8.38 | 10.26 | 6.50 | 4.30 | 4.20 |
| 2015 | 5.08 | 7.98 | 7.75 | 5.96 | 7.02 | 7.40 | 7.75 | 8.25 | 9.86 | 7.85 | 5.48 | 4.59 |
| Sum | 110.75 | 159.65 | 206.05 | 251.63 | 247.48 | 244.88 | 285.53 | 278.95 | 238.91 | 149.23 | 78.38 | 70.23 |
| Mean | 3.57 | 5.70 | 6.65 | 8.99 | 7.98 | 8.16 | 9.21 | 9.00 | 8.24 | 4.81 | 2.61 | 2.42 |

Appendix Table 3 Monthly rain fall collected from Holeta Agricultural Research Center Metrological Station (1985-2015)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 2.4 | 0.0 | 47.7 | 58.0 | 48.5 | 45.6 | 257.3 | 281.9 | 105.1 | 21.1 | 41.0 | 0.0 |
| 1986 | 0.0 | 51.2 | 82.9 | 136.1 | 87.6 | 157.9 | 243.9 | 273.4 | 144.0 | 11.9 | 12.0 | 0.0 |
| 1987 | 2.4 | 76.7 | 112.1 | 82.4 | 137.0 | 86.5 | 184.1 | 256.8 | 112.4 | 19.0 | 23.0 | 27.4 |
| 1988 | 10.3 | 108.7 | 5.4 | 90.1 | 24.9 | 108.0 | 291.6 | 283.9 | 239.9 | 31.9 | 25.0 | 0.2 |
| 1989 | 7.1 | 86.9 | 78.0 | 69.8 | 8.3 | 74.9 | 240.7 | 278.6 | 117.5 | 3.0 | 4.0 | 21.6 |
| 1990 | 0.5 | 162.4 | 34.9 | 95.4 | 55.5 | 131.8 | 263.4 | 338.2 | 155.5 | 8.0 | 0.0 | 0.9 |
| 1991 | 23.9 | 74.8 | 118.0 | 27.3 | 37.2 | 89.9 | 241.1 | 229.0 | 172.6 | 2.6 | 0.3 | 5.8 |
| 1992 | 57.4 | 34.8 | 58.8 | 95.0 | 34.6 | 115.3 | 190.9 | 312.8 | 112.1 | 35.1 | 0.6 | 7.8 |
| 1993 | 18.2 | 83.8 | 3.8 | 127.0 | 60.3 | 103.1 | 218.1 | 276.1 | 214.8 | 27.4 | 0.7 | 5.0 |
| 1994 | 0.0 | 2.3 | 86.7 | 45.9 | 29.8 | 107.3 | 216.4 | 209.3 | 149.7 | 0.0 | 0.7 | 36.0 |
| 1995 | 0.0 | 84.6 | 41.9 | 122.8 | 81.3 | 86.4 | 191.9 | 262.7 | 82.1 | 3.9 | 0.7 | 0.0 |
| 1996 | 62.6 | 8.5 | 96.1 | 58.4 | 45.4 | 192.6 | 249.8 | 236.4 | 120.7 | 5.3 | 0.7 | 0.0 |
| 1997 | 15.3 | 0.0 | 21.1 | 77.4 | 13.5 | 131.0 | 233.5 | 206.6 | 42.5 | 53.5 | 0.7 | 0.0 |
| 1998 | 54.6 | 42.3 | 25.7 | 65.7 | 80.4 | 141.5 | 341.6 | 238.1 | 168.3 | 67.4 | 0.7 | 0.0 |
| 1999 | 77.3 | 4.6 | 34.0 | 16.6 | 54.6 | 98.9 | 272.8 | 307.7 | 88.9 | 65.4 | 0.7 | 56.0 |
| 2000 | 0.0 | 0.0 | 12.5 | 123.8 | 50.8 | 89.8 | 187.1 | 260.6 | 120.5 | 9.5 | 0.7 | 0.0 |
| 2001 | 7.9 | 10.6 | 130.7 | 48.6 | 101.2 | 176.5 | 301.6 | 161.2 | 103.2 | 24.2 | 0.7 | 0.0 |
| 2002 | 72.6 | 25.7 | 56.9 | 38.1 | 49.4 | 123.2 | 273.1 | 194.0 | 77.4 | 0.0 | 0.7 | 58.0 |
| 2003 | 17.5 | 11.3 | 33.3 | 84.2 | 13.6 | 117.1 | 194.0 | 237.2 | 107.4 | 10.0 | 0.7 | 0.0 |
| 2004 | 12.7 | 0.8 | 42.5 | 155.1 | 27.0 | 121.4 | 204.0 | 226.6 | 119.7 | 3.6 | 0.7 | 0.0 |
| 2005 | 22.0 | 4.5 | 61.7 | 49.1 | 94.4 | 81.8 | 253.9 | 187.5 | 130.7 | 31.5 | 3.8 | 12.0 |
| 2006 | 0.0 | 9.0 | 68.4 | 99.1 | 98.4 | 113.7 | 288.6 | 250.0 | 116.1 | 13.1 | 6.0 | 0.6 |
| 2007 | 0.0 | 14.0 | 61.2 | 36.4 | 73.5 | 253.3 | 159.3 | 249.5 | 88.5 | 18.8 | 0.0 | 0.0 |
| 2008 | 0.0 | 18.5 | 1.0 | 31.3 | 86.6 | 87.6 | 287.2 | 157.8 | 195.7 | 43.0 | 64.4 | 3.5 |
| 2009 | 20.4 | 8.6 | 0.0 | 30.0 | 10.6 | 64.8 | 214.8 | 234.2 | 75.9 | 15.6 | 6.2 | 39.4 |
| 2010 | 6.0 | 40.7 | 83.2 | 65.3 | 76.9 | 93.0 | 287.9 | 224.2 | 192.2 | 0.0 | 24.1 | 16.8 |
| 2011 | 0.0 | 38.8 | 42.6 | 33.3 | 73.5 | 151.8 | 237.3 | 270.4 | 168.1 | 0.0 | 16.7 | 0.0 |
| 2012 | 0.0 | 0.0 | 4.1 | 98.6 | 0.0 | 60.7 | 246.1 | 171.4 | 232.3 | 6.4 | 0.0 | 5.7 |
| 2013 | 0.0 | 0.0 | 23.0 | 133.2 | 43.8 | 120.7 | 81.8 | 201.9 | 110.1 | 19.1 | 5.0 | 0.0 |
| 2014 | 20.7 | 21.0 | 31.1 | 36.1 | 94.3 | 68.4 | 137.3 | 222.4 | 70.3 | 0.3 | 0.1 | 0.0 |
| Total | 511.8 | 1025.1 | 1499.3 | 2230.1 | 1692.9 | 3394.5 | 6991.1 | 7240.4 | 3934.2 | 550.6 | 240.6 | 296.7 |
| Mean | 16.5 | 36.6 | 48.4 | 79.6 | 54.6 | 113.1 | 225.5 | 233.6 | 135.7 | 18.4 | 8.3 | 9.6 |

Appendix Table 4 Monthly reference evapotranspiration

| Month | Min Temp $^{o}C$ | Max Temp $^{o}C$ | Humidity % | Wind speed km/day | Sunshine Hours | ETo Mm/day |
|---|---|---|---|---|---|---|
| January | 3.4 | 23.4 | 51 | 130 | 8.0 | 3.37 |
| February | 5.0 | 23.9 | 50 | 147 | 7.6 | 3.72 |
| March | 6.7 | 24.4 | 51 | 147 | 7.1 | 3.32 |
| April | 7.9 | 23.9 | 56 | 138 | 7.0 | 3.56 |
| May | 6.8 | 24.4 | 56 | 130 | 6.3 | 3.76 |
| June | 7.7 | 22.4 | 66 | 95 | 5.1 | 3.60 |
| July | 9.1 | 20.0 | 78 | 104 | 3.4 | 3.22 |
| August | 9.1 | 19.6 | 80 | 95 | 8.1 | 3.41 |
| September | 7.8 | 20.3 | 74 | 104 | 5.0 | 3.72 |
| October | 4.9 | 21.9 | 57 | 156 | 7.6 | 3.84 |
| November | 2.3 | 22.4 | 52 | 147 | 8.7 | 3.38 |
| December | 1.9 | 22.8 | 51 | 147 | 8.6 | 2.89 |
| Average | 6.0 | 22.4 | 60 | 128.3 | 6.9 | 3.48 |

Appendix Table 5 Irrigation scheduling of potato throughout the growing season

| No of irrigation | Irrigation Interv.ays | Date | Eta % | Depl % | Deficit Mm | Gross irr. Mm | Flow l/s/ha |
|---|---|---|---|---|---|---|---|
| 1 | 12Dec | Init | 56 | 65 | 0.00 | 71.8 | 0.59 |
| 2 | 3Jan | Dev | 90 | 50 | 0.00 | 74.1 | 0.39 |
| 3 | 16Jan | Dev | 97 | 42 | 0.00 | 72.0 | 0.64 |
| 4 | 29Jan | Mid | 98 | 43 | 0.00 | 73.1 | 0.65 |
| 5 | 11Feb | Mid | 97 | 45 | 0.00 | 76.5 | 0.68 |
| 6 | 23Feb | Mid | 98 | 43 | 0.00 | 72.9 | 0.70 |
| 7 | 8Mar | End | 100 | 42 | 0.00 | 72.5 | 0.65 |
| 8 | 24Mar | End | 100 | 42 | 0.00 | 71.4 | 0.52 |
| End | 28Mar | End | 0 | 7 | 0.00 | | |

Appendix Table 6 Analysis of Variance for Application efficiency of 1st irrigation

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 3046.45 | 3 | 1015.484 | 7.77 | 3.49 | 5.95 |
| Rep | 861.467 | 4 | 215.36675 | 1.65 | 3.26 | 5.41 |
| Error | 1568.773 | 12 | 130.7310 | | | |
| Total | 5476.69 | 19 | | | | |

Appendix Table 7 Analysis of variance for application efficiency of 2nd irrigation

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 4541.756 | 3 | 1513.918667 | 26.46 | 3.49 | 5.95 |
| Rep | 1230.323 | 4 | 307.580750 | 5.38 | 3.26 | 5.41 |
| Error | 686.54 | 12 | 57.212417 | | | |
| Total | 5476.69 | 19 | | | | |

Appendix Table 8 Analysis of variance for application efficiency of 3rd irrigation

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 5874.95 | 3 | 1958.316667 | 15.11 | 3.49 | 5.95 |
| Rep | 192.8 | 4 | 48.2 | 0.37 | 3.26 | 5.41 |
| Error | 1554.8 | 12 | 129.566667 | | | |
| Total | 5476.69 | 19 | | | | |

Appendix Table 9 Analysis of variance for application efficiency of 4th irrigation

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 6134.95 | 3 | 2044.983333 | 29.41 | 3.49 | 5.95 |
| Rep | 97.3 | 4 | 24.3250 | 0.35 | 3.26 | 5.41 |
| Error | 1554.8 | 12 | 129.566667 | | | |
| Total | 5476.69 | 19 | | | | |

Appendix Table 10 Analysis of variance for application efficiency of 5th irrigation

| Source | Df | SS | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 3 | 6162.200000 | 2054.066667 | 70.44 | 3.49 | 5.95 |
| Rep | 4 | 1482.175000 | 370.543750 | 12.71 | 3.26 | 5.41 |
| Error | 12 | 349.925000 | 29.160417 | | | |
| Total | 19 | 5476.69 | | | | |

Appendix Table 11 Analysis of variance for application efficiency of 6th irrigation

| Source | Df | SS | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 3 | 4823.600000 | 1607.866667 | 18.03 | 3.49 | 5.95 |
| Rep | 4 | 1477.300000 | 369.325000 | 4.14 | 3.26 | 5.41 |
| Error | 12 | 1069.900000 | 89.158333 | | | |
| Total | 19 | 5476.69 | | | | |

Appendix Table 12 Analysis of variance for application efficiency of 7th irrigation

| Source | Df | SS | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 3 | 4247.400000 | 1415.800000 | 45.41 | 3.49 | 5.95 |
| Rep | 4 | 1836.700000 | 459.175000 | 14.73 | 3.26 | 5.41 |
| Error | 12 | 374.100000 | 31.175000 | | | |
| Total | 19 | 5476.69 | | | | |

Appendix Table 13 Analysis of variance for application efficiency of 8th irrigation

| Source | Df | SS | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 3 | 5710.150000 | 1903.383333 | 86.65 | 3.49 | 5.95 |
| Rep | 4 | 1689.200000 | 422.300000 | 19.22 | 3.26 | 5.41 |
| Error | 12 | 263.600000 | 21.966667 | | | |
| Total | 19 | 5476.69 | | | | |

Appendix Table 14 Analysis of variance for total tuber yield

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 49578759.32 | 3 | 16526253.11 | 5.02 | 3.49 | 5.95 |
| Rep | 29617940.99 | 4 | 7404485.25 | 2.25 | 3.26 | 5.41 |
| Error | 39479621.6 | 12 | 3289968.5 | | | |
| Total | 118676321.91 | 19 | | | | |

Appendix Table 15 Analysis of variance for marketable tuber yield

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 61402167.08 | 3 | 20467389.03 | 15.35 | 3.49 | 5.95 |
| Rep | 14831180.78 | 4 | 3707795.20 | 2.78 | 3.26 | 5.41 |
| Error | 16004516.96 | 12 | 1333709.75 | | | |
| Total | 92237864.82 | 19 | | | | |

Appendix Table 16 Analysis of Variance for unmarketable tuber yield

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 5303609.568 | 3 | 1767869.856 | 13.57 | 3.49 | 5.95 |
| Rep | 115607.630 | 4 | 28901.907 | 0.22 | 3.26 | 5.41 |
| Error | 16004516.96 | 12 | 1333709.75 | | | |
| Total | 21423734.158 | 19 | | | | |

Appendix Table 17 Analysis of variance for number of tubers per plant

| Source | SS | Df | MS | F-ratio | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 308.56584 | 3 | 102.85528 | 17.21 | 3.49 | 5.95 |
| Rep | 31.96672 | 4 | 7.9916800 | 1.34 | 3.26 | 5.41 |
| Error | 71.70816 | 12 | 8.586 | | | |
| Total | 412.24072 | 19 | | | | |

Appendix Table 18 Analysis of Variance for Water productivity (WP)

| Source | SS | Df | MS | F Value | 5% SL | 1% SL |
|---|---|---|---|---|---|---|
| Trt | 184.15 | 3 | 61.384 | 735.76 | 3.49 | 5.95 |
| Rep | 0.48 | 4 | 0.1202 | 1.44 | 3.26 | 5.41 |
| Error | 1.0011 | 12 | 0.083 | | | |
| Total | 185.6311 | 19 | | | | |

Appendix Table 19 Determination of application efficiency (AE) at 1st irrigation

| Treatments | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation (mm) | Depth of water stored per layer (mm) | Depth of water applied per plot (mm) | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.97 | 16.85 | 12.88 | 50.1 | 67 |
| | 20-40 | 2.45 | 14.8 | 12.35 | | |
| | 40-60 | 1.56 | 9.8 | 8.24 | | |
| | Total | 7.98 | 41.45 | 33.47 | | |
| AFI | 0-20 | 3.26 | 10.56 | 8.3 | 25.1 | 81 |
| | 20-40 | 2.56 | 8.85 | 6.29 | | |
| | 40-60 | 1.6 | 7.43 | 5.83 | | |
| | Total | 7.42 | 26.84 | 20.42 | | |
| FFI | 0-20 | 3.85 | 10.23 | 6.38 | 25.1 | 75 |
| | 20-40 | 2.89 | 9.45 | 6.56 | | |
| | 40-60 | 1.7 | 7.67 | 5.97 | | |
| | Total | 8.44 | 27.35 | 18.91 | | |
| FP | 0-20 | 3.56 | 19.6 | 16.04 | 75.3 | 48 |
| | 20-40 | 2.87 | 13.75 | 10.88 | | |
| | 40-60 | 1.84 | 6.5 | 4.66 | | |
| | Total | 8.3 | 39.9 | 31.58 | | |

Appendix Table 20 Determination of coefficient of uniformity (Cu) at 1st irrigation

| Treatments | Points of sampling (m) | Depth of sampling (cm) | Depth of water stored after irrigation (mm) | Average depth x | rrigation $Cuc = \left(1 - \frac{\sum\lvert X_i - X\rvert}{nX}\right) 100$ |
|---|---|---|---|---|---|
| | 2 | | 14.35 | | 88 |
| | 5 | 0-20 | 13.18 | | |
| | 8 | | 11.12 | 12.88 | |
| EFI | 2 | | 13.86 | | |
| | 5 | 20-40 | 12.55 | | |
| | 8 | | 10.68 | 12.35 | 86 |
| | 2 | | 9.16 | 8.24 | |
| | 5 | | 8.88 | | |
| | 8 | 40-60 | 6.69 | | 87 |
| | 2 | | 8.76 | | |
| | 5 | | 7.03 | | |
| | 8 | 0-20 | 6.02 | 7.3 | 86 |
| AFI | 2 | | 7.22 | | |
| | 5 | | 6.12 | | |
| | 8 | 20-40 | 5.55 | 6.29 | 90 |
| | 2 | | 6.38 | | |
| | 5 | | 6.01 | | |
| | 8 | 40-60 | 5.12 | 5.83 | 92 |
| | 2 | | 8.65 | 7.41 | |
| | 5 | | 7.12 | | |
| | 8 | 0-20 | 6.46 | | 75 |
| FFI | 2 | | 7.28 | 6.56 | |
| | 5 | | 7.12 | | |
| | 8 | 20-40 | 5.28 | | 80 |
| | 2 | | 7.11 | | |
| | 5 | | 6.12 | | |
| | 8 | 40-60 | 5.12 | 5.97 | 86 |
| | 2 | | 19.82 | | 77 |
| | 5 | | 17.88 | | |
| | 8 | 0-20 | 10.56 | 16.09 | |
| FP | 2 | | 13.58 | | |
| | 5 | | 11.86 | | |
| | 8 | 20-40 | 6.96 | 10.88 | 77 |
| | 2 | | 6.13 | | |
| | 5 | 40-60 | 5.12 | | |
| | 8 | | 2.98 | 4.66 | 74 |

Appendix Table 21 Determination of application efficiency (AE) at 2nd irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation (mm) | Depth of water stored per layer (mm) | Depth of water applied per plot (mm) | AE |
|---|---|---|---|---|---|---|
| EF | 0-20cm | 3.27 | 17.86 | 14.59 | 50.3 | 65 |
| | 20-40 | 2.45 | 14.8 | 12.35 | | |
| | 40-60 | 1.26 | 9.8 | 8.54 | | |
| | Total | 6.98 | 42.45 | 35.48 | | |
| AFI | 0-20 | 3.56 | 11.56 | 8 | 25.15 | 82 |
| | 20-40 | 2.89 | 9.85 | 6.96 | | |
| | 40-60 | 1.6 | 7.43 | 5.83 | | |
| | Total | 8.05 | 27.84 | 20.79 | | |
| FFI | 0-20 | 3.26 | 10.31 | 7.05 | 25.15 | 77 |
| | 20-40 | 2.89 | 8.6 | 5.71 | | |
| | 40-60 | 1.6 | 6.67 | 5.07 | | |
| | Total | 7.75 | 28.13 | 17.83 | | |
| FP | 0-20 | 3.56 | 18 | 14.44 | 75.5 | 43 |
| | 20-40 | 2.87 | 12.5 | 9.63 | | |
| | 40-60 | 1.84 | 6.5 | 4.66 | | |
| | Total | 8.3 | 39.9 | 28.73 | | |

Appendix Table 22 Determination of coefficient of uniformity (Cu) at 2nd irrigation

| Trt | Points (m) | Depth of sampling (cm) | Depth of stored after Irrigation ($x_i$) mm | Average depth x | ı) at 2nd irri $\sum|$tion<br>$Cuc = \left(1 - \frac{x_i - x|}{nX}\right)100$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 13.98 | 14.58 | 88 |
| | 5 | | 14.78 | | |
| | 8 | | 14.98 | | |
| | 2 | 20-40 | 13.42 | 12.35 | 87 |
| | 5 | | 12.03 | | |
| | 8 | | 11.61 | | |
| | 2 | 40-60 | 9.92 | 8.54 | 87 |
| | 5 | | 8.72 | | |
| | 8 | | 6.81 | | |
| AFI | 2 | 0-20 | 9.09 | 7 | 94 |
| | 5 | | 7.05 | | |
| | 8 | | 6.05 | | |
| | 2 | 20-40 | 8.06 | 6.96 | 92 |
| | 5 | | 6.78 | | |
| | 8 | | 6.10 | | |
| | 2 | 40-60 | 7.02 | 5.83 | 90 |
| | 5 | | 6.01 | | |
| | 8 | | 5.13 | | |
| FFI | 2 | 0-20 | 9.01 | 7.75 | 78 |
| | 5 | | 7.04 | | |
| | 8 | | 6.18 | | |
| | 2 | 20-40 | 7.45 | 6.56 | 79 |
| | 5 | | 7.18 | | |
| | 8 | | 5.07 | | |
| | 2 | 40-60 | 7.11 | 6.07 | 78 |
| | 5 | | 7.02 | | |
| | 8 | | 6.14 | | |
| FP | 2 | 0-20 | 19.79 | 16.09 | 71 |
| | 5 | | 17.89 | | |
| | 8 | | 10.59 | | |
| | 2 | 20-40 | 13.88 | 10.88 | 69 |
| | 5 | | 12.46 | | |
| | 8 | | 6.36 | | |
| | 2 | 40-60 | 6.12 | 4.66 | 71 |
| | 5 | | 5.01 | | |
| | 8 | | 2.98 | | |

Appendix Table 23 Determination application efficiency (AE) at 3rd irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation (mm) | Depth of water stored per layer (mm) | Depth of water applied per plot (mm) | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.23 | 18.12 | 14.89 | 50.6 | 60 |
| | 20-40 | 2.38 | 16.8 | 14.42 | | |
| | 40-60 | 1.46 | 10.95 | 9.49 | | |
| | Total | 7.07 | 45.87 | 38.8 | | |
| AFI | 0-20 | 3.44 | 12.7 | 9.24 | 25.3 | 84 |
| | 20-40 | 2.98 | 10.13 | 7.15 | | |
| | 40-60 | 1.98 | 8.12 | 6.14 | | |
| | Total | 8.4 | 30.23 | 22.53 | | |
| FFI | 0-20 | 3.26 | 11 | 7.74 | 25.3 | 73 |
| | 20-40 | 2.85 | 8.83 | 5.97 | | |
| | 40-60 | 1.86 | 7.64 | 5.78 | | |
| | Total | 7.97 | 29.032 | 19.4 | | |
| FP | 0-20 | 3.86 | 17.68 | 13.82 | 76 | 38 |
| | 20-40 | 2.98 | 13.25 | 10.27 | | |
| | 40-60 | 1.98 | 8.75 | 6.77 | | |
| | Total | 8.82 | 45.58 | 30.16 | | |

Appendix Table 24 Determination of Coefficient of uniformity (Cu) at 3rd irrigation

| Trt | Points (m) | Depth of sampling (cm) | Depth of stored after irrigation ( $x_i$) mm | Average depth x | t 3rd irrigati∑\|¹ $Cuc = \left(1 - \frac{X_i - X\|}{nX}\right)100$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 16.78 | 14.89 | 89 |
| | 5 | | 14.89 | | |
| | 8 | | 12.99 | | |
| | 2 | 20-40 | 15.86 | 14.42 | 90 |
| | 5 | | 14.74 | | |
| | 8 | | 12.67 | | |
| | 2 | 40-60 | 10.85 | 9.49 | 89 |
| | 5 | | 9.68 | | |
| | 8 | | 7.95 | | |
| AFI | 2 | 0-20 | 10.13 | 8.54 | 91 |
| | 5 | | 8.64 | | |
| | 8 | | 6.86 | | |
| | 2 | 20-40 | 8.56 | 7.15 | 92 |
| | 5 | | 6.75 | | |
| | 8 | | 6.15 | | |
| | 2 | 40-60 | 7.56 | 6.14 | 91 |
| | 5 | | 5.89 | | |
| | 8 | | 4.96 | | |
| FFI | 2 | 0-20 | 10.13 | 8.3 | 84 |
| | 5 | | 8.11 | | |
| | 8 | | 6.68 | | |
| | 2 | 20-40 | 8.36 | 6.98 | 85 |
| | 5 | | 6.98 | | |
| | 8 | | 5.58 | | |
| | 2 | 40-60 | 7.05 | 5.78 | 84 |
| | 5 | | 5.62 | | |
| | 8 | | 4.7 | | |
| FP | 2 | 0-20 | 19.76 | 16.12 | 76 |
| | 5 | | 17.86 | | |
| | 8 | | 10.65 | | |
| | 2 | 20-40 | 15.68 | 12.87 | 74 |
| | 5 | | 14.97 | | |
| | 8 | | 7.97 | | |
| | 2 | 40-60 | 10.88 | 7.77 | 73 |
| | 5 | | 7.58 | | |
| | 8 | | 4.85 | | |

Appendix Table 25 Determination of application efficiency (AE) at 4th irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation (mm) | Depth of water stored per layer (mm) | Depth of water applied per plot Mm | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.17 | 18.2 | 15.03 | 52.5 | 60 |
| | 20-40 | 2.35 | 16.8 | 14.45 | | |
| | 40-60 | 1.36 | 11.3 | 9.94 | | |
| | Total | 6.88 | 44.31 | 39.42 | | |
| AFI | 0-20 | 3.14 | 12.56 | 9.42 | 26.7 | 87 |
| | 20-40 | 2.97 | 9.85 | 6.88 | | |
| | 40-60 | 1.96 | 7.23 | 5.27 | | |
| | Total | 8.07 | 28.61 | 21.57 | | |
| FFI | 0-20 | 3.16 | 10.56 | 7.4 | 26.7 | 74 |
| | 20-40 | 2.75 | 8.56 | 5.81 | | |
| | 40-60 | 1.76 | 7.2 | 5.44 | | |
| | Total | 7.67 | 27.67 | 18.6 | | |
| FP | 0-20 | 3.76 | 17.25 | 13.49 | 80 | 40 |
| | 20-40 | 2.97 | 13.15 | 10.18 | | |
| | 40-60 | 1.88 | 8.35 | 6.47 | | |
| | Total | 8.61 | 45.03 | 30.14 | | |

Appendix Table 26 Determination of coefficient of uniformity (Cu) at 4th irrigation

| Trt | Points (m) | Depth of sampling (cm) | Depth of stored after irrigation ( $x_i$) mm | Average depth x | $Cuc = \left(1 - \frac{\sum\lvert X_i - X\rvert}{nX}\right)100$ |
|---|---|---|---|---|---|
| | 2 | 0-20 | 15.98 | 14.39 | 88 |
| | 5 | | 14.22 | | |
| | 8 | | 12.86 | | |
| EFI | 2 | 20-40 | 14.69 | 13.45 | 89 |
| | 5 | | 13.98 | | |
| | 8 | | 11.68 | | |
| | 2 | | 10.92 | 9.59 | |
| | 5 | 40-60 | 9.88 | | 88 |
| | 8 | | 7.98 | | |
| | 2 | | 10.2 | 8.42 | |
| | 5 | 0-20 | 8.16 | | 92 |
| | 8 | | 6.92 | | |
| AFI | 2 | | 8.22 | | |
| | 5 | 20-40 | 6.25 | 6.85 | 88 |
| | 8 | | 6.1 | | |
| | 2 | | 6.11 | | |
| | 5 | 40-60 | 5.05 | 5.27 | 91 |
| | 8 | | 4.85 | | |
| | 2 | | 9.75 | 7.96 | |
| | 5 | 0-20 | 7.86 | | 79 |
| | 8 | | 6.28 | | |
| FFI | 2 | | 7.15 | 6.38 | |
| | 5 | 20-40 | 6.98 | | 80 |
| | 8 | | 5.05 | | |
| | 2 | | 6.75 | | |
| | | 40-60 | | 5.66 | 82 |
| | 5 | | 6.12 | | |
| | 8 | | 5.86 | | |
| | 2 | | 19.69 | 16.02 | 77 |
| | 5 | 0-20 | 17.82 | | |
| | 8 | | 10.55 | | |
| FP | 2 | | 15.48 | 12.78 | |
| | 5 | 20-40 | 14.88 | | 74 |
| | 8 | | 7.98 | | |
| | 2 | | 10.76 | 7.62 | |
| | 5 | 40-60 | 7.23 | | 72 |
| | 8 | | 4.88 | | |

Appendix Table 27 Determination of application efficiency (AE) at 5th irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation mm | Depth of water stored per layer mm | Depth of water applied per plot Mm | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.17 | 17.6 | 14.43 | | |
| | 20-40 | 2.35 | 15.8 | 12.04 | | 60 |
| | 40-60 | 1.36 | 10.95 | 8.6 | 52.7 | |
| | Total | 6.88 | 44.31 | 35.07 | | |
| AFI | 0-20 | 3.14 | 11.56 | 8.42 | | |
| | 20-40 | 2.97 | 9.82 | 6.85 | | |
| | 40-60 | 1.96 | 7.23 | 5.27 | 25.3 | 88 |
| | Total | 8.07 | 28.61 | 20.54 | | |
| FFI | 0-20 | 3.16 | 11.12 | 7.96 | | |
| | 20-40 | 2.75 | 9.13 | 6.38 | | |
| | 40-60 | 1.76 | 7.42 | 5.66 | 25.3 | 75 |
| | Total | 7.67 | 27.67 | 20 | | |
| FP | 0-20 | 3.76 | 19.78 | 16.02 | | |
| | 20-40 | 2.97 | 15.75 | 12.28 | | |
| | 40-60 | 1.88 | 9.5 | 7.62 | 79 | 41 |
| | Total | 8.61 | 45.03 | 35.92 | | |

Appendix Table 28 Determination of coefficient of uniformity (Cu) at 5th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth x | ) at 5th irrigation<br>$Cuc = \left(1 - \frac{\sum\lvert X_i - X\rvert}{nX}\right)100$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 15.79 | 14.03 | 89 |
|  | 5 |  | 13.43 |  |  |
|  | 8 |  | 12.86 |  |  |
|  | 2 | 20-40 | 14.03 | 12.04 | 85 |
|  | 5 |  | 11.42 |  |  |
|  | 8 |  | 10.68 |  |  |
|  | 2 | 40-60 | 9.92 | 8.6 | 87 |
|  | 5 |  | 8.18 |  |  |
|  | 8 |  | 7.68 |  |  |
| AFI | 2 | 0-20 | 10.2 | 8.42 | 91 |
|  | 5 |  | 8.16 |  |  |
|  | 8 |  | 6.92 |  |  |
|  | 2 | 20-40 | 8.22 | 6.85 | 89 |
|  | 5 |  | 6.25 |  |  |
|  | 8 |  | 6.1 |  |  |
|  | 2 | 40-60 | 6.05 | 5.27 | 90 |
|  | 5 |  | 5.05 |  |  |
|  | 8 |  | 4.7 |  |  |
| FFI | 2 | 0-20 | 9.75 | 7.96 | 81 |
|  | 5 |  | 7.86 |  |  |
|  | 8 |  | 6.28 |  |  |
|  | 2 | 20-40 | 7.1 | 6.38 | 83 |
|  | 5 |  | 6.88 |  |  |
|  | 8 |  | 5.05 |  |  |
|  | 2 | 40-60 | 6.65 | 5.66 | 79 |
|  | 5 |  | 5.56 |  |  |
|  | 8 |  | 4.76 |  |  |
| FP | 2 | 0-20 | 19.49 | 15.85 | 76 |
|  | 5 |  | 17.52 |  |  |
|  | 8 |  | 10.55 |  |  |
|  | 2 | 20-40 | 15.48 | 12.45 | 76 |
|  | 5 |  | 13.88 |  |  |
|  | 8 |  | 7.98 |  |  |
|  | 2 | 40-60 | 10.76 | 7.62 | 73 |
|  | 5 |  | 7.23 |  |  |
|  | 8 |  | 4.88 |  |  |

Appendix Table 29 Determination of application efficiency (AE) at 6th irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation mm | Depth of water stored per layer mm | Depth of water applied per plot mm | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.15 | 17.6 | 14.45 | 52.8 | 60 |
| | 20-40 | 2.35 | 15.11 | 12.76 | | |
| | 40-60 | 1.36 | 10.95 | 9.59 | | |
| | Total | 6.86 | 43.66 | 36.8 | | |
| AFI | 0-20 | 3.23 | 12.12 | 8.89 | 26.7 | 84 |
| | 20-40 | 2.62 | 10.81 | 8.19 | | |
| | 40-60 | 1.86 | 7.12 | 5.26 | | |
| | Total | 7.71 | 30.05 | 22.34 | | |
| FFI | 0-20 | 3.23 | 11.33 | 8.094 | 26.7 | 75 |
| | 20-40 | 2.45 | 9.52 | 7.07 | | |
| | 40-60 | 1.23 | 7.21 | 5.98 | | |
| | Total | 6.9 | 28.1 | 21.144 | | |
| FP | 0-20 | 3.76 | 18.45 | 14.69 | 80 | 43 |
| | 20-40 | 2.67 | 14.55 | 11.88 | | |
| | 40-60 | 1.88 | 9.75 | 7.87 | | |
| | Total | 8.31 | 42.75 | 34.44 | | |

Appendix Table 30 Determination of coefficient of uniformity (Cu) at 6th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth x | ) at 6th irrig<br>$Cuc = \left(1 - \frac{\sum\lvert X_i - X\rvert}{nX}\right)100$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 16.65 | 14.45 | 90 |
| | 5 | | 13.84 | | |
| | 8 | | 12.86 | | |
| | 2 | 20-40 | 14.68 | 12.76 | 89.3 |
| | 5 | | 12.48 | | |
| | 8 | | 10.87 | | |
| | 2 | 40-60 | 10.78 | 9.58 | 88.9 |
| | 5 | | 9.98 | | |
| | 8 | | 7.98 | | |
| AFI | 2 | 0-20 | 10.88 | 8.89 | 91 |
| | 5 | | 8.88 | | |
| | 8 | | 6.97 | | |
| | 2 | 20-40 | 9.95 | 8.19 | 92 |
| | 5 | | 7.85 | | |
| | 8 | | 6.66 | | |
| | 2 | 40-60 | 6.05 | 5.26 | 94 |
| | 5 | | 5.05 | | |
| | 8 | | 4.7 | | |
| FFI | 2 | 0-20 | 9.87 | 8.1 | 80 |
| | 5 | | 7.86 | | |
| | 8 | | 6.38 | | |
| | 2 | 20-40 | 8.12 | 7.1 | 79 |
| | 5 | | 7.23 | | |
| | 8 | | 6.05 | | |
| | 2 | 40-60 | 7.37 | 5.98 | 82 |
| | 5 | | 5.68 | | |
| | 8 | | 4.88 | | |
| FP | 2 | 0-20 | 18.62 | 15.3 | 75 |
| | 5 | | 16.67 | | |
| | 8 | | 10.75 | | |
| | 2 | 20-40 | 15.48 | 11.88 | 75 |
| | 5 | | 12.88 | | |
| | 8 | | 7.28 | | |
| | 2 | 40-60 | 10.86 | 7.68 | 69 |
| | 5 | | 7.97 | | |
| | 8 | | 4.82 | | |

Appendix Table 31 Determination of application efficiency (AE) at 7th irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation mm | Depth of water stored per layer mm | Depth of water applied per plot Mm | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.25 | 17.86 | 14.61 | 52.1 | 60 |
| | 20-40 | 2.45 | 15.65 | 13.2 | | |
| | 40-60 | 1.26 | 10.86 | 9.6 | | |
| | Total | 6.96 | 44.37 | 37.41 | | |
| AFI | 0-20 | 3.13 | 11.62 | 8.49 | 26 | 83 |
| | 20-40 | 2.42 | 9.81 | 7.39 | | |
| | 40-60 | 1.86 | 7.52 | 5.66 | | |
| | Total | 7.41 | 28.95 | 21.54 | | |
| FFI | 0-20 | 3.12 | 10.84 | 7.72 | 26 | 65 |
| | 20-40 | 2.45 | 9.56 | 7.11 | | |
| | 40-60 | 1.33 | 7.36 | 6.03 | | |
| | Total | 6.9 | 27.76 | 20.86 | | |
| FP | 0-20 | 3.26 | 17.55 | 14.29 | 78.3 | 42 |
| | 20-40 | 2.78 | 13.86 | 11.08 | | |
| | 40-60 | 1.28 | 9.455 | 8.175 | | |
| | Total | 7.32 | 40.865 | 33.545 | | |

Appendix Table 32 Determination of coefficient of uniformity (Cu) at 7th irrigation

| Trt | Points M | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth x | | i) at 7th irrig ion<br>$Cuc = \left(1 - \frac{\sum\lvert X_i - X\rvert}{nX}\right)100$ |
|---|---|---|---|---|---|---|
| | 2 | 0-20 | 17.36 | 14.61 | | 86 |
| | 5 | | 14.42 | | | |
| | 8 | | 11.86 | | | |
| EFI | 2 | 20-40 | 15.12 | 13.2 | 85 | 88.9 |
| | 5 | | 13.23 | | | |
| | 8 | | 11.27 | | | |
| | 2 | 40-60 | 11.12 | 9.61 | | 88.2 |
| | 5 | | 9.82 | | | |
| | 8 | | 7.98 | | | |
| | 2 | 0-20 | 10.18 | 8.49 | | 89 |
| | 5 | | 8.38 | | | |
| | 8 | | 6.97 | | | |
| AFI | 2 | 20-40 | 9.11 | 7.39 | | 88 |
| | 5 | | 7.03 | | | |
| | 8 | | 6.11 | | | |
| | 2 | 40-60 | 6.76 | 5.66 | | 88 |
| | 5 | | 5.25 | | | |
| | 8 | | 4.75 | | | |
| | 2 | 0-20 | 9.27 | 7.72 | | 79 |
| | 5 | | 7.42 | | | |
| | 8 | | 6.48 | | | |
| FFI | 2 | 20-40 | 8.12 | 7.1 | | 75 |
| | 5 | | 7.23 | | | |
| | 8 | | 6.05 | | | |
| | 2 | 40-60 | 7.37 | 5.98 | | 84 |
| | 5 | | 5.68 | | | |
| | 8 | | 4.88 | | | |
| | 2 | 0-20 | 18.76 | 14.6 | | 72 |
| | 5 | | 16.62 | | | |
| | 8 | | 8.56 | | | |
| FP | 2 | 20-40 | 15.78 | 11.5 | | 68 |
| | 5 | | 12.28 | | | |
| | 8 | | 6.65 | | | |
| | 2 | 40-60 | 11.96 | 8.17 | | 70 |
| | 5 | | 7.97 | | | |
| | 8 | | 4.28 | | | |

Appendix Table 33 Determination of application efficiency (AE) at 8th irrigation

| Trt | Depth (cm) | Moisture content before irrigation (mm) | Moisture Content after irrigation mm | Depth of water stored per layer mm | Depth of water applied per plot Mm | AE |
|---|---|---|---|---|---|---|
| EFI | 0-20cm | 3.35 | 18.22 | 14.87 | | |
| | 20-40 | 2.64 | 15.55 | 12.91 | | 61 |
| | 40-60 | 1.64 | 12.4 | 10.76 | 51.7 | |
| | Total | 7.63 | 46.17 | 38.54 | | |
| AFI | 0-20 | 3.45 | 12.54 | 9.09 | | |
| | 20-40 | 2.68 | 10.23 | 7.55 | | |
| | 40-60 | 1.86 | 7.76 | 5.9 | 25.9 | 87 |
| | Total | 7.99 | 30.53 | 22.54 | | |
| FFI | 0-20 | 3.12 | 10.64 | 7.52 | | |
| | 20-40 | 2.45 | 9.46 | 7.01 | | |
| | 40-60 | 1.33 | 7.26 | 5.93 | 25.9 | 73 |
| | Total | 6.9 | 27.36 | 20.46 | | |
| FP | 0-20 | 3.45 | 17.45 | 14 | | |
| | 20-40 | 2.85 | 13.56 | 10.71 | | |
| | 40-60 | 1.68 | 9.45 | 7.77 | 77.6 | 41 |
| | Total | 7.98 | 40.46 | 32.48 | | |

Appendix Table 34 Determination of Coefficient of uniformity (Cu) at 8th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth x | $CuC = \left(1 - \frac{\sum\lvert X_i - X\rvert}{nX}\right)100$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 17.46 | 14.87 | 87.5 |
| | 5 | | 15.12 | | |
| | 8 | | 12.15 | | |
| | 2 | 20-40 | 14.98 | 12.91 | 89.3 |
| | 5 | | 12.87 | | |
| | 8 | | 10.89 | | |
| | 2 | 40-60 | 12.69 | 10.75 | 87.2 |
| | 5 | | 10.88 | | |
| | 8 | | 8.69 | | |
| AFI | 2 | 0-20 | 10.36 | 9.1 | 94 |
| | 5 | | 9.58 | | |
| | 8 | | 7.26 | | |
| | 2 | 20-40 | 9.11 | 7.5 | 88 |
| | 5 | | 7.35 | | |
| | 8 | | 6.11 | | |
| | 2 | 40-60 | 6.86 | 5.7 | 95 |
| | 5 | | 5.45 | | |
| | 8 | | 4.85 | | |
| FFI | 2 | 0-20 | 12.98 | 10.36 | 86 |
| | 5 | | 9.98 | | |
| | 8 | | 8.12 | | |
| | 2 | 20-40 | 11.67 | 9.2 | 87 |
| | 5 | | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | 40-60 | 9.86 | 5.98 | 79.4 |
| | 5 | | 6.78 | | |
| | 8 | | 5.86 | | |
| FP | 2 | 0-20 | 21.23 | 17.12 | 76 |
| | 5 | | 20.23 | | |
| | 8 | | 9.86 | | |
| | 2 | 20-40 | 18.75 | 12.96 | 78 |
| | 5 | | 12.28 | | |
| | 8 | | 7.86 | | |
| | 2 | 40-60 | 13.96 | 9.17 | 65 |
| | 5 | | 7.97 | | |
| | 8 | | 5.28 | | |

Appendix Table 35 Determination of Distribution uniformity (DU) at 1st irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DUlq = 100 * \frac{LQ}{M}$ |
|---|---|---|---|---|---|
| | 2 | | 17.46 | 14.87 | |
| | 5 | 0-20 | 15.12 | | 87 |
| | 8 | | 12.15 | | |
| EFI | 2 | | 14.98 | | |
| | 5 | 20-40 | 12.87 | 12.91 | 85 |
| | 8 | | 10.89 | | |
| | 2 | | 12.69 | 10.75 | |
| | 5 | 40-60 | 10.88 | | 84 |
| | 8 | | 8.69 | | |
| | 2 | | 10.36 | 9.1 | |
| | 5 | 0-20 | 9.58 | | 88 |
| | 8 | | 7.26 | | |
| AFI | 2 | | 9.11 | 7.5 | |
| | 5 | 20-40 | 7.35 | | 87 |
| | 8 | | 6.11 | | |
| | 2 | | 6.86 | 5.7 | |
| | 5 | 40-60 | 5.45 | | 84 |
| | 8 | | 4.85 | | |
| 3 | 2 | | 12.98 | 10.36 | |
| | 5 | 0-20 | 9.98 | | 72 |
| | 8 | | 8.12 | | |
| FFI | 2 | | 11.67 | 9.2 | 76 |
| | 5 | 20-40 | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | | 9.86 | 5.98 | |
| | 5 | 40-60 | 6.78 | | 74 |
| | 8 | | 5.86 | | |
| | 2 | | 21.23 | 17.12 | 66 |
| | 5 | 0-20 | 20.23 | | |
| | 8 | | 9.86 | | |
| FP | 2 | | 18.75 | 12.96 | |
| | 5 | 20-40 | 12.28 | | 62 |
| | 8 | | 7.86 | | |
| | 2 | | 13.96 | 9.17 | |
| | 5 | 40-60 | 7.97 | | 65 |
| | 8 | | 5.28 | | |

Appendix Table 36 Determination of Distribution uniformity (DU) at 2nd Irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DU_{lq} = 100 * \frac{LQ}{M}$ |
|---|---|---|---|---|---|
| | 2 | | 17.46 | 14.87 | |
| | 5 | 0-20 | 15.12 | | 88 |
| | 8 | | 12.15 | | |
| EFI | 2 | | 14.98 | | |
| | 5 | 20-40 | 12.87 | 12.91 | 85 |
| | 8 | | 10.89 | | |
| | 2 | | 12.69 | 10.75 | |
| | 5 | 40-60 | 10.88 | | 83 |
| | 8 | | 8.69 | | |
| | 2 | | 10.36 | 9.1 | |
| | 5 | 0-20 | 9.58 | | 90 |
| | 8 | | 7.26 | | |
| AFI | 2 | | 9.11 | 7.5 | |
| | 5 | 20-40 | 7.35 | | 94 |
| | 8 | | 6.11 | | |
| | 2 | | 6.86 | 5.7 | |
| | 5 | 40-60 | 5.45 | | 93 |
| | 8 | | 4.85 | | |
| | 2 | | 12.98 | 10.36 | |
| | 5 | 0-20 | 9.98 | | 77 |
| | 8 | | 8.12 | | |
| FFI | 2 | | 11.67 | 9.2 | 75 |
| | 5 | 20-40 | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | | 9.86 | 5.98 | |
| | 5 | 40-60 | 6.78 | | 74 |
| | 8 | | 5.86 | | |
| | 2 | | 21.23 | 17.12 | 65 |
| | 5 | 0-20 | 20.23 | | |
| | 8 | | 9.86 | | |
| FP | 2 | | 18.75 | 12.96 | |
| | 5 | 20-40 | 12.28 | | 59 |
| | 8 | | 7.86 | | |
| | 2 | | 13.96 | 9.17 | |
| | 5 | 40-60 | 7.97 | | 66 |
| | 8 | | 5.28 | | |

Appendix Table 37 Determination of Distribution uniformity (DU) at 3rd irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DUlq = 100 * \frac{LQ}{M}$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 17.46 | 14.87 | 86 |
| | 5 | | 15.12 | | |
| | 8 | | 12.15 | | |
| | 2 | 20-40 | 14.98 | 12.91 | 88 |
| | 5 | | 12.87 | | |
| | 8 | | 10.89 | | |
| | 2 | 40-60 | 12.69 | 10.75 | 84 |
| | 5 | | 10.88 | | |
| | 8 | | 8.69 | | |
| AFI | 2 | 0-20 | 10.36 | 9.1 | 94 |
| | 5 | | 9.58 | | |
| | 8 | | 7.26 | | |
| | 2 | 20-40 | 9.11 | 7.5 | 89 |
| | 5 | | 7.35 | | |
| | 8 | | 6.11 | | |
| | 2 | 40-60 | 6.86 | 5.7 | 97 |
| | 5 | | 5.45 | | |
| | 8 | | 4.85 | | |
| FFI | 2 | 0-20 | 12.98 | 10.36 | 78 |
| | 5 | | 9.98 | | |
| | 8 | | 8.12 | | |
| | 2 | 20-40 | 11.67 | 9.2 | 75 |
| | 5 | | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | 40-60 | 9.86 | 5.98 | 75 |
| | 5 | | 6.78 | | |
| | 8 | | 5.86 | | |
| FP | 2 | 0-20 | 21.23 | 17.12 | 64 |
| | 5 | | 20.23 | | |
| | 8 | | 9.86 | | |
| | 2 | 20-40 | 18.75 | 12.96 | 61 |
| | 5 | | 12.28 | | |
| | 8 | | 7.86 | | |
| | 2 | 40-60 | 13.96 | 9.17 | 68 |
| | 5 | | 7.97 | | |
| | 8 | | 5.28 | | |

Appendix Table 38 Determination of Distribution uniformity (DU) at 4th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DUlq = 100 * \frac{LQ}{M}$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 17.46 | 14.87 | 86 |
| | 5 | | 15.12 | | |
| | 8 | | 12.15 | | |
| | 2 | 20-40 | 14.98 | 12.91 | 82 |
| | 5 | | 12.87 | | |
| | 8 | | 10.89 | | |
| | 2 | 40-60 | 12.69 | 10.75 | 84 |
| | 5 | | 10.88 | | |
| | 8 | | 8.69 | | |
| AFI | 2 | 0-20 | 10.36 | 9.1 | 88 |
| | 5 | | 9.58 | | |
| | 8 | | 7.26 | | |
| | 2 | 20-40 | 9.11 | 7.5 | 87 |
| | 5 | | 7.35 | | |
| | 8 | | 6.11 | | |
| | 2 | 40-60 | 6.86 | 5.7 | 87 |
| | 5 | | 5.45 | | |
| | 8 | | 4.85 | | |
| FFI | 2 | 0-20 | 12.98 | 10.36 | 78 |
| | 5 | | 9.98 | | |
| | 8 | | 8.12 | | |
| | 2 | 20-40 | 11.67 | 9.2 | 72 |
| | 5 | | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | 40-60 | 9.86 | 5.98 | 76 |
| | 5 | | 6.78 | | |
| | 8 | | 5.86 | | |
| FP | 2 | 0-20 | 21.23 | 17.12 | 66 |
| | 5 | | 20.23 | | |
| | 8 | | 9.86 | | |
| | 2 | 20-40 | 18.75 | 12.96 | 62 |
| | 5 | | 12.28 | | |
| | 8 | | 7.86 | | |
| | 2 | 40-60 | 13.96 | 9.17 | 65 |
| | 5 | | 7.97 | | |
| | 8 | | 5.28 | | |

Appendix Table 39 Determination of Distribution uniformity (DU) at 5th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DUlq = 100 * \frac{Le}{M}$ |
|---|---|---|---|---|---|
| | 2 | | 17.46 | 14.87 | |
| | 5 | 0-20 | 15.12 | | 88 |
| | 8 | | 12.15 | | |
| EFI | 2 | | 14.98 | | |
| | 5 | 20-40 | 12.87 | 12.91 | 89 |
| | 8 | | 10.89 | | |
| | 2 | | 12.69 | 10.75 | |
| | 5 | 40-60 | 10.88 | | 85 |
| | 8 | | 8.69 | | |
| | 2 | | 10.36 | 9.1 | |
| | 5 | 0-20 | 9.58 | | 94 |
| | 8 | | 7.26 | | |
| AFI | 2 | | 9.11 | 7.5 | |
| | 5 | 20-40 | 7.35 | | 89 |
| | 8 | | 6.11 | | |
| | 2 | | 6.86 | 5.7 | |
| | 5 | 40-60 | 5.45 | | 88 |
| | 8 | | 4.85 | | |
| | 2 | | 12.98 | 10.36 | |
| | 5 | 0-20 | 9.98 | | 72 |
| | 8 | | 8.12 | | |
| FFI | 2 | | 11.67 | 9.2 | 78 |
| | 5 | 20-40 | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | | 9.86 | 5.98 | |
| | 5 | 40-60 | 6.78 | | 73 |
| | 8 | | 5.86 | | |
| | 2 | | 21.23 | 17.12 | 68 |
| | 5 | 0-20 | 20.23 | | |
| | 8 | | 9.86 | | |
| FP | 2 | | 18.75 | 12.96 | |
| | 5 | 20-40 | 12.28 | | 63 |
| | 8 | | 7.86 | | |
| | 2 | | 13.96 | 9.17 | |
| | 5 | 40-60 | 7.97 | | 64 |
| | 8 | | 5.28 | | |

Appendix Table 40 Determination of Distribution uniformity (DU) at 6th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DU_{lq} = \frac{irrigation}{100} * \frac{LQ}{M}$ |
|---|---|---|---|---|---|
| | 2 | | 17.46 | 14.87 | |
| | 5 | 0-20 | 15.12 | | 87 |
| | 8 | | 12.15 | | |
| EFI | 2 | | 14.98 | | |
| | 5 | 20-40 | 12.87 | 12.91 | 85 |
| | 8 | | 10.89 | | |
| | 2 | | 12.69 | 10.75 | |
| | 5 | 40-60 | 10.88 | | 86 |
| | 8 | | 8.69 | | |
| | 2 | | 10.36 | 9.1 | |
| | 5 | 0-20 | 9.58 | | 94 |
| | 8 | | 7.26 | | |
| AFI | 2 | | 9.11 | 7.5 | 90 |
| | 5 | 20-40 | 7.35 | | |
| | 8 | | 6.11 | | |
| | 2 | | 6.86 | 5.7 | |
| | 5 | 40-60 | 5.45 | | 96 |
| | 8 | | 4.85 | | |
| | 2 | | 12.98 | 10.36 | |
| | 5 | 0-20 | 9.98 | | 78 |
| | 8 | | 8.12 | | |
| FFI | 2 | | 11.67 | 9.2 | 73 |
| | 5 | 20-40 | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | | 9.86 | 5.98 | |
| | 5 | 40-60 | 6.78 | | 74 |
| | 8 | | 5.86 | | |
| | 2 | | 21.23 | 17.12 | 67 |
| | 5 | 0-20 | 20.23 | | |
| | 8 | | 9.86 | | |
| FP | 2 | | 18.75 | 12.96 | |
| | 5 | 20-40 | 12.28 | | 60 |
| | 8 | | 7.86 | | |
| | 2 | | 13.96 | 9.17 | |
| | 5 | 40-60 | 7.97 | | 65 |
| | 8 | | 5.28 | | |

Appendix Table 41 Determination of Distribution uniformity (DU) at 7th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DUlq = 100 * \frac{LQ}{M}$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 17.46 | 14.87 | 87 |
| | 5 | | 15.12 | | |
| | 8 | | 12.15 | | |
| | 2 | 20-40 | 14.98 | 12.91 | 84 |
| | 5 | | 12.87 | | |
| | 8 | | 10.89 | | |
| | 2 | 40-60 | 12.69 | 10.75 | 85 |
| | 5 | | 10.88 | | |
| | 8 | | 8.69 | | |
| AFI | 2 | 0-20 | 10.36 | 9.1 | 89 |
| | 5 | | 9.58 | | |
| | 8 | | 7.26 | | |
| | 2 | 20-40 | 9.11 | 7.5 | 84 |
| | 5 | | 7.35 | | |
| | 8 | | 6.11 | | |
| | 2 | 40-60 | 6.86 | 5.7 | 85 |
| | 5 | | 5.45 | | |
| | 8 | | 4.85 | | |
| FFI | 2 | 0-20 | 12.98 | 10.36 | 81 |
| | 5 | | 9.98 | | |
| | 8 | | 8.12 | | |
| | 2 | 20-40 | 11.67 | 9.2 | 78 |
| | 5 | | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | 40-60 | 9.86 | 5.98 | 76 |
| | 5 | | 6.78 | | |
| | 8 | | 5.86 | | |
| FP | 2 | 0-20 | 21.23 | 17.12 | 57 |
| | 5 | | 20.23 | | |
| | 8 | | 9.86 | | |
| | 2 | 20-40 | 18.75 | 12.96 | 55 |
| | 5 | | 12.28 | | |
| | 8 | | 7.86 | | |
| | 2 | 40-60 | 13.96 | 9.17 | 56 |
| | 5 | | 7.97 | | |
| | 8 | | 5.28 | | |

Appendix Table 42 Determination of Distribution uniformity (DU) at 8th irrigation

| Trt | Points m | Depth of sampling cm | Depth of stored after irrigation ( $x_i$) mm | Average depth M | $DU_{lq} = \frac{\text{irrigation}}{100} * \frac{lq}{M}$ |
|---|---|---|---|---|---|
| EFI | 2 | 0-20 | 17.46 | 14.87 | 86 |
| | 5 | | 15.12 | | |
| | 8 | | 12.15 | | |
| | 2 | 20-40 | 14.98 | 12.91 | 85 |
| | 5 | | 12.87 | | |
| | 8 | | 10.89 | | |
| | 2 | 40-60 | 12.69 | 10.75 | 81 |
| | 5 | | 10.88 | | |
| | 8 | | 8.69 | | |
| AFI | 2 | 0-20 | 10.36 | 9.1 | 91 |
| | 5 | | 9.58 | | |
| | 8 | | 7.26 | | |
| | 2 | 20-40 | 9.11 | 7.5 | 87 |
| | 5 | | 7.35 | | |
| | 8 | | 6.11 | | |
| | 2 | 40-60 | 6.86 | 5.7 | 83 |
| | 5 | | 5.45 | | |
| | 8 | | 4.85 | | |
| FFI | 2 | 0-20 | 12.98 | 10.36 | 74 |
| | 5 | | 9.98 | | |
| | 8 | | 8.12 | | |
| | 2 | 20-40 | 11.67 | 9.2 | 78 |
| | 5 | | 8.23 | | |
| | 8 | | 7.65 | | |
| | 2 | 40-60 | 9.86 | 5.98 | 76 |
| | 5 | | 6.78 | | |
| | 8 | | 5.86 | | |
| FP | 2 | 0-20 | 21.23 | 17.12 | 61 |
| | 5 | | 20.23 | | |
| | 8 | | 9.86 | | |
| | 2 | 20-40 | 18.75 | 12.96 | 59 |
| | 5 | | 12.28 | | |
| | 8 | | 7.86 | | |
| | 2 | 40-60 | 13.96 | 9.17 | 58 |
| | 5 | | 7.97 | | |
| | 8 | | 5.28 | | |

Appendix Table 43 Determination of infiltration rate using Double-Ring Infiltrometer

| Watch Reading | Time interval (min) | Cumulative time (min) | water level reading | | Infiltration (mm) | Infiltration rate (mm/min) | infiltration rate (mm/hr) | cumulative infiltration (mm) |
|---|---|---|---|---|---|---|---|---|
| | | | before (mm) | after (mm) | | | | |
| | start = 0 | | | | | | | start = 0 |
| 5:23 | | 0 | | 100 | | | | |
| | 2 | | | | 5 | 2.5 | 150 | |
| 5:25 | | 2 | 95 | 99 | | | | 5 |
| | 2 | | | | 4 | 2 | 120 | |
| 5:27 | | 4 | 95 | 100 | | | | 9 |
| | 2 | | | | 2 | 1 | 60 | |
| 5:29 | | 6 | 98 | 100 | | | | 11 |
| | 5 | | | | 4 | 0.8 | 48 | |
| 5:34 | | 11 | 96 | 100 | | | | 15 |
| | 5 | | | | 3.5 | 0.7 | 42 | |
| 5:39 | | 16 | 96.5 | 99 | | | | 18.5 |
| | 10 | | | | 5.3 | 0.53 | 31.8 | |
| 5:49 | | 26 | 94.7 | 99 | | | | 23.8 |
| | 10 | | | | 3 | 0.4 | 23.5 | |
| 5:59 | | 36 | 95.5 | 100 | | | | 26.8 |
| | 15 | | | | 5.5 | 0.37 | 21.5 | |
| 6:15 | | 51 | 94.5 | 99 | | | | 32.3 |
| | 15 | | | | 4 | 0.27 | 15.7 | |
| 6:30 | | 66 | 95 | 100 | | | | 36.3 |
| | 20 | | | | 4 | 0.2 | 11.78 | |
| 6:50 | | 86 | 96 | 99 | | | | 40.3 |
| | 20 | | | | 3.3 | 0.17 | 10 | |
| 7:10 | | 106 | 95.7 | 100 | | | | 43.6 |
| | 45 | | | | 7.7 | 0.17 | 10 | |
| 7:55 | | 151 | 92.3 | 100 | | | | 51.3 |
| | 45 | | | | 7.7 | 0.17 | 10 | 59 |
| 8:50 | | 196 | 92.3 | | | | | |