EVALUATION OF ALTERNATE, FIXED AND CONVENTIONAL FURROW IRRIGATION SYSTEMS WITH DIFFERENT WATER APPLICATION LEVELS ON ONION PRODUCTION IN DUBTI, AFAR

MSc. THESIS

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This is to certify that the thesis entitled '**Evaluation of Alternate, Fixed and Conventional Furrow Irrigation Systems with Different Water Application Levels on Onion Production in Dubti, Afar' s**ubmitted in partial fulfillment of the requirement for the degree of Master's with specialization in **Irrigation and Drainage Engineering**, the Graduate program of the Department of Water Resource and Irrigation Engineering and has been carried out by **Zinabu Akele Derbew, Id. No PGIDE/015/09** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by **Zinabu Akele Derebew** have read and evaluated his thesis entitled " **Evaluation of Alternate, Fixed and Conventional Furrow Irrigation Systems with Different Water Application Levels on Onion Production in Dubti, Afar "**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of **Masters of Science in Irrigation and Drainage Engineering.**

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DEDICATION

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ACRONYMS

AFI	Alternate Furrow Irrigation
ANOVA	Analysis Of Variance
APARI	Afar Pastoral and Agro pastoral Research Institute
CFI	Conventional Furrow Irrigation
CWUE	Crop Water Use Efficiency
CV	Coefficient of Variance
DF	Degree of Freedom
DI	Deficit Irrigation
DPARC	Dubti Pastoral and Agro pastoral Research Center
ET_C	Reference Crop Evapotranspiration
ET_O	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
FFI	Fixed Furrow Irrigation
FWUE	Field Water Use Efficiency
IL	Irrigation Levels
IL * IS	Interaction Effect of Irrigation Levels and Irrigation Systems
IR	Irrigation Requirement
IRg	Gross Irrigation Requirement
IS	Irrigation Systems
Kc	Crop Coefficient
LSD	Least Significant Difference
MS	Mean Square
PRD	Partial Root Drying
PWP	Permanent Wilting Point
RAW	Readily Available Water
RCBD	Randomly Completely Block Design
RDI	Regulated Deficit Irrigation
REP	Replication

SS	Sum Square
TAW	Total Available Water
TOPs	Transitioning out of Pastoralism’s
WUE	Water Use Efficiency
Y	Crop Yield
θ_v	Water Content on Volume Basis
θ_{dw}	Water Content on Weight Basis

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ABSTRACT

Water scarcity is a major constraint for the production of food required in arid and semi-arid areas. Therefore, deficit irrigation and application of irrigation systems are important concerns to improve water productivity and sustained production in the areas with water shortage like lower Awash valley. A field experiment was conducted with the objective of evaluating the performance of alternate, fixed and conventional furrow irrigation systems under different water application levels on onion yield in Dubti, lower Awash basin. The treatments were three deficit irrigation levels of 50%, 75% and 100% of crop water requirements with three furrow irrigation systems of conventional, alternate and fixed furrow were laid out a factorial random complete block design (RCBD) with three replications. Data on plant growth and bulb yield were collected and analyzed. The result of the study indicated highly significant ($\alpha \leq 0.0$) differences for yield and WUE's. The highest bulb yield of 25.46 ton/ha was obtained at 100% ET_C with conventional furrow irrigation method. AFI 50% ET_C water application level gave the highest water use efficiency. In contrast, the minimum water use efficiency was recorded with conventional furrow method with 100% water application level. CFI 100%, CFI 75%, and AFI 50% were not shown significant difference on yield which is 25.46 ton/ha, 24.88 ton/ha, and 24.54 ton/ha respectively, besides better water use efficiency of 8.39 kg/m^3 was recorded from AFI 100%. In relative to the control CFI 100%, applying AFI 100% able to increase 0.868 ha net additional irrigable land per each hectare. Therefore, it can be decided that Alternative furrow irrigation with 100% ET_C increased water use efficiency and can solve a problem of water shortage by improving WUE without significant reduction of yield.

Key word: Water Use Efficiency, Onion, Alternative Furrow, Deficit Irrigation and Conventional Furrow.

1. INTRODUCTION

1.1. Background and Justification

Land and water scarcity are major constraints for the production of food required to meet the quantitative and qualitative shifts of the world's demand in the mid-twenty-first century. Whereas land and water availability are constrained on a global scale, there are important regional and crop-specific differences that need to be understood, quantified, and managed (Vector. et.al, 2007). Water scarcity is a global problem (WHO, 2009). As cities grow and populations increase, the problem worsens since the demand for water increase in households, industry, and agriculture. These days, the tension between supply and demand of scarce water resource is aggravated owing to competition among agricultural, domestic and industrial water supply sectors (Perry *et al.,* 2009, and Rodrigues and Pereira, 2009). Moreover, the effect of a global climatic change is exacerbating the scarcity of water (Behera and Panda, 2009).

Irrigation accounts for more than 70% of the total water of the water withdrawn and for more than 90% of total consumptive use (Doll, 2009). According to Kirda, (2002), irrigated agriculture uses more than 70% of the water withdrawn from the earth's rivers; in developing countries, the proportion exceeds 80%. The possibility for further irrigation development to meet food demand in the future is constrained by decreasing water resources availability and growing competition for clean water. While on global scale water resources are still ample, there are serious water shortages in the arid and semi-arid regions as existing water resources were fully exploited. The situation is exacerbated by the declining quality of water and soil resources. As a result, the dependency on water has become a critical constraint on further progress and threatens to slow down development, endangering food supplies and aggravating rural poverty.

The great challenge for the coming decades will, therefore, be the task of increasing food production per unit of water consumption, particularly in countries with limited water and land resources as well as inefficient water use.

Increasing optimum water productivity, especially the value produced per unit of water, can be an important pathway for poverty alleviation (Perry *et al.*, 2009). Therefore, as they reported mechanisms which increase the water productivity of the irrigation scheme should be introduced. Improvement of irrigation water management is portrayed as the key issue in copping up with crop irrigation needs and future water scarcity. One of the irrigation management practices which could result in water saving is through deficit irrigation (Eck et al., 1987). Deficit irrigation improves water productivity and irrigation management practices resulting in water saving by maintaining soil moisture content below optimum level throughout the growth season (Enchalew. et.al, 2016). It may give an alternative way to provide water for other water needs through water savings and sustaining agricultural production, which in turn needs the knowledge of yield response factor for different crops at a specific location.

One of alternate option to increase water productivity through deficit level is alternate furrow irrigation system. The studies of Du et.al, (2010) and Horst et.al. (2005) improved by converting conventional furrow irrigation to alternate furrow irrigation (AFI) in order to increase water use efficiencies. The AFI method is essentially the same as CFI, except that instead of irrigating every furrow, irrigation is applied to alternate furrows, while the in-between furrows remain dry. 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). Fixed furrow irrigation means that irrigation fixed to one of the two neighboring furrows that increased water productivity (Eldeiry, 2005).

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From an economics standpoint, maximum profit per unit farm for farmers may be obtained with the fulfillment of the entire crop water requirements. However, practicing deficit irrigation could increase the irrigated area or the frequency of cultivation leads to enhance productivity and income. For many crops, high yields and high water use efficiency could be obtained if the right choice of the period of water application is made. Based on the growing season, appropriate irrigation management practices could double the cropping area without significant yield loss and ultimately increases economic return (Bazza, 1994).

Onion is the most important widely grown vegetable crop throughout the world (Brewster, 1997). In Ethiopia, it is widely cultivated as a cash crop by small-scale and private large-scale farmers. The country has great potential to produce onion throughout the year for both local consumption and export (Nikus and Mulugeta, 2010). It can be produced throughout the year if there is sufficient moisture in the soil through rainfall or irrigation. In the lower Awash valley onion is the main crop production next to maize; however, rainfall is unreliable and insufficient to support onion production that makes irrigation an indispensable practice. Therefore, this study investigated the yield response of onion to different furrow irrigation systems and the amount of water application levels.

1.2. Statement of the problem

Drought is the main climatic related risk in Ethiopia. Even in good years, Ethiopia cannot meet its large food deficit through rainfed agriculture production. The economic basis of the country is rainfed agriculture. The rainfall is, however, scanty, erratic and inadequate. Thus with the traditional agricultural practices, natural resources are severely degraded due to human as well as natural devastation.

In the lower Awash valley, which is located in the Afar region, there is suitable land for surface irrigation to produce lowland crops and legumes. However, in the area, which is characterized as semi-arid and arid climate, water is the most limiting factor for crop production. The amount and distribution of rainfall are not sufficient to sustain crop growth and development in the study region. For this reason, river and groundwater are used as a source of irrigation water. The society wants to irrigate extra lands to produce crops but water is a limited resource. Therefore, in the arid and semi-arid area application of deficit irrigation could provide greater economic returns than maximizing yields per unit of water. The deficit irrigation could be considered as a way of maximizing water use efficiency (WUE) by applying a reduced amount of irrigation water, which has no significant impact on yield. Yet, there is a lack of studies about the application of deficit irrigation and the performance of irrigation systems in the study region.

Hence, this study aims to investigate the performance of alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) system on onion producing farms in the Lower Awash valley. However, there is lack of studies on the comparative of alternate, fixed and conventional irrigation systems in the study area. The output of this study will contribute to the improvement of the irrigation and water use efficiency and the crop productivity on the farm level.

1.3. General Objective

- The general objective of this study was to evaluate the performance of alternate, fixed and conventional furrow irrigation systems under different water application levels on onion yield in arid climate Dubti, lower Awash basin.

1.3.1. Specific objectives:-

- To investigate the effect of alternate, fixed, and conventional furrow irrigation systems on onion yield and water use efficiencies.
- To identify the level of deficit irrigation water without significant losses of Onion yield.
- To identify effects of alternate, fixed, and conventional furrow irrigation systems on yield parameters.

1.4. Scope of the study

This study assessed the performance evaluation of conventional, alternative and fixed irrigation systems and the effects of deficit irrigation on onion production. The study will address to irrigate extra lands under a given water for onion in the lower Awash valley, which has a scarcity of water and lack of information. On this study, only one cropping season and, hence, one growing season data collected.

1.5. Significance of the study

Due to various drought, erratic rainfall and depletions of rangeland an Ethiopian government aimed to transition out of pastoralism's (TOPs). One of the alternatives is crop production through irrigated agriculture. In the Afar region, there is a significant increment in the number of dropouts of full pastoralists into agro-pastoralists (Teshome and Bayissa, 2014). However, there is a lack of experience and knowledge about irrigated agriculture such as how much and when to irrigate their crops. This study will assess the extent of problems regarding sustainable water management and the furrow irrigation systems. Without extra water, additional land could be irrigated under deficit irrigation. Consequently, sustainable and effective utilization of scarce water resources for crop production may promote and contribute to poverty reduction in the area and enhance food security.

2. LITERATURE REVIEW

2.1. Importance of Irrigation

The need for additional food supplies is necessitating a rapid expansion of irrigated agriculture throughout the world (Verma, et.al, 2014). Even though irrigation is of major importance in the arid regions of the world, it is also becoming increasingly important in humid regions (Israelsen, et al., 1980).

Provision of water is vital for plant life. Adequate quantities of water should be readily available within the root zone for plants. When such water is not present in the soil naturally, it may be supplied by irrigation. Rainfall is estimated that one-third of the earth's surface receives less than 250 mm of yearly rainfall and the other one-third receives only 250 to 500 mm yearly (Walker, 1982). In the remaining areas, rainfall is concentrated within a few months during the year. This shows that depending exclusively on rainfall for crop production is not sustainable. Therefore, Irrigation is, required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount (Allen et al., 1998).

Reliable and suitable irrigation water supply can improve agricultural production and enhance the economic growth of a region. Many civilizations have been dependent on irrigated agriculture to provide the basics of their society and enhance the food security of their people. Only 15-20 percent of the global cultivated area is under irrigated agriculture. Comparing yields obtained from irrigated and non-irrigated farms, relatively small fraction of irrigated agriculture is contributing as much as 30-40 percent of gross agricultural output (Walker, 1989).

2.2. Advantage of Furrow Irrigation over Other Surface Irrigation Methods

Furrows are small, parallel channels, made to carry water in order to irrigate the crop. The crop is usually grown on the ridges between the furrows (Brouwer, 2001). 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.) (Doorenbos and Kassam, 1986). 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 (Brouwer, 2001). The method reduces labor requirements in the land preparation and irrigation. Also compared to check basin method, in furrow irrigation, there is no wastage of land in field ditches (Darra, Raghuvenshi, 1999). Most crops can be irrigated by the 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 such crops may be planted on beds between furrows (Michael, 1997).

Moderate to high application efficiency can be obtained if good water management practices are exercised and the land is properly prepared. For furrow irrigation, the initial capital investment is relatively low on lands not requiring extensive land forming because common farm implements can construct it. Soils, which form surface crusts when flooded, can readily be irrigated by furrow irrigation because water moves laterally under the surface. According to Jensen, (1983), Furrow 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.

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 the land of uneven topography (Michael, 1997). Furrow irrigation is adaptable to a great variation in slope (Israelsen et al., 1980).

It can avoid 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 (Walker W.R., and Skogerboe., 1987). 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 than other surface irrigation systems. The discharge per unit width of the field is substantially reduced and topographical variations can be more severe. The smaller wetted surface area the lower evaporation losses would be. 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).

2.3. Deficit Irrigation

2.3.1. Concepts of deficit irrigation

Water deficit is one of the most important environmental factors inhibiting photosynthesis, growth, and production under field conditions in the Mediterranean (Chaves et al., 2002). It is the application of water below the evapotranspiration requirements of the plant. Water be saved from field irrigation and devoted to other uses. Deficit Irrigation especially allows economic optimization of water use concerning crop output where water is limited, but it also involves structural adjustments (e.g. policies that support this kind of measure) in the agricultural system. (Fereres and Soriano, 2007).

Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant stress and consequently in production loss, DI maximizes irrigation water productivity, which is the main limiting factor. (English, 1990)

DI can improve the water use efficiency by eliminating the least productive irrigation or reducing irrigation adequacy (English, 1990). Furthermore, this watering technique is a complex, inducing changes at technical, socio-economic and institutional level. (Fereres and Soriano, 2007).

Many investigations have been conducted to gain experiences in irrigation of crops to maximize performances, efficiency, and profitability. However, investigations in water saving irrigation still are continued (Sleper et al., 2007). Farmers in non-limited or even water-limited areas use full irrigation. In this method, crops receive full evapotranspiration requirements to results the maximum yield. Nowadays, full irrigation is considered a luxury use of water that can be reduced with minor or no effect on profitable yield (Kang and Zhang, 2004). However, the amount of irrigation reduction is crop-dependent and generally accompanied by no or minor yield loss that increases the water productivity (Ahmadi et al., 2010). Water-saving irrigations are used to improve water productivity. The proper application of deficit irrigation practices can generate significant savings in irrigation water allocation and full water requirement during the first two stages of maize is not advisable if water shortage cannot be avoided during the remaining of the season especially during the mid-season stage (Yenesew, 2007).

2.3.2. Experiences with deficit irrigation

Bekele and Tilahun (2007) conducted an experiment of RDI on onions in Ethiopia. They observed that all RDI strategies increased the WUE of onions from a minimum of 6% to a maximum of 13%. However, in no cases were the yields higher than that in optimum (full) irrigation.

Imitiyaz et al. (2000) determined the yield and economic return of vegetable crops (i.e. winter broccoli, carrot, rape, and cabbage) under deficit irrigation in Botswana. The experimental results suggested that crops should be irrigated at 80% evaporation replenishment, in order to obtain an optimum marketable yield, irrigation production efficiency and net return. The net return from the vegetables investigated increased sharply from 20% to 80% evaporation replenishment. The net return at 100% evaporation replenishment increased slightly because there was no significant change in marketable yield.

Sepaskhah and Gharaman (2004) incorporated a considerable reduction in applied water and an insignificant decrease in yield may result in higher water use efficiency for sorghum, barley and wheat crops.

Rodriguez et al. (2003) identified DI strategies that provided reduced crop water demand with acceptable impacts on yields in Portugal. DI strategies for maize only proved to be feasible when the irrigation deficit is limited and water restrictions are low to moderate. Results for the sunflower show the feasibility of DI because the crop is subsided, which compensates for yield losses.

To quantify the level of DI it is first necessary to define the full crop ET requirements. Fortunately, since Penman developed the combination approach to calculating ET, research on crop water requirements has produced several reliable methods for its calculation. At present, the modified Penman-Monteith equation (Allen et al., 1998) is the established method for determining the ET of the major herbaceous crops with sufficient precision for management purposes.

2.3.2. Benefits of deficit irrigation

The core benefit of deficit irrigation is maximizing productivity of water use efficiency. In arid and semiarid areas, which have scarcity of water practicing of deficit irrigation is economically more profitable than maximizing yield per unit area (Perry *et al.*, 2009). It creates less humid environment around the crop than full irrigation, thus decreasing the risk of fungal and associated diseases (Cicogna et al., 2005). Reduce nutrient loss through leaching, thus require less fertilizer application and improve groundwater quality. Increases assimilate partitioning to grain from vegetative parts. Reduces crop cycle length (i.e., crop period), thus facilitates to increase cropping intensity (Kirda, 2002).

2.4. Concept of Alternate, Fixed and Conventional Furrow Irrigation systems

Alternate furrow irrigation (AFI) means one of the two neighboring furrows alternately irrigated during consecutive watering. Fixed furrow irrigation (FFI) means that irrigation fixed to one of the two neighboring furrows. Conventional furrow irrigation (CFI) or traditional irrigation means irrigating every furrow (Eldeiry, 2005).

2.4.1. Alternate furrow irrigation

Alternate Furrow Irrigation system (AFI) offers an opportunity for reducing the size of irrigation and permits irrigating a 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 (Musick and Dusek, 1974). When the supply of water is limited, irrigation is applied through alternate furrows. Besides, the AFI system is adopted where salt is a problem. This system saves quite a good amount of water and is very useful and crucial in areas of water scarcity and salt problems (Majumdar, 2002). 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. 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 of wet soil surface compared to that in every-furrow irrigation (Stone et al., 1979).

According to Karajeh et al. (2000), application of alternate furrow irrigation system has improved irrigation water use. Under this furrow irrigation system, 56.7-72 percentage of the water supply has been used to replenish soil moisture, 12-21.1 percentage for infiltration within the temporary irrigation network and 11.3-17.8 percentage for surface runoff. Working conditions of labors carrying out irrigation process were improved as this technology allowed them moving on the dry furrows. Alternate furrow irrigation and early termination of irrigation are two simple deficit irrigation strategies that would result in water conservation (Fernandez, 1996).

According to Yemane et al. (2018), AFI can allow saving a substantial amount of water and labor without high reduction of onion yield in northern Ethiopia. This also demonstrates that crop water use efficiency would be increased by using AFI which may result in substantial benefits, under limited water condition, labor saving and improved flexibility in farm irrigation management are also expected to be achieved using AFI.

According to Zhang et al. (2000), alternate furrow irrigation method uses less irrigation water but can keep the same grain yield production as that of conventional furrow irrigation with high irrigation amounts. This is believed to be because of continuous regulation by root drying signal on stomatal opening. When part of the root zone was alternately irrigated, maize plants showed significant primary root initiation and greater root biomass build-up in the soil. Alternate furrow irrigation treatments were better than fixed furrow irrigation and conventional furrow irrigation treatments in terms of root growth. Alternate furrow irrigation not only enhanced root development but also helped release the adverse effect on the root development when watering was cut too severely. Total water use efficiency (CWUE) and net irrigation water use efficiency (FWUE) were larger in AFI than in CFI and FFI with the same irrigation amount.

Alternate furrow irrigation maintained high grain yield with up to 50% reduction in irrigation amount, while FFI and CFI all showed a substantial decrease in yield with reduced irrigation. Therefore, water use efficiency for irrigated water was substantially increased and concluded that alternate furrow irrigation is an effective water-saving irrigation method in arid areas where maize production relies heavily on repeated irrigation (Kang et al., 2000).

Torres et al. (1996) investigated the potential of AFI for sugarcane production over a seven-year period. An initial experiment conducted on a disturbed vertisol indicated that AFI yielded 38 t/ha cane less than CFI. However, AFI was found to be much more successful on other soil types with water savings of 43-50% achieved under the Columbian conditions. AFI was also used in Mauritius for sugar cane production and they found good and still using this system

Bakker, et al. (1997), explored alternate furrow irrigation has been effectively used in a variety of cropping systems and climatic conditions to preserve water without loss in production. Recent experimental work investigating AFI in Colombia for sugar cane production found that AFI resulted in both substantial water and labor savings. In the Burdekin region, the use of AFI was found to reduce yield compared with conventional furrow irrigation (CFI) when the same irrigation frequency was applied to both treatments. However, when AFI was applied more frequently in response to the crops evapotranspiration demand, there was no decrease in yield. AFI was also found to produce improved crop water use efficiency and AFI may be successfully used within the sugar industry in areas or periods of restricted water supply.

2.4.2. Fixed furrow Irrigation

Fixed furrow irrigation system supplies water to one side of each furrow ridge. Usually, this technique applies water to more area in a given amount of time than the conventional furrow irrigation. System benefit of irrigating every other furrow is the ability to store rainfall in a recently irrigated soil. FFI should not be used on steep slopes or on soils with low intake rates. On steep slopes, the water flowing down the furrow is in contact with only a limited amount of soil surface, causing low intake rates. Research indicates that every other furrow irrigation results in yields comparable to those achieved when every furrow is irrigated. According to Yonts et al. (2003), irrigation water application may be reduced 20 to 30 percent by implementing every other furrow irrigation (FFI). Because of increased lateral infiltration, infiltration is not reduced by one–half compared to watering every furrow. In general, the FFI technique is a trade-off between lower yield and higher WUE (Kang et al., 2000).

Many ways of conserving agricultural water have been investigated. Researchers fixed some furrows for irrigation, while adjacent furrows were not irrigated for the whole season. Water was saved mainly by reduced evaporation from the soil surface, as in the case of drip-irrigation and also used wide spaced furrow irrigation or skipped crop rows as a means to improve WUE. In general, FFI technique is a trade-off between lower yield and higher WUE (Kang et al., 2000).

2.4.3. Conventional furrow irrigation

According to Karajeh et al. (2000), under conventional furrow irrigation (CFI) system, irrigation water has been used as follows: 51-54% of the total water supply was used to moisten soil (saturation), 20-25% for infiltration within the temporary irrigation network and in the fields, 5-6% for the evaporation from water surface, and 18-21% for surface runoff. In addition, Karajeh et al. (2000) also stated, significant quantities of irrigation water losses by infiltration and surface runoff (about 40% of total water supply) reduced water supply to the irrigated lands 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.

In areas under no limitation of irrigation water, the yield of Bombay Red onion variety could be improved substantially by applying 100% irrigation amount with CFI (Yemane et al, 2018).

Mintesinot et al. (2004), made a comparative study that has been undertaken over two irrigation seasons between the traditional irrigation management (every furrow-traditional scheduling) and alternative water management options on maize plots in northern Ethiopia. Results were analyzed based on total yield, water use efficiencies, and economic productivity concepts. The yield-based comparison has shown that every furrow-scientific scheduling generates the highest yield levels followed by alternate furrows-scientific scheduling. The yield increase (by every furrow-scientific scheduling) over the traditional management was found to be 54%. Water productivity based comparison has shown that alternate furrows-scientific scheduling generates the highest water productivity values followed by every furrow-scientific scheduling. The increase (by alternate furrow irrigation, scientific scheduling) over the traditional irrigation management was 58%. An economic productivity-based comparison has shown that the highest economic return was obtained from every furrow-scientific scheduling followed by alternate furrows-scientific scheduling. The increase in income (by every furrow scientific scheduling) over the traditional irrigation management was 54 %.

As reported by Graterol et al. (1993) the excessive evapotranspiration and deep percolation in the CFI system did not increase yields. This may be so because a greater portion of the evapotranspiration and deep percolation could be due to non-productive water losses arising from evaporation from the higher amount of wet soil surface or from deep percolation.

2.5. Crop Water Productivity

Crop water productivity (WP) expressed in kg/m^3 is an efficiency term, expressing the amount of marketable product (e.g. kilograms of grain) in relation to the amount of input needed to produce that output (cubic meters of water) (Kijne et al.,2003). The water used for crop production is referred to as crop evapotranspiration. This is a combination of water lost by evaporation from the soil surface and transpiration by the plant, occurring simultaneously. Except by modeling, distinguishing between the two processes (evaporation and transpiration) is difficult. The water utilization efficiency for harvested yield (E_Y) for onion bulb is 8 to 10 kg/m^3 (Doorenbos and Kassam, 1986). Representative values of WUE for cereals at field level, expressed with evapotranspiration in the denominator, can vary between 0.10 and 4 kg/m^3 (Zwart et al., 2000).

2.6. Cultural Practices of Onion

Onion is one of the most important vegetables, which belong to the family (Dawar et, al 2007). It is originated in central Asia between Turkmenistan and Afghan where some of its relatives still grow as wild plants. It is a recently introduced crop to Ethiopia from Sudan, then spread too many parts of the country, and now became important vegetable crop for markets and domestic purpose in a standard of living (Nikus and Mulugeta, 2010).

Onion is sown in a well-prepared nursery where it takes about 30 to 45 days before being transplanted into the field. Seeds can also be sown directly into the field. The crop is planted in rows spaced at 0.3-0.5 x 0.05-0.1 m. The soil temperature favorable for germination is from 15°C to 25°C. Bulbs are ready for harvesting between 130 and 175 days from transplanting depending on climate (Doorenbos and Kassam, 1986).

The crop performs well on medium textured and well-drained soils of high fertility with a pH range of 6 to 7. However, onions grown in sandy soils require more frequent irrigation applications and such a crop usually mature early because bulbs are particular about the density of the soil and do not grow well if they are not able to expand easily. Sandy loams to clay loam soils are generally suitable for onion cultivation. Alkaline and saline soils are unsuitable for onion cultivation. Salt concentration above 4mmhos/cm^2 inhibits the growth of most of the onion cultivar. Soils, which experience a waterlogging problem, can cause crop development failure. Onion performs well and produces optimum yield under application of 350 to 550 mm of water throughout the growing season. Water stress affects onion development during transplanting, yield formation and during flowering period for seed crop. The crop is less sensitive to water deficit during the vegetative growth period and late season stage (Steduto et al, 2012).

The majority of onion production is found in the Central Rift Valley (CRV) of Ethiopia. In recent times, in the lower awash, where the vegetable production is widely cultivated as a cash crop by small-scale and private farmers, rainfall is insufficient to support onion production. Therefore, irrigation is an indispensable practice for onion production. Agro pastorals prefer to produce onion under irrigation during the dry period (October-April). It is grown primarily for its bulb, which is used for flavoring the local stew, '*wot*'. It is also widely cultivated as a source of income by many farmers in many parts of the country.

2.7. Experimental Design

2.7.1. Randomized complete block design

The randomized complete block design (RCBD) is one of the most widely used experimental design in agricultural research. The design is especially suited for field experiment where the number of treatment is not large and the experimental area has predictable productivity gradient. The primary distinguishing feature of the RCB design is the presence of blocks of equal size, each of which contains all the treatment (Gomez and Gomez, 1984)

The RCBD assumes that a population of experimental units can be divided into a number of relatively homogeneous subpopulations or blocks. The treatments are then randomly assigned to experimental units such that each treatment occurs equally often (usually once) in each block (i.e. each block contains all treatments). Blocks usually represent levels of naturally occurring differences or sources of variation that are unrelated to the treatments, and the characterization of these differences is not of interest to the researcher. In the analysis, the variation among blocks can be partitioned out of the experimental error (MSE), thereby reducing this quantity and increasing the power of the test (Douglas, 2005).

A two-factor factorial design is an experimental design in which data is collected for all possible combinations of the levels of the two factors of interest. If equal sample sizes are taken for each of the possible factor combinations then the design is a balanced two-factor factorial design (Douglas, 2005).

Two factors are said to interact if the effect of one factor changes as the level of the other factor changes. We shall define and describe the measurement of the interaction effect based on an experiment with two factors. An interaction effect between two factors can be measured only if the two factors are tested' together in the same experiment (i.e., in a factorial experiment). When interaction is absent, the simple effect of a factor is the same for all levels of the other factors and equals the main effect (Gomez and Gomez, 1984).

2.7.2. Coefficient of variance

The coefficient of variation (CV) is defined as the ratio of the standard deviation to the mean (Everitt, 1998). It shows the extent of variability in relation to the mean of the population. The coefficient of variation should be computed only for data measured on a ratio scale, as these are the measurements that allow the division operation.

On the premise that the various biophysical features of an experimental plot do not have independently but are often functionally related to each other. The analysis of covariance simultaneously examines the variances and covariance among selected variables such that the treatment effect on the character of primary interest is more accurately characterized than by use of analysis of variance only (Gomez and Gomez, 1984).

2.7.3. Least significant difference

The least significant difference (LSD) test is the simplest and the most commonly used procedure for making pair comparisons. The procedure provides for a single LSD value, at a prescribed level of significance, which serves as the boundary between significant and non-significant differences between any pair of treatment means. That is, two treatments are declared significantly different at a prescribed level of significance if their difference exceeds the computed LSD value; otherwise, they are not significantly different (Gomez and Gomez, 1984).

3. MATERIAL AND METHODS

3.1. Description of the study area

The study was conducted at Dubti, Afar regional state located in the northeastern part of the Ethiopian Rift Valley at the lower portion of the Awash basin. The study area is situated about 600 km northeast of Addis Ababa (capital city of Ethiopia) and 10 km from Samara, the capital city of Afar. Geographically, it is located between 11˚20' - 12˚25' N Latitudes and 40˚06' - 41˚30'E longitudes with an altitude that ranges from 339 - 381 m. a. s. l. and its slope ranges between 0.03 - 0.3% (WWDSE, 2004).

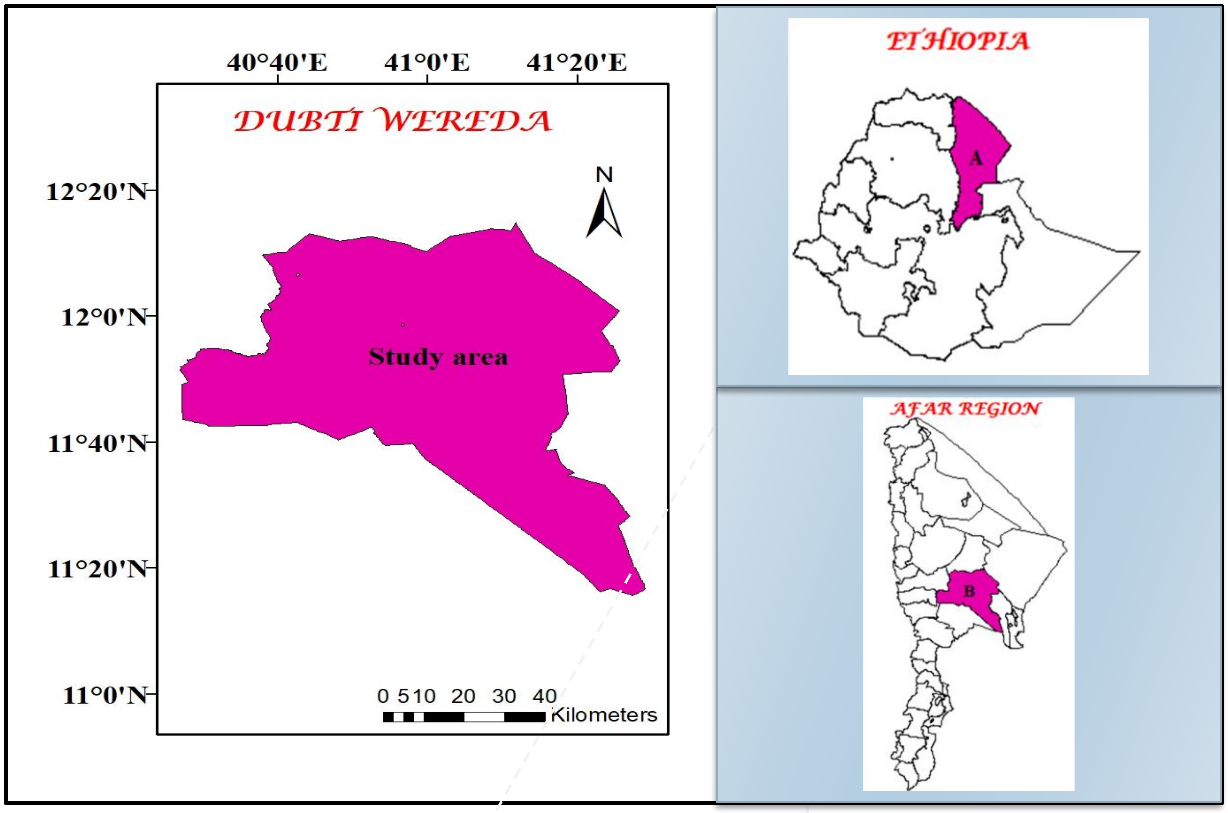

Figure 1: Location map of the study area

The Afar region in Ethiopia (A); Dubti wereda in Afar region (B); Dubti wereda (study area)

Average annual rainfall is 222 mm (from Dubti station from 1986 – 2014) which is characterized by bimodal rainfall pattern. The long rainy season from mid-June to mid-September is locally called "*karma*", while the short rainy season that extends from March to April is locally called "*sugum*". The rainfall is erratic in nature and is not sufficient for rainfed agriculture. Hence, crop production is practiced using irrigation. The annual mean minimum and maximum temperatures are 22.6 °C and 38.8 °C, respectively with mean annual evapotranspiration (ET) of 2854 mm (Abbi S., 2016).

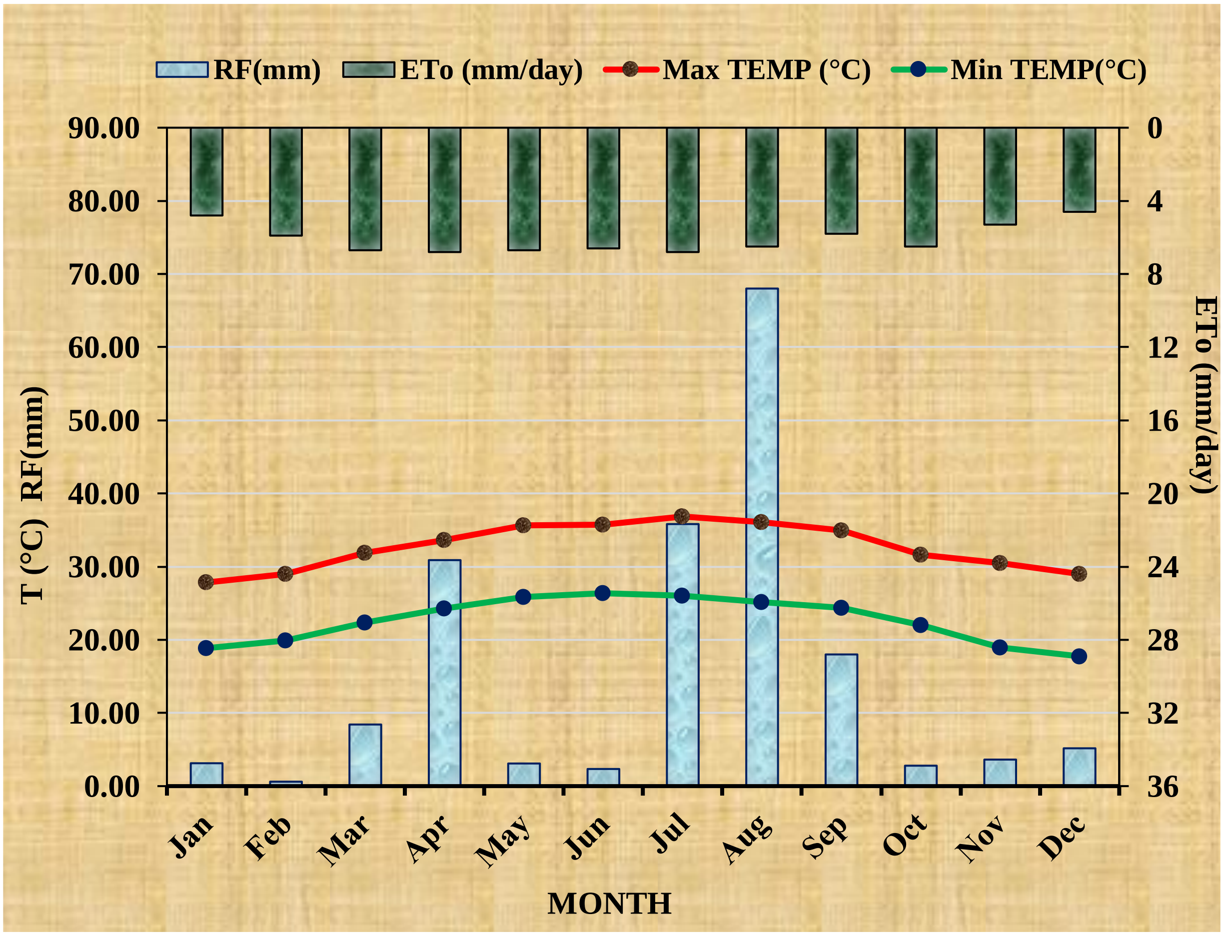

Figure 2: Mean monthly rainfall, maximum and minimum temperature of the study area (Dubti Meteorological Station, 2002 - 2016)

The study area consists of two major geologic formations: Tertiary and Quaternary volcanics of the Ethiopian Rift System, characterized as basaltic parent rock materials and some other volcanic formations with alluvial and colluvial deposits (Seeul, 2008). In general, the parent materials of the soils may be grouped as volcanic materials, general skeletal soils of ancient alluvial and lacustrine sediments of varying phases: fine, saline, sodic and recently deposited alluvium at the Rift Valley depressions adjacent to the Awash River. Soils from those parent materials are generally heavier in texture and patches of the original state were saline/ alkaline in nature (Afework, 2009).

3.2. Soil analysis

The soil physical and chemical characteristics were determined in Sirinka agricultural research center. The soil physical properties include texture, bulk density, organic matter, water retention at field capacity (FC) and permanent wilting point (PWP).

Moisture contents at FC and PWP measured using a pressure plate apparatus by applying pressures at 0.33 and 15 bars, respectively. The moisture content of the soil samples on the volume basis was determined by multiplying the gravimetric water content on the weight basis by the bulk density.

Estimates of total organic carbon (OC expressed as C) are used to assess the amount of organic matter in soils. (Nelson et al., 1996)

$$OM = OC * 1.72 \tag{1}$$

where $OM =$ organic matter (%)

OC = organic carbon (%)

The soil bulk density is defined as the oven dry weight of soil in a given volume, as it occurs in the field. It was determined by oven dry method. Soil bulk-density data was taken as cores in the field at four depths 0-15cm, 15-30 cm, 30-60cm and 60-100 cm, oven dried for 24 hrs. at 105°c and weighed for dry density using the following formula.

$$\rho_b = \frac{W_d}{V_c} \qquad (2)$$

where ρ_b = soil bulk-density (gm/ cm^3)

W_d = weight of dry soil (gm)

V_c = volume of core (cm^3)

3.3. Crop Water Requirement and Irrigation Scheduling

3.3.1. Climatic Data

Daily Climatic Data (maximum and minimum temperature, relative humidity, and wind speed and sunshine hours), geographical location of study site (altitude, latitude, and longitude) data were collected from Dubti metrological station and Afar pastoral and agro-pastoral research institute (APARI).

3.3.2. Crop agronomy

Onion Bombe red having growing period of 145 days, was planted in the nursery and transplanted to the experimental plot after 45 days. The crop parameters used for the estimation of the actual evapotranspiration, water balance calculations, and yield reductions due to stress include Kc, length of the growing season, critical depletion level p, and yield response factor taken from Doorenbos and Kassam, (1986) guideline.

Table 1: Relevant onion data for irrigation

Growth stage	Initial	Development	Mid	Late	Total
Stage lengths (days)	15	30	25	20	90
Crop coefficient (Kc)	0.7	---	1.05	0.75	
Rooting depth (m)	0.25	---	0.45	0.60	
Depletion levels (P)	0.30	0.38	0.45	0.50	

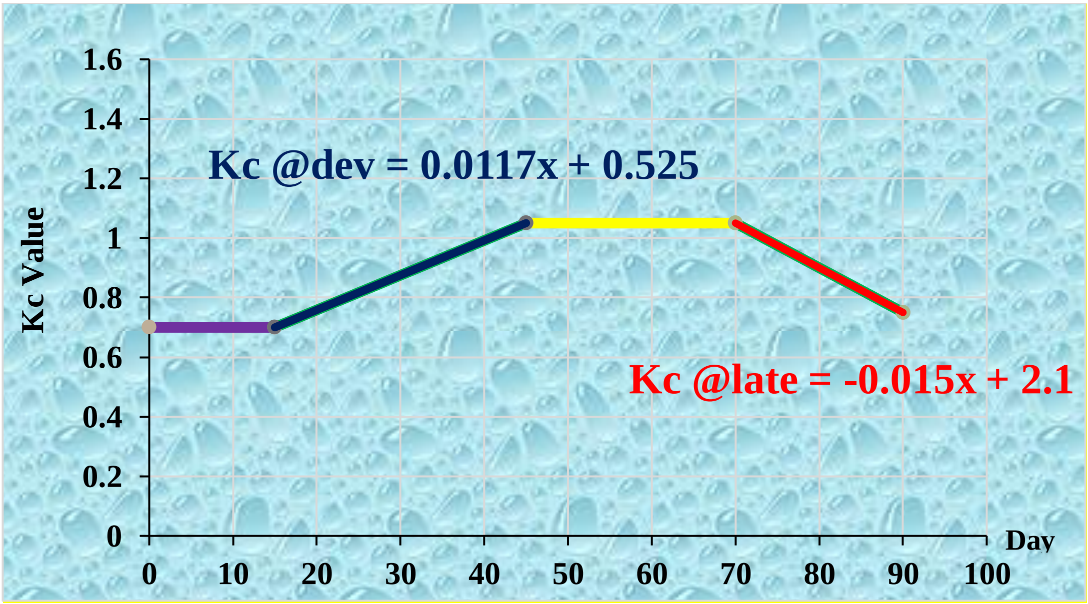

Figure 3: Daily K_C value at different stage

3.3.3. Determination of reference evapotranspiration

Using daily meteorological data, the daily reference evapotranspiration (ET_o) was determined by applying the modified FAO Penman-Monteith equation (Allen *et al*., 1998) with the help of CROPWAT software 8. The input data for the CROPWAT software includes location (altitude, latitude, and longitude) of the meteorological station, daily values of maximum and minimum air temperatures, air humidity, sunshine duration, wind speed, and agronomic data were used. The crop water requirement of the test crop was calculated by multiplying the reference ET_c with crop coefficient (K_C). In fact, this estimated daily crop water requirement has been used as a control mechanism to know how much water could be possibly consumed by the test crop; however the amount of water applied was based on monitoring the allowable depletion level, growth stage and the correspondent effective root depth as indicated in table 1.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{(\Delta + \gamma(1 + 0.34U_2)} \tag{3}$$

where, ET_O	Reference evapotranspiration [mm day^{-1}],
R_n	Net radiation at the crop surface [MJ m^{-2} day^{-1}],
G	Soil heat flux density [MJ m^{-2} day^{-1}],
T	Air temperature at 2 m height [°C],
U_2	Wind speed at 2 m height [m s^{-1}],
e_s	Saturation vapor pressure [kPa],
e_a	Actual vapor pressure [kPa],
$e_s - e_a$	Saturation vapor pressure deficit [kPa],
Δ	Slope vapor pressure curve [kPa $°C^{-1}$],
γ	Psychometrics constant [kPa $°C^{-1}$].

3.3.4. Determination of crop water requirement (ETc)

Computation of ETc requires planting dates, length of growing season, daily reference evapotranspiration and K_c-values at different crop stages. Daily ET_C was estimated from the expression of Allen *et al*., (1998):

$$ET_C = K_c * ET_o \tag{4}$$

where, $ET_C =$ crop water requirement (mm per day) and

K_c is infraction which is an empirical ratio of actual crop water use to reference evapotranspiration. The K_c values obtained from reference texts of (Allen *et al*., 1998).

3.3.5. Irrigation Water Requirement

Computation of IR requires daily rainfall data. The values were obtained during the computation of ETc and effective rainfall, which is part of the rainfall that entered into the soil and made available for crop production. Generally, IR was estimated using the method given by (Allen et al., 1998) as:

$$IR = ET_C - P_{eff} \tag{5}$$

where, $IR =$ Irrigation requirement (mm),

$ET_C =$ Crop water requirement (mm) and

P_{eff}= Effective rainfall (mm).

The effective rainfall which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (P_{eff}) was estimated using the method given by Allen et al., (1998) as.

$$Peff\ = 0.6 * P - \frac{(10)}{3} \qquad If\, P < \frac{70}{3} \tag{6}$$

$$Peff\ = 0.8 * P - \frac{(24)}{3} \qquad If\, P < \frac{70}{3} \tag{7}$$

where, P = precipitation (mm/month)

3.3.6. Irrigation Scheduling

Soil water availability refers to the capacity of a soil to retain water available to plants. After heavy rainfall or irrigation, the soil will drain until field capacity is reached. TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth. The total available soil Water (TAW) was computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using the following expression (Allen et al., 1998).

$$TAW = 10 * (FC - PWP) * Dz \tag{8}$$

where TAW= total available water in mm

FC = Field Capacity in % on volume basis

PWP = Permanent Wilting Point in % on volume basis,

Dz = is the maximum effective root zone depth in m

In this study, optimal irrigation schedule was analyzed using allowable soil moisture depletion/ readily available soil moisture. One of the computation methods for the optimal irrigation scheduling for no yield reduction is the irrigation given at 100 % readily available soil moisture depletion to refill the soil to its field capacity. The readily available soil water, RAW is the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW could be computed from the expression (Allen et al., 1998).

$$RAW = p * TAW \tag{9}$$

where RAW = readily available water (mm per depth) of soil,

p= allowable soil moisture depletion for no water stress infraction, and

TAW= total available water (mm per depth) of soil.

.Considering the ET_C, TAW, $D_{Z,}$ and p, the irrigation interval was computed from the expression (Allen et al., 1998).

$$Interval\ (days) = \frac{RAW}{ET_C} \tag{10}$$

where, RAW= readily available water in mm and

ET_C= crop water requirement in mm day^{-1}

The gross irrigation requirement, IR_g, in a particular event could be computed from the expression: (Allen et al., 1998).

$$IRg = \frac{Interval * IR}{Ea} \tag{11}$$

where IRg = Gross irrigation requirement in mm,

$Interval$ = irrigation interval in days,

IR= Irrigation requirement in mm day^{-1}

Ea= Irrigation efficiency infraction. (60%)

3.3.7. Flow time measurement

A 2-inch standard Parshal flume was set near the up-stream furrows, to monitor the rate of inflowing irrigation water. Based on the calibrated depth vs. discharge table (Appendix table 11) the time required to deliver the desired depth of water into each furrow was calculated using the equation recommended by Israelsen and Hansen (1980).

$$\boldsymbol{t} = \frac{\boldsymbol{d_{rz} * l * w}}{\boldsymbol{6 * q}} \tag{12}$$

where $\boldsymbol{t}$ = time in (min)

$\boldsymbol{d_{rz}}$=depth of root zone in (cm)

$\boldsymbol{l}$= length (m)

$\boldsymbol{w}$=width (m)

$\boldsymbol{q}$=discharge ($^{l}/_{s}$)

3.4. Experimental design

The treatments considered for the experiment with two factors; namely, three irrigation systems and three irrigation levels. The three irrigation systems were AFI, FFI, and CFI and the three levels of irrigation were 100% (Full), 75% (Three-fourth) and 50% (Half) of the irrigation requirement.

With full irrigation treatments, the amount of irrigation water applied was computed crop water requirement with the aid of CROPWAT model. Three-fourth and half irrigation levels meant three-fourth and half of the full irrigation requirement, respectively.

Each experimental plot was 4 m * 2.8 m with 2 m free space between plots and a 3m wide road between replications. The spacing between ridges, rows, and plants were 40 cm, 20 cm and 10 cm respectively with a double row, as suggested by Abera and Chimdo (2001). Each plot has six ridges and seven ends blocked furrows and having 40 plants in each row with a total plant population of (560) in each plot.

Each treatment were replicated three times and the plots have lied following a Factorial Randomized Complete Block Design (RCBD) as shown the figure below. Hence, the design was two factors factorial experiment (3^2) in RCBD. CFI 100% was the control treatment. The experimental treatments were:

Treatment	Combinations	
T1	Conventional furrow irrigated at 100% ET_C	CFI 100%
T2	Conventional furrow irrigated at 75% ET_C	CFI 75%
T3	Conventional furrow irrigated at 50% ET_C	CFI 50%
T4	Alternative furrow irrigated at 100% ET_C	AFI 100%
T5	Alternative furrow irrigated at 75% ET_C	AFI 75%
T6	Alternative furrow irrigated at 50% ET_C	AFI 50%
T7	Fixed furrow irrigated at 100% ET_C	FFI 100%
T8	Fixed furrow irrigated at 75% ET_C	FFI 75%
T9	Fixed furrow irrigated at 50% ET_C	FFI 50%

FFI 50%	AFI 100%	CFI 75%	AFI 50%	FFI 75%	FFI 100%	AFI 75%	CFI 100%	CFI 50%
CFI 50%	AFI 100%	AFI 50%	CFI 75%	FFI 50%	AFI 75%	FFI 100%	CFI 100%	FFI 75%
AFI 100%	FFI 50%	CFI 75%	CFI 50%	FFI 100%	AFI 75%	CFI 100%	FFI 75%	AFI 50%

Figure 4: Randomization of treatments across replication

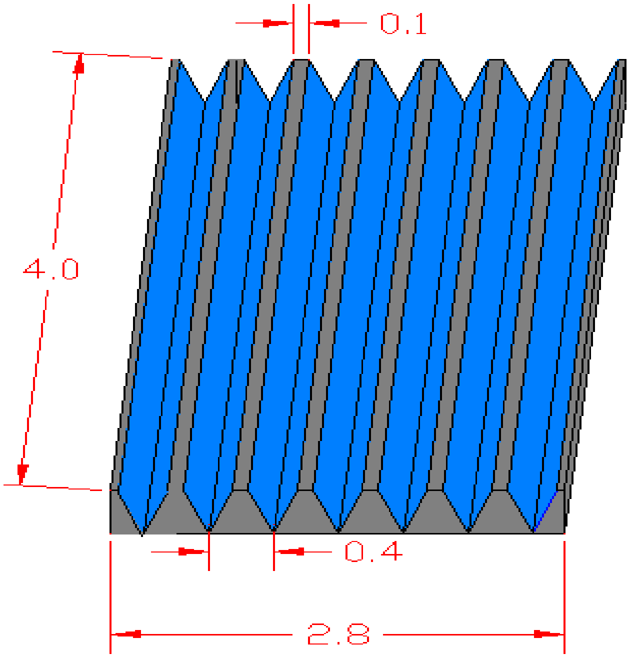

Figure 5: Plot layout and Dimension (m)

3.5. Soil Moisture Determination

Soil samples were taken from 0-25cm depth to monitored moister content until it reaches 30% (P=0.3) of depletion level to apply the first irrigation. The wet soil samples were dry in an oven at a temperature of 105°C for 24 hrs. Its gravimetric water content was determined using the expression (Michael, 1978).

$$\theta_{dw} = \frac{W_{ws} - W_{ds}}{W_{ds}} * 100 \qquad (13)$$

where θ_{dw}= water content expressed on a weight basis in (%)

W_{ws}= weight of wet soil (gm),

W_{ds} = weight of dry soil (gm)

The volumetric water content was calculated using the following expression: (Michael, 1978)

$$\theta_{v} = \frac{\rho_b}{\rho_w} * \theta_{dw} * 100 \qquad (14)$$

where θ_{v}= water content expressed on a volumetric basis (%)

θ_{dw}= water content expressed on a weight basis (%)

ρ_b= soil bulk density (gm/cm^3), and

ρ_w= water density g/cm^3 (1 gm/cm^3)

3.6. Water use efficiency (WUE)

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water (kg/m^3). (Skewes, 1997).

$$WUE = \frac{Y}{ET_C} \tag{15}$$

where WUE= water use efficiency (kg/ha-mm)

Y= yield in kg/ha and

ETc= crop evapotranspiration in mm

3.7. Collected data

Date of transplanting, plant height, and other relevant agronomic parameters was recorded during the period of the experiment. Five random plants per plot excluding the border rows and border plants in the central four rows were taken as a sample to record plant height, bulb diameter, bulb height, and average weight. Measurements were carried out by tapping the main stem height from the ground level up to the tip of the leaf with the help of a ruler graduated in centimeters. The extent of total bulb yields was collected and weighed from the four central rows of each plot to avoid border effects. The harvested yield was graded into marketable and nonmarketable categories of onion bulb according to the size and degree of damage. Onion bulbs with less than 3 cm in diameter were categorized under non-marketable (Moray et al., 2012)

Stand count during the harvesting stage all survival plants at each plot were counted in order to estimate how many plants were survived compared to initially transplanted (560 plants per plot).

Plant height (cm) five onion plants were selected from the interior rows to avoid border effect. The height of these five plants was measured from the soil surface to the tip of the plant using ruler/tape meter.

Bulb height (mm) refers to the length of randomly selected five plant bulbs were measured using caliper in centimeter. Then, the average bulb length was calculated.

Bulb diameter (mm) refers to the diameter of five sample randomly selected plant bulbs measured at the widest point in the middle portion of the mature bulb using a slide caliper.

Average bulb weight (gm) refers to the bulb weight of randomly selected plants weighted using a digital balance

Total bulb yield (ton/ha) was recorded from the net plot by weighing all bulbs taken from the central row and converted into ton/ha.

Marketable bulb yield (ton/ha) refers to the yield of onions, which are not undersized (>3cm in diameter), free from physiological disordered and pest damaged bulbs. It was determined from the weight of bulbs harvested from the net plot using digital balance.

Water use efficiency (kg/m^3) was determined by dividing the bulb yield produced from each treatment to the amount of water applied.

3.8. Data analyses and computations

The computations and all statistical analyses were analyzed using the **Statistics 10** statistical software. Mean separation was carried out using least significance difference (LSD) test at 5% probability level. The experiment was considered as two factors (furrow irrigation systems and amount of irrigation level) with Randomized Complete Block Design (RCBD) during the analysis.

4. RESULTS AND DISCUSSIONS

4.1. General soil physical characteristics of the study area

4.1.1. Soil Texture of the Experimental Area

The result of the soil textural analysis of the experimental site analyzed by the hydrometer method. The average composition of sand, silt, and clay percentages were 10.67%, 53.83%, and 35.50%, respectively, according to the USDA soil textural classification, the percent particle size determination for the experimental site was revealed that Silty clay loam soil (See Table 3).

Table 2: Soil textural class

	Particle size distribution (%)			
Depth (cm)	Sand (%)	Silt (%)	Clay (%)	**Textural class**
0-15	10.00	69.33	20.67	**Silty clay loam**
15-30	10.67	60.00	29.33	**Silty clay loam**
30-60	13.33	43.33	43.33	**Silty clay**
60-100	8.67	42.67	48.67	**Silty clay**
Average	10.67	53.83	35.50	**Silty clay loam**

Soil organic matter is the organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells, and tissues of soil organisms, and substances synthesized by soil organisms (Tate, 1987).The organic matter content of the soil is taken as a basic measure of fertility status by improve water-holding capacity, nutrient release and soil structure. The experimental site organic matter contents were 0.92 %, which rated as low. Thus, it needs additional nutrients that increase the amount of organic matter in the soils.

4.1.2. Field capacity, Permanent wilting point and Bulk density

The topsoil surface had a slightly lower bulk density (1.25gm/cm^3) than the subsurface (1.45gm/cm^3) which might be high organic matter contents in the topsoil surface and the compaction level increased in the lower part. In general, the average soil bulk density (1.33 gm/cm^3) was suitable for crop root growth.

The experimental site of field capacity soil moister contents were 17.33%, 19.33%, 25.67% and 22.33% at 0-15 cm, 15-30 cm, 30-60 cm, and 60-100cm depths, respectively. The average soil moisture content at the permanent wilting point was 8%, 9% 11%, and 9% at 0-15 cm, 15-30 cm, 30-60 cm, and 60-100cm depths, respectively and showed similarity along the depth. The total available water (TAW) is the amount of water that a crop can extract from its root zone is directly related to variation in FC and PWP and its root depth. Onion root depth extends only to 60 cm and hence the TAW of onion is 73.5 mm. TAW of the experimental site soil was found to be 126.83 mm per meter depth (See Table 4)

Table 3: Average BD, FC and PWP, TAW of the experimental site

Soil depth (cm)	**Bulk density (gm/cm^3)**	**FC (%)**	**PWP (%)**	**TAW(mm)**
0-15	1.25	17.33	8.00	14.00
15-30	1.31	19.33	9.00	15.50
30-60	1.33	25.67	11.00	44.00
60-100	1.45	22.33	9.00	53.33
Total	**1.33**	**21.17**	**9.25**	**126.83**

4.2. Irrigation Water Requirements of Onion

Table 4: Crop and irrigation water requirement of the control treatment (CFI 100%)

Irrigation Day	ET_C Mm	Rain Fall mm/period	P_{eff} mm/period	NIR mm/period	Gross IR mm/period
5-Feb	15.32			15.32	25.53
8-Feb	13.13			13.13	21.88
11-Feb	12.01	16.00	9.24		0.00
14-Feb	12.38			15.15	25.25
17-Feb	12.31			12.31	20.52
21-Feb	16.02			16.02	26.70
25-Feb	16.11			16.11	26.85
1-Mar	20.79	25.00	19.14		0.00
5-Mar	23.86			25.50	42.50
9-Mar	24.71			24.71	41.18
13-Mar	25.73	10.00	5.68	20.05	33.42
17-Mar	28.08			28.08	46.80
22-Mar	29.03			29.03	48.38
27-Mar	32.06			32.06	53.43
1-Apr	32.71			32.71	54.52
6-Apr	36.79			36.79	61.32
11-Apr	35.65			35.65	59.42
17-Apr	43.16			43.16	71.93
24-Apr	38.92			38.92	64.87
2-May	47.65			47.65	79.42
Total	**516.42**	**51**	**34.06**	**482.35**	**803.92**

The daily weather data during the growing period from February 2 to May 2, 2018, were collected from Dubti Meteorological Station; (Appendix Table 2). Total precipitation and effective rainfall during the season were 51mm and 34.06mm respectively, which is rated as low rainfall. Based on daily ET_O and K_C value, the seasonal crop and irrigation water requirement were found to be 516.42 mm and 482.35 mm, respectively, this amount needed for full irrigation level treatments (CFI 100%). (See Table 5).

Crop water requirement (ET_C) values were low at the initial stage and late stage and increased gradually from the development to mid-stage to attain a maximum soil moister depletion level (Table 6). During the season, the maximum amount of water was applied around the bulb formation and assimilating partitioned onion of bulbs. This is in agreement with Doorenbos and Kassam (1996), irrigation application every 2 - 4 days is commonly practiced.

By using daily climatic data, ET_C was calculated with the aid of FAO CROPWAT software. Irrigation water requirement was governed by the capacity of the soil to holding available water, growth stage, depletion levels and effective root depth. As the net amount of irrigation, water was applied to refill the Soil Moisture Deficit (SMD). The depth applied to other treatments is taken simply as a percentage of the optimal irrigation throughout the growing season

4.3. Irrigation Water Application on the Experimental Treatments

The results of conventional furrow irrigation (CFI) with 100%, 75% and 50% ETc was found to be 482.35 mm, 361.76 mm and 241.18 mm respectively. In addition, alternate and fixed furrow irrigation systems with 100%, 75%, and 50% of ETc were 258.21 mm, 200.04 mm and 139.04 mm respectively. AFI and FFI received an equal amount of water, the only difference is AFI irrigated alternately neighbor furrows while in FFI only one fixed furrows were irrigated from the neighbor. From the effective rainfall 34.06 mm, half of 17.03 mm was additional to the net ET_C of AFI and FFI. Because in AFI and FFI the neighbor furrow must be dried but due to rainfall half furrows were wetted. (See Table 6).

Table 5: Net irrigation depth (mm) of experimental treatments

Day	CFI 100%	CFI 75%	CFI 50%	AFI/FFI 100 %	AFI/FFI 75%	AFI/FFI 50 %
5-Feb	15.32	11.49	7.66	7.66	5.75	3.83
8-Feb	13.13	9.85	6.57	6.57	4.92	3.28
11-Feb	0.00	0.00	0.00	4.62	4.62	4.62
14-Feb	15.15	11.36	7.58	7.58	5.68	3.79
17-Feb	12.31	9.23	6.16	6.16	4.62	3.08
21-Feb	16.02	12.02	8.01	8.01	6.01	4.01
25-Feb	16.11	12.08	8.06	8.06	6.04	4.03
1-Mar	0.00	0.00	0.00	9.57	9.57	9.57
5-Mar	25.50	19.13	12.75	12.75	9.56	6.38
9-Mar	24.71	18.53	12.36	12.36	9.27	6.18
13-Mar	20.05	15.04	10.03	12.87	9.65	6.43
17-Mar	28.08	21.06	14.04	14.04	10.53	7.02
22-Mar	29.03	21.77	14.52	14.52	12.26	7.31
27-Mar	32.06	24.05	16.03	16.03	12.02	8.02
1-Apr	32.71	24.53	16.36	16.36	12.27	8.18
6-Apr	36.79	27.59	18.40	18.40	13.80	9.20
11-Apr	35.65	26.74	17.83	17.83	13.37	8.91
17-Apr	43.16	32.37	21.58	21.58	16.19	10.79
24-Apr	38.92	29.19	19.46	19.46	14.60	9.73
2-May	47.65	35.74	23.83	23.83	17.87	11.91
Total	**482.35**	**361.76**	**241.18**	**258.21**	**200.04**	**139.04**

4.4. Irrigation Effect on Bulb Yield and Yield Parameters

4.4.1. Stand count

The ANOVA in Appendix Table 3, shows that generally there was no significant difference ($\alpha<0.05$) in stand count either in irrigation system or irrigation level. In addition, the interaction effect also did not show significant difference in stand count. This might be because of during the first season all treatments received full irrigation for the establishment of transplanted onion.

4.4.2. Plant height

As indicated in Appendix Table 4, the ANOVA result on plant height was not shown significant difference ($\alpha < 0.05$) by the interaction effects of the treatments. However, the furrow irrigation systems and irrigation levels were highly significantly different from each other in plant height at ($\alpha \leq 0.01$).

The highest and lowest plant height of 45.02 cm and 41.73 cm was recorded by 100% and 50% ETc of irrigation depth respectively. 50% of irrigation depth of water applied recorded the lowest plant height. 100% ETc got 3.29 cm, which was greater than plant heights recorded in treatments that received 50% of irrigation depth. (See Table 6)

The highest plant height was 43.74 cm recorded by conventional furrow irrigation systems. Subsequently alternative and fixed furrow irrigation systems having, 43.32 cm and 42.84 cm plant height, respectively. (See Table 6)

Table 6: Effects of an irrigation system and amount of irrigation level on plant height

	Irrigation systems(IS)			**Irrigation levels(IL)**			**Grand Mean**	**CV**	**P**
	CFI	**AFI**	**FFI**	**100%**	**75%**	**50%**			
Plant Height (cm)	**43.74a**	**43.32b**	**42.84c**	**45.02a**	**43.15b**	**41.73c**	**43.3**	**0.91**	**0.00**

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

The results of this study are consistent with those of Payero et al. (2006) who found that water stress reduces crop height, which in turn affects yield. The finding of this study is also in agreement with those of Yemane et al. (2018), who reported that water deficit significantly reduced plant height. Furthermore, Ghooshchi et al. (2008) also reported significant plant height reduction as compared with the control upon subjecting plants under water deficits conditions. Plant height increase at 100% of irrigation water level and conventional furrow irrigation systems. It could be mainly due to better availability of soil moisture that in turn may enhance effects on the vegetative growth of plants by increasing cell division and elongation.

This study outcome is in line with the research that has done by Vaux and Pruit, (1983); they reported an application of adequate depth of irrigation water rises plant height that indicates the favorable effect of water in keeping the turgor pressure of the cell, which is the major prerequisite for growth. Similarly, Sammis et al. (1988) informed that plant height could vary at the different level of water deficit. Plant height is a good sign to determining the scarcity of water.

4.4.3. Bulb height

As indicated in Appendix Table 5, the ANOVA result showed no significant difference ($\alpha \leq 0.05$) due to the interaction effect of furrow techniques and irrigation level on bulb height. However, the furrow irrigation systems and irrigation levels were highly significantly different from each other on bulb height at ($\alpha \leq 0.01$).

As indicated in Table 7, the furrow irrigation systems were highly significant ($\alpha \leq 0.01$) different from each other in bulb height. Significantly higher bulb height of 53.80 mm height was recorded at conventional furrow irrigation followed by 50.53 mm of AFI and 45.49 mm of FFI.

This study showed that different levels of irrigation water application have highly significant ($\alpha \leq 0.01$) influenced on bulb height of onion. Significantly higher bulb height of 52.42 mm was recorded at full irrigation (100%) followed by 50.16 mm and 47.25 mm at 75% and 50% ETc, respectively. The highest bulb heights of onion were found at 100% ETc whereas the short bulb heights of onion were recorded at 50% ETc of irrigation level. (See Table 7).

This result is in agreement with that of Olalla *et al.* (2004) who observed smaller sized bulbs in mild water stressed onion plants. The result revealed that the 50% irrigation depth might have minimized transpiration and photosynthesis and assimilate available for growth of the crop, which thus caused to produce small bulbs.

Table 7: Effects of an irrigation systems and irrigation levels on bulb height

	Irrigation systems(IS)			**Irrigation levels(IL)**			**Grand mean**	**CV**	**P**
	CFI	**AFI**	**FFI**	**100%**	**75%**	**50%**			
Bulb Height (cm)	**53.80a**	**50.53b**	**45.49c**	**52.42a**	**50.16b**	**47.25c**	**49.94**	**2.43**	**0.00**

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

4.4.4. Bulb diameter

As indicated in Appendix Table 6, the analysis of variance for the furrow irrigation systems and irrigation level has shown that there was a highly significant difference ($\alpha \leq 0.01$) on bulb diameter. Nevertheless, the analysis of variance revealed that the interaction effect showed no significant difference ($\alpha \leq 0.05$) on bulb diameter.

On this test, the irrigation systems show that the largest bulb diameter was recorded for CFI and AFI with the value of 55.05 mm and 52.56 mm respectively. However, the least bulb diameter 50.03 mm was recorded for fixed furrow irrigation. (See Table 8)

The irrigation level, largest onion bulbs were 54.09 mm diameter recorded from 100% ETc (full irrigation) amount of irrigation water applied. On the other hand, the least bulb diameter 50.76 mm was recorded from irrigation level treated with 50% irrigation depth. (See Table 8)

The result has in agreement with Enchalew et.al (2016) and Yemane, (2018) they reported bigger photosynthetic area of the plant like the height of plants and number of leaves were formed due to high irrigation levels, which increased the amount of assimilating partitioned to the bulbs and increased bulb diameter. Also, the result is in line to Olalla et al. (2004) reported that plots which received the maximum volumes of water yielded harvests with greater percentages of large size bulbs whereas limitation of water led to small-size bulbs. In addition, Biswas et al. (2003) indicated that the bulb diameter of onions was increased at a higher amount of irrigation. Similarly, this indicates that transpiration, photosynthesis and growth rates were lowered by water stress as a stressed plant produces smaller sized bulbs.

Table 8: Effects of irrigation systems and irrigation levels on bulb diameter

	Irrigation systems(IS)			**Irrigation levels(IL)**			**Grand mean**	**CV**	**P**
	CFI	**AFI**	**FFI**	**100%**	**75%**	**50%**			
Bulb Diameter (cm)	**55.05a**	**52.56b**	**50.03c**	**54.09a**	**52.78b**	**50.76c**	**52.54**	**2.13**	**0.00**

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at P ≤ 0.05; CV= coefficient of variation; P=Probability level***

4.4.5. Average bulb weight

As indicated in Appendix Table 7, the average bulb weight per plant was shown significantly differenced by their interaction effects (α ≤ 0.05). Moreover, the average bulb weight per plant of onion was a highly significant difference (α ≤ 0.01) by the main effects of irrigation systems and irrigation levels.

On this result, the highest average bulb weight 61.63 gm was recorded from Convectional Furrow irrigation and Alternative Furrow irrigation was an average bulb size of 59.47 gm; whereas the lowest average bulb weight was recorded at Fixed Furrow irrigation with 56.88 gm weight (See Table 9).

Decreasing applied water by 25% and 50% of ETc led to decreased average bulb weight of onion by 4.00% and 9.17 %, respectively. The maximum value of the average bulb weigh per plant was recorded as 62.05 gm for 100% of irrigation level. While for 75% and 50% were obtained 59.57 gm and 56.36 gm, respectively. The lowest average bulb weight per plant was obtained from the treatment of 50% of irrigation level. (See Table 9)

Table 9: Effects of irrigation systems and irrigation levels on average bulb weight

	Irrigation systems(IS)			**Irrigation levels(IL)**			**Grand mean**	**CV**	**P**
	CFI	**AFI**	**FFI**	**100%**	**75%**	**50%**			
Average Bulb Weight (gm)	**61.63a**	**59.47b**	**56.88c**	**62.05a**	**59.57b**	**56.36c**	**59.33**	**1.14**	**0.00**

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

Among the treatments of furrow irrigation, the bulb weight for CFI was 4.75 gm; higher than the Fixed Furrow irrigation. On the other hand, full irrigation (100%) was 5.69 gm higher than, to the treatment of 50% irrigation level.

Similarly, Subedi et al. (2002) reported that average bulb weight of onion was significantly increased at 120% ET_c irrigation levels. Average bulb weight of onion responded to an increased level of irrigation water applied. The increment in bulb weight due to increase in irrigation levels might be because the growth of taller plants is depicted by a higher number of leaves causing for better synthesis and transportation that assimilates from source to sinks (Biswas *et al.*, 2003).

4.4.5. Total bulb yield

With the intention of comparing the yield performance of the three irrigation systems with irrigation levels. Onion bulb yield was collected from the four centered ridges of every plot ($4.8m^2$), and converted into hectare basis. As indicated in Appendix Table 8, the total bulb yields was shown highly significant difference ($\alpha \leq 0.01$) on the interaction effect of irrigation systems and irrigation levels.

The interaction effect, significantly higher bulb yield of 25.46 ton/ha, 24.88 ton/ha, 24.54 ton/ha and 23.20 ton/ha, was recorded by CFI 100%, CFI 75%, AFI 100%, and CFI 50%, respectively. The CFI at full irrigation (100%) was gave 0.58 ton/ha greater than it produced in plots which received 75% and 0.92 ton/ha greater which received 100% irrigation level of AFI. The least bulb yield was recorded on FFI 50%, followed by FFI 75%, FFI 100% and AFI 50% which is 14.56 ton/ha, 16.75 ton/ha, 19.86 ton/ha and 21.56 ton/ha, respectively. However, the effects of AFI 100%, CFI 75%, and CFI 100% have no significant difference on yield. Therefore, AFI 100% saves more water than full irrigation without significant loss of yield. (See Table 10)

Table 10: Interaction effects of furrow irrigation systems and irrigation levels on bulb yield (ton/ha)

Group	100%	75%	50%	Mean
CFI	25.46a	24.88a	23.20b	**24.51a**
AFI	24.54a	22.64bc	21.69c	**22.96b**
FFI	19.86d	16.75e	14.56f	**17.06c**
Mean	**23.29a**	**21.42b**	**19.81c**	
Grand mean	**25.51**			
CV	**3.18**			
P	**0.009**			

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

Furrow irrigation systems and irrigation levels have shown highly significant differences ($\alpha \leq 0.01$) effect. Higher total onion bulb yield was recorded when conventional furrow irrigation system was applied that gave 24.51ton/ha and 22.96 ton/ha was recorded under alternative furrow irrigation. The lowest total bulb yield of 17.06 ton/ha was recorded at fixed furrow irrigation. (See Table 11)

Irrigation levels as the main effect was shown in Table 12; there was a highly significant difference among irrigation level on total bulb yield ($\alpha \leq 0.01$). The yield of onion decreased as the irrigation level decreased. The highest total bulb yield of 23.29 ton/ha was recorded on irrigation level of 100% ET_C and followed by 21.42 ton/ha, for 75% ET_C. The lowest value of 19.81 ton/ha yield was observed in 50% of water applied. Decreasing applied water by 25%, and 50% of ET_C led to decreased in bulb yield of onion by 8.03% and 14.95 %, respectively. (See Table 12)

Table 11: Effects of an irrigation systems on total bulb yield

Irrigation system	Yield in ton/ha
CFI	24.51a
AFI	22.96b
FFI	17.06c
Grand mean	**21.51**
CV	**3.18**
P	**0.00**

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

Table 12: Effects of irrigation levels on total bulb yield

Water application level	Yield in ton/ha
100%	23.29a
75%	21.42b
50%	19.81c
Grand mean	**21.51**
CV	**3.18**
P	**0.00**

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

Similarly, Kang et al (2000) evaluated the alternate furrow irrigation, fixed furrow irrigation and conventional furrow irrigation with different irrigation amounts for crop production. They reported that the reduction of crop yield in alternate furrow irrigation was not shown a significant difference, unlike fixed furrow irrigation. The rise in onion total bulb yield might be attributed to the large size of onion bulb due to an application of a high amount of irrigation.

This is because, raise of irrigation level encourages cell elongation, above ground vegetative growth and imparts dark green colour of leaves, which is important for more assimilate production and partition that favors onion bulb growth (Brady, 1985).

Generally, an application of conventional furrow irrigation with an increased level of irrigation level produced higher total bulb yield.

4.4.6. Marketable yield

As indicated in Appendix Table 9, ANOVA shows the interaction effect of furrow irrigation systems and irrigation levels were shown highly significant differences ($\alpha \leq 0.01$) on the marketable bulb yield of onion. Similarly, Marketable bulb yield of onion was shown highly significantly affected ($\alpha \leq 0.01$) by the furrow irrigation systems and irrigation levels.

On this study, conventional furrow irrigation systems gave more Marketable yield with irrigation water amount of 100% (full irrigation) followed by AFI 100% and CFI 75% which is 25.42 ton/ha, 22.51 ton/ha and 21.20 ton/ha, respectively. The least marketable yield was scored in FFI 50% and AFI 50% with 12.94 ton/ha and 14.50 ton/ha, respectively. Yet, CFI with 100% gave optimum yield followed by AFI with 100% (See table 13).

In terms of the irrigation systems, the higher marketable yield was recorded in conventional furrow irrigation with 21.02 ton/ha. Followed by alternate furrow irrigation and fixed furrow irrigation. The least marketable yield was recorded in FFI which is 15.88 ton/ha (See Table 13).

Irrigation levels, in its main effect, increased bulb yield highly significantly, producing higher marketable bulb yield of onion 22.31 ton/ha with full irrigation of 100%ET_C and followed by 75%, and 50% irrigation level with the value of 19.07 ton/ha and 14.63 ton/ha, respectively.

Significantly lower marketable bulb yield was recorded with 50% of irrigation level (See Table 13).

This result agreed with the general principle that the results of the crop to optimum irrigation is generally greater under irrigated environments than none irrigated one (Michael, 1978). The increment in marketable bulb yield due to an application of irrigation water could be attributed to the increment in vegetative growth and total bulb yield, which is associated with an increment in bulb diameter and average bulb weight (Neeraja *et al.*, 1999).

Table 13: Interaction Effects of irrigation systems and irrigation levels on marketable bulb yield (ton/ha)

Group	**100%**	**75%**	**50%**	**Mean**
CFI	25.42a	21.20c	16.45e	**21.02a**
AFI	22.51b	20.31c	14.50f	**19.11b**
FFI	19.00d	15.70ef	12.94g	**15.88c**
Mean	**22.31a**	**19.07b**	**14.63c**	
Grand mean	**18.67**			
CV	**4.02**			
P	**0.0085**			

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

4.4.7. Water use efficiency (WUE)

As shown in Appendix Table 10, Irrigation levels and furrow irrigation systems were highly significant ($\alpha \leq 0.01$) on crop water use efficiency of onion. In addition, their interaction effect was shown highly significant difference ($\alpha \leq 0.01$) on water use efficiency.

The analysis of variance shows that through interaction effect, significantly higher water use efficiencies were 14.84 kg/m^3, 10.33 kg/m^3, 9.96 kg/m^3 and 8.99 kg/m^3 were recorded by AFI 50%, AFI 75%, FFI 50% and CFI 50%, respectively. The least water use efficiencies were recorded on CFI 100%, followed by CFI 75%, FFI 100% and FFI 75% which is 4.93 kg/m^3 , 6.42 kg/m^3 , 6.79 kg/m^3 and 7.64 kg/m^3, respectively (See Table 14).

Note the effects of AFI 100%, CFI 75% and CFI 100% have no significant difference on yield.

The analysis of variance shows that irrigation systems as the main effect influenced water use efficiency. WUE values with the furrow irrigation systems recorded 6.77 kg/m^3 for conventional furrow irrigation and while AFI and FFI had higher values of 11.19 kg/m^3 and 8.13 kg/m^3, respectively. The highest WUE was recorded from alternate furrow irrigation. (See Table 14)

Irrigation levels, as main effect, increased WUE ($\alpha < 0.01$) to a higher value of 11.26 kg/m^3 with 50% whereas 75% and 100% irrigation levels got 8.13 kg/m^3 and 6.71 kg/m^3, respectively. (See Table 14)

In line with this result, Samson and Ketema (2007) reported that deficit irrigations increased the water use efficiency of onion than full irrigation. Alternate furrow irrigation also increased water use efficiency in wheat-cotton rotation in Punjab, India Yazar et al (2009). Furthermore, use of the alternate furrow irrigation increased water use efficiency rather than conventional furrow irrigation in sugarcane fields in southern part of Iran.

The total amount of water used by AFI and FFI system reduced by half that contribute to increment of total water use efficiency. This is consistent with the significant improvements in WUE that have been associated with AFI (Kang et al., 2000). In addition, the results of this research are in agreement with Gencoglan and Yazar (1999), who reported that WUE values decreased with increasing irrigation level.

Table 14: Interaction Effects of irrigation systems and irrigation levels on water use efficiency (kg/m^3)

Group	**100%**	**75%**	**50%**	**Mean**
CFI	4.930g	6.423f	8.984c	**6.779c**
AFI	8.396d	10.330b	14.840a	**11.189a**
FFI	6.795f	7.641e	9.963b	**8.133b**
Mean	**6.707c**	**8.131b**	**11.262a**	
Grand mean	**8.70**			
CV	**3.36**			
P	**0.00**			

- ***Means with different letters are significant different and any two means having the same letters are not significantly different at $P \leq 0.05$; CV= coefficient of variation; P=Probability level***

Generally, water use efficiencies were influenced by crop yield potential, irrigation method, measurement of evapotranspiration, crop environment, and climatic characteristics of the region. The results related to the efficiencies showed that when irrigation water is limited, 75% and 50% deficit irrigation could be applied by maximizing the water use efficiencies. Mansouri-Far et al. (2010) reported that irrigation water can be conserved and yields maintained (as sensitive crop to drought stress) under water-limited conditions.

4.5. Correlation

Parameters of plant height, bulb height, bulb diameter, and average bulb weight were shows from slightly-strongly positively relationship with the total bulb yield. However, water use efficiency was shown negatively relationship from all other parameters (See Table15).

Table 15: Relationships of parameters

	Plant Height	**Bulb Height**	**Bulb Diam.**	**Average B Weight**	**Total B Yield**	**Mark**	**WUE**
Plant Height	1.000						
Bulb Height	0.641	1.000					
Bulb Diameter	0.653	0.868	1.000				
Average B W	0.852	0.903	0.850	1.000			
Total B Yield	0.573	0.879	0.881	0.813	1.000		
Marketable	0.886	0.840	0.808	0.949	0.779	1.000	
WUE	-0.661	-0.491	-0.493	-0.642	-0.221	-0.633	1.000

4.6. Water Production Function

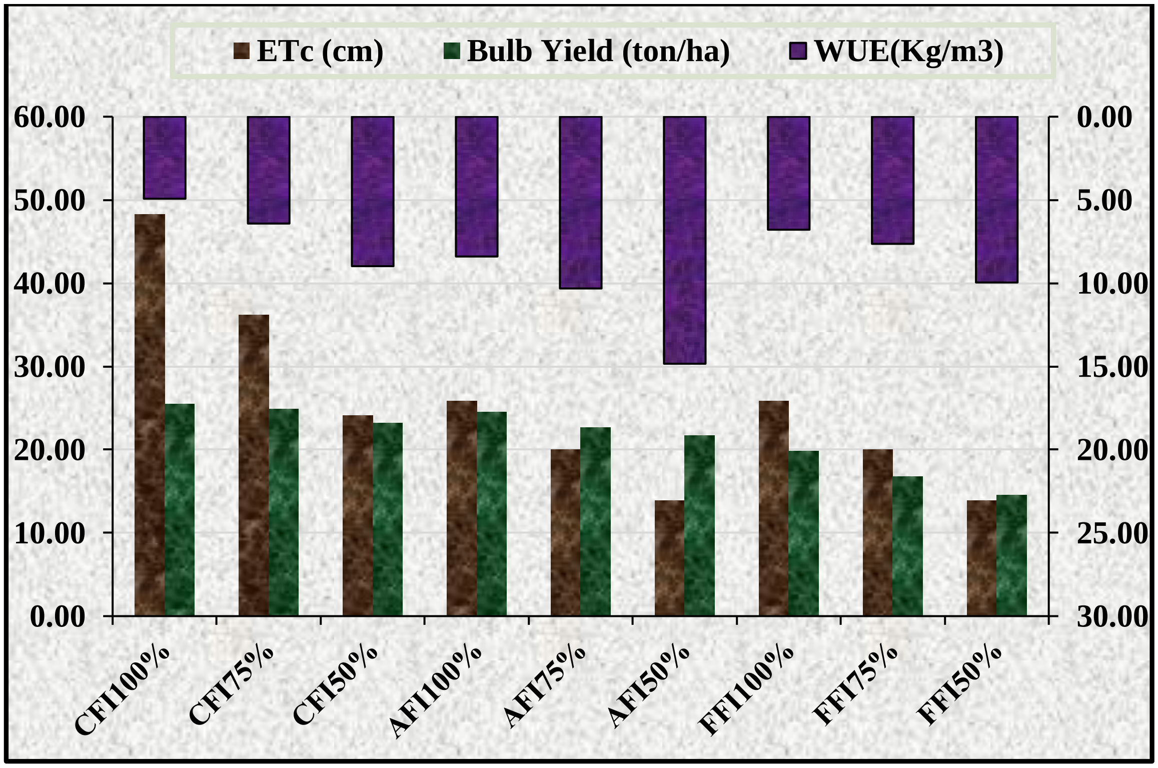

Figure 6: Onion ET_C as a function of irrigation systems and levels

From a sustainability perspective, the primary objective of this study whether furrow irrigation overdraft the reduction of irrigation water consumption to maximize cultivation land with little yield loses when compared with optimize water productivity.

As indicated in Figure 6, the amount of water applied and yield were increased over conventional furrow irrigation, but high water productivity of water was gained from Alternate furrow irrigation. Since the relationship of deficit irrigation levels and irrigation systems result in this research gave that there was no significant difference in bulb yield between treatments of CFI 100%, CFI 75%, and AFI 100% water requirement. Relatively alternate furrow irrigation with 100% ET_C gave optimum yield and water production. Therefore, application of AFI 100% is a recommended irrigation system and irrigation level for onion in the lower Awash valley.

Table 16: Extent of saved water and yield reduction

Treatment	Marketable (ton/ha)	Yield Reduction (%)	NIrr (m^3/ha)	Water saved from NIrr (m^3/ha)	Water saved from NIrr (%)
CFI100%	25.42	0.00%	482.35	0.00	0.00%
CFI75%	21.20	16.60%	361.76	120.59	25.00%
CFI50%	16.45	35.29%	241.18	241.17	50.00%
AFI100%	22.51	11.45%	258.21	224.14	46.47%
AFI75%	20.31	20.10%	200.04	282.31	58.53%
AFI50%	14.50	42.96%	139.04	343.31	71.17%
FFI100%	19.00	25.26%	258.21	224.14	46.47%
FFI75%	15.70	38.24%	200.04	282.31	58.53%
FFI50%	12.94	49.10%	139.04	343.31	71.17%

Net additional irrigable area due to water saved from irrigation methods and application levels of onion production estimated according to water applied for each treatment. As indicated in Table 16, the result showed that the minimum yield reduction was from AFI 100% ETc correspondingly saves 46.47% water from the required amount of net irrigation for one hectare. Accordingly, 0.868 ha area able to irrigate additionally per each hectare. CFI with 100% ETc was used as control for all treatment. It clearly seen that the value of net yield generated was not influenced only by water applied but also furrow irrigation methods. (See Table 16)

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study, an attempt was made to evaluate three furrow irrigation systems and three irrigation levels in lower Awash valley of Dubti for onion yield. These different irrigation systems were CFI, AFI and FFI with three water application levels were 100%, 75%, and 50%.

A field experiment was designed as a two-factor for nine treatment combinations replicated three times under Completely Randomized Block Design (RCBD). Bombay Red onion variety was transplanted after 45 days on double rows with a spacing of 40 cm x 20 cm x 10 cm. Five sample plants were randomly taken from each plot for determination of growth and bulb characters. The effect of irrigation treatments was tested using yield and yield components: plant height, bulb height, bulb diameter, average bulb weight, total bulb yield, and marketable bulb yield. Crop water use efficiency was estimated for each irrigation treatment. The relevant data collected were subjected to analysis of variance using Statistix10 software and significant treatment means were computed using least significant difference (LSD) test at 5% probability level.

Independently, irrigation systems and irrigation levels have shown a highly significant difference in plant height, bulb height, bulb diameter, average bulb weight, total bulb yield, marketable yield, and water use efficiency. The interaction effect of irrigation systems and irrigation levels was shown significantly different on average bulb weight and highly significant difference on total bulb yield, marketable yield, and crop water use efficiency. However, the interaction effect of irrigation systems and irrigation levels was not shown significantly different on stand count, plant height, bulb height, and bulb diameter.

AFI and FFI also saved water by 50%, because in CFI four furrows were irrigated at the same time while in AFI and FFI only two furrows were irrigated out of four furrows. Results obtained from this study was shown that the AFI 100% system lead to lesser water input and yet was still able to generate comparable onion yield with CFI 100% and CFI 75%. Relative to the control of CFI 100% the lowest marketable yield percentage of 11.45% was recorded in AFI 100%. Moreover, applying of AFI 100%, net area of 0.868 ha will be able to irrigate additionally per each hectare. Using AFI 100%, which may result in significant benefits under limited water condition, labor saving and enhanced flexibility in farm irrigation management.

5.2. Recommendations

In the lower Awash valley, it is possible to improve water use efficiency without significant loss of onion yield when we apply AFI 100%.

Under the area of sufficient water, implementing conventional furrow irrigation system with 100% irrigation level is recommended.

The test crop considered here is onion. However, other crops like maize, sesame, tomato, pepper and sugar cane also grow under irrigation in the region. Hence, AFI system should be test in other crops too.

As one of the difficulties of graduate research, the experiment is a one season and one place experiment. Hence repeating the experiment in space and time shall improve the validity of the finding.

6. REFERENCES

Abbi S. 2016.Status of salt affected soils, irrigation water quality and land suitability of Dubti/tendaho area, northeastern Ethiopia, unpublished document.

Abera Deressa and Chimdo Anchala, 2001. Available Agricultural Production Technology Packages for user. Melkassa Agricultural Research Center

Afework, M 2009. Analysis and Mapping of Soil Salinity levels in Metehara Sugarcane Estate Irrigation Farm using Different Models. M.Sc.thesis submitted to Addis Ababa University, Adiis Ababa, Ethiopia.

Ahmadi, S. H., Andersen, M.N., Plauborg, F., Poulsen, R.T., Jensen, C.R., Sepaskhah, A.R., Hansen, S., 2010. Effects of irrigation strategies and soils on field grown potatoes: Yield and water productivity. Agricultural Water Management

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop Evapotranspiration Guidelines for Calculating Crop Water Requirements. FAO, 56 Rome, Italy.

Bakker, D. M., S. R. Raine and M. J. Robertson, 1997. A preliminary investigation of alternate furrow irrigation for sugar cane production. Egan Ferguson and Campany Queensland. P 302 to 309

Bazza, M., 1994. Identification of wheat varieties suitable for arid and semi-arid conditions and of the characters for selection and breeding in regard to water-use efficiency. Report submitted to IAEA within the framework of the Research Coordination Programme on

"The use of Isotopes in Increasing and Stabilizing Plant Productivity in Low Phosphate and Semi-arid and Sub-humid Soils of the Tropics and Sub-tropics".

Behera, S.K. and R.K. Panda, 2009. Integrated management of irrigation water and fertilizer for wheat crop using field experiment and simulation modeling: Agricultural water Management 96: pp. 1532–1540.

Bekele, S. and Tilahun, K. (2007) Regulated deficit irrigation scheduling of onion in a semiarid region in Ethiopia. Agricultural Water Management, published on line 20

Biswas, S.K., P.K. Sarker, A. K. M, Mazharulislam, M.A. Bhuyan and B.C. Kundu. 2003. Effect of irrigation on onion production. Pakistan Journal Biology Science, 6(20): 1725-1728.

Brewster J.L. 1997.Onions and Garlic. In: Wien HC (ed.). The Physiology of Vegetable Crops. CAB International, Uk: pp. 581-619

Brouwer, C.2001. Irrigation Water Management: Irrigation Methods, Training manual no 5.

Chaves, M.M.; Pereira, J.S.; Maroco, J.; Rodrigues, M.L.; Ricardo, C.P.P.; Oso´rio, M.L.; Carvalho, I.; Faria, T.; Pinheiro, C. (2002). How plants cope with water stress in the field. Photosynthesis and growth. Ann. Bot. 89, 907–916.

Cicogna, A., Dietrich, S., Gani, M., Giovanardi, R., and Sandra, M. 2005.Use of Meteorological radar to estimate leaf wetness as data input for application of territorial epidemiological model. Journal of Physics Earth 30: 201-207.

Darra B.L and. Raghuvanshi, C.S 1999. Irrigation management, volume II: pp 92-95

Dawar MN, Wazir KF, Dawar MD, Dawar HS (2007) Effect of planting density on growth and yield of onion varieties under climatic condition of peshawar. Journal of Agriculture 23: 911-918

Doll, P., 2009. Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment.

Doorenbos J and A.H. Kassam. FAO. 1986. Yield response to water, Irrigation and Drainage Paper 33. Rome, Italy.

Douglas C. Montgomery, 2005. Design and analysis of experiments. 6th edition.

Du, T. S., Kang, S. Z., Sun, J. S., Zhang, X. Y., Zhang, J. H., 2010. An improved water use efficiency of cereals under temporal and spatial deficit irrigation in north China. Agric. Water Manag. 97 (1), 66–74.

Eck, H.V., A.C. Mathers, and J.T. Musick., 1987. Plant water stress at various growth stagesand growth and yield of soybean. Field Crop Research, 17: pp. 1-16.

Enchalew B, Gebre SL, Rabo M, Hindaye B, Kedir M, et al. (2016) Effect of Deficit Irrigation on Water Productivity of Onion (Allium cepal.) under Drip Irrigation. Irrigation Drainage Sys Eng 5:172. doi: 10.4172/2168- 9768.1000172

English, M., (1990). Deficit Irrigation. I: Analytical Framework. Irrigation and Drainage Engineering.-ASCE 116, 399-412.

Eldeiry, A. A., Garcia, L. A., El-Zaher, A. S. A., & Kiwan, M. E. S. (2005). Furrow irrigation system design for clay soils in arid regions. *Applied engineering in agriculture*, *21*(3), 411-420.

Everitt Brain, 1998. The Cambridge Dictionary of Stastics. Cambridge, UK New York: Cambridge University Press.

Kang, S.Z., and Zhang, J.H., 2004. Controlled alternate partial root-zone irrigation: its physiological consequences and impact on water use efficiency. Journal of Experimental Botany, 55: 2437-2446

Kirda, C. (2002). Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. Food and Agricultural Organization of the United Nations, Deficit Irrigation Practices, Water Reports, 22, 102.Fereres, E., Soriano, M.A., (2007).Deficit irrigation for reducing agricultural water use J. Exp. Bot. 58, 147-158

Fernandez, C. J., 1996. Deficit Irrigation in Corn: Alternate Furrow Application, termination Tim, and Hybrid interactions. Texas A & M Agricultural Research &Extension Center at Uvalde.

Ghooshchi, F., M. Seilsepour and P. Jafari, 2008. Effects of Water Stress on Yield and Some Agronomic Traits of Maize. American-Eurasian J. Agri. & Environ. Sci. 4 (3): 302-305.

Gencoglan, C., and Yazar, A. 1999. The effects of deficit irrigations on corn yield and water use efficiency. Turkish J. Agric. Forest. 23: 233-241.

Graterol, Y. E., D. E. Eisenhauer and R. W. Elmore, 1993. Alternate furrow irrigation for soybean production. Agricultural Water Management, 24: 133-145

Gomez, A.K, and A.A. Gomez. 1984. Statistical Procedures for Agricultural Research. John Willy and Sons.

Horst, M. G., Shamutalov, S. S., Pereira, L. S., Goncalves, J.M., 2005. Field assessment of the water saving potential with furrow irrigation in Fergana, Aral Sea basin. Agric. Water Manag. 77 (1–3), 210–231

Imitiyaz, M.; Mgadla, N.P.; Manase S.K.; Chendo, K.; Mothobi, E.O. (2000). Yield and economic return of vegetable crops under variable irrigation. Irrigation Science, 19, 87-93.

Israelsen, O.W., and Hansen, V. E., 1980. Irrigation Principles and Practices. New York, London.

Jensen, M.E., 1983. Design Operation of Farm Irrigation Systems. ASAE Monograph. Revised Printing No.3. pp. 564-597.

Kang S., Z. Liang, Pan, Y. and. Zhang, J. 2000. Alternate furrow irrigation for maize production in an arid area. Agricultural Water Management 45: pp. 267-274

Karajeh, F., V. Mukhamedjanov and F. Vyshepolskiy, 2000. On-farm water and drainage management strategy in Kazakhstan’s Arys-Turkestan area. 49: pp. 35-50.

Kijne, J.W., Barker, R., and Molden, D., 2003. Improving water productivity in agriculture: editor's overview. In: Kijne, J.W., Barker, R.M.D. (eds.), Water productivity in agriculture: limits and opportunities for improvement. International Water Management Institute, Colombo, Sri Lanka, p.xi-xix.

Majumdar, D. K., 2002. Irrigation Water Management, Principles and practice. New Delhip 487.

Mansouri-Far, C., Sanavy, S.A.M.M., and Saberali, S.F. 2010. Maize yield response to deficit irrigation during low-sensitive growth stages and nitrogen rate under semi-arid conditions. Agric. Water Manage. 97: 12-22.

Mashori, A. S., 2013. Evaluation of the performance of the alternate furrow irrigation under climatic conditions of Sindh.In: M. E. Thesis. Sindh Agriculture University, Tandojam, Pakistan

Michael, A.M. 1978. Irrigation theory and practices. Indian Agricultural Research Institute, New Delhi, India.

Michael, A.M., 1997. Irrigation Theory and Practice (Revised.). Vikas publishing house Pvt Ltd, New Delhi.

Mintesinot B., H. Verplancke, E. Vanranst, Mitiku Haile, 2004. Examining traditional irrigation methods, irrigation scheduling and alternate furrows irrigation on vertisols in northern Ethiopia. Agricultural Water Management 64: 17-27

Moray, M.G., Marey, R.A., Karam,S.S and Abo-Dahab, A.M.A. 2012.Productivity and storability of onion as influenced by the different levels of NPKfertilization. Agricultural Research, 38 (1): 171-187.

Musick, J. T and Dusek, D. A. 1974. Alternate furrow irrigation of fine textured soils. Transaction of the ASAE: pp. 289-294

Neeraja, G., K.M. Reddy, I.P.Reddy and Y.N. Reddy. 1999. Effect of irrigation and nitrogen on growth, yield and yield attributes of rabi onion (Allium cepa L.)

Nelson, Darrell W., and Lee E. Sommers. "Total carbon, organic carbon, and organic matter." Methods of soil analysis part 3—chemical methods methodsofsoilan3 (1996): 961-1010.

Nikus O. and Mulugeta F., 2010.Onion Seed Production Techniques, A Manual for Extension Agents and Seed Producers

Olalla, F.S., A. D. Padilla and R. Lopez. 2004. Production and quality of the onion crop (Allium cepa L.) Cultivated under controlled deficit irrigation conditions in a semi-arid climate. Agricultural Water Management, 68: 77-89.

Payero, J.O., S.R. Melvin, S. Irmak and D. Tarkalson, 2006. Yield response of corn to deficit irrigation in a semiarid climate. Agri. Water Manage. 84 : 101–112.

Perry, C., P. Steduto, R.A. Allen and C.M. Burt, 2009. Increasing productivity in irrigated Agriculture: Agronomic constraints and hydrological realities. Agricultural water Management 96: pp.1517–1524.

Rodriguez, P.N.; Machado, T.; Pereira, L.S.; Teixeira, J.L.; El Amami, H.; Zairi, A. (2003). Feasibility of deficit irrigation with center-pivot to cope with limited water supplies in

Alentejo, Portugal. In Rossi G.; Cancelliere A.; Pereira L.S.; Oweis T.; Shatanawi M.; Zairi A. (Eds). Tools for drought mitigation in Mediterranean regions, 44 Kluwer.

Rodrigues, G. C. and Pereira, L.S. 2009. Assessing economic impacts of deficit irrigation as related to water productivity and water costs. Elsevier: pp. 536–551.

Sammis, T.W., Smeal, D., and Williams, S. 1988. Predicting corn yield under limited irrigation using plant height. Transaction s of the ASAE.3 (13): 830-838.

Sahasrabudhe, M. R. 1979. Lipid composition of oats (Avena sativaL.). J. Am. Oil Chem. Soc. 56:

Seeul (School of Earth and Environment, University of Leeds). 2008. Geology of the Afar Region. http: //www.see.leeds.ac.uk/afar/websitepages/ geology of afar region.htm

Sepaskhah, A.R. and Akbari, D. (2005). Deficit irrigation under variable seasonal rainfall. Biosystems Engineering, 92(1), 97-106

Skewes, M. A. (1997) Technology vs management skill – the challenge of efficient irrigation. Striking the Balance: Irrigation and the Environment – the 44th Annual ANCID Conference and Study Tour. Deniliquin, NSW, ANICD, Australia.

Sleper, D.A., Fales, S.L., and Collins, M.E. 2007. Foreword. In:Lascano R.J. andSojka, R.E. (eds.),Irrigation of agricultural crops 2nd edition, Agronomy Monograph no. 30. ASACSSA-SSSA publishing, 664p

Steduto, Pasquale, Theodore C. Hsiao, Elias Fereres, and Dirk Raes. *Crop yield response to water*. Vol. 1028. Rome: fao, 2012.

Stone,J. F, J. E. Garton, B. B. Reeves, and H. E. Keflemariam,1979.Irrigation water conservation using wide-spaced furrows. Soil Sci. Am. J., 43: pp. 407-411

Subedi, D. K., D.M. Gautam, S.M. Shakya and A. Srivastava. 2002. Effect of Irrigation on Production of Onion Bulb.

Tate, Robert L, 1987. "Soil organic matter: biological and ecological effects." *Biochemistry* 57: 282-291

Teshome J. and Bayissa Z., 2014.A Literature Review Report on Understanding the Context of People Transitioning out of Pastoralism (TOPs) in Ethiopia, Haramaya University.

Torres, J. S., F. Villegas and R. Cruz, 1996. Alternate furrow irrigation of sugar cane. Proc. 22 ISSCT Congress. Cali, Clombia.

Vaux, H. J. and W.O.Pruit. 1983. Crop water production function. In: D. Hillel (Ed). Advance irrigation, 12:16-93.

Verma, Priyanka, et al. "Development, characterization and cross-species transferability of genomic SSR markers in berseem (Trifolium alexandrinum L.), an important multi-cut annual forage legume." *Molecular breeding* 35.1 (2015): 23.

Walker, Alta S. "Deserts of China: Deserts now make up more than 13 percent of the land area in China, and various methods are being used to transform them into farmland." *American Scientist* 70.4 (1982): 366-376.

Walker, W.R. 1989. Guidelines for Design and Evaluating Surface Irrigation System. FAO irrigation and drainage paper 45. Rome.

Walker W.R., and Skogerboe G.V., (1987): Surface Irrigation: Theory and Practice. Prentice-Hall, Englewood Cliffs.

World Health Organization (WHO), 2009. Ten facts about water scarcity. Available at: http://www.who.int/features/factfiles/water/en/index.html. Accessed on 28 Dec. 2017.

Water Works, Design, Supervision and Enterprise (WWDSE). 2004. Investigation, planning design of irrigation and drainage system of Tendaho dam and sugar project, unpublished document, Addis Ababa, Ethiopia.

Yazar A, Gokle F and Sezen M.S 2009. Corn yield response to partial root zone drying and deficit irrigation strategies applied with drip system. Plant soil Environ, 55,2009 (11) 494 - 503

Yemane M., Abraham W., And Solomon H., 2018. Response of onion (Allium cepa l.) to deficit irrigation under different furrow irrigation water management techniques in Raya Valley, Northern Ethiopia. *African Journal of Plant Science. Vol. 12(5), pp. 105-113*

Yenesew Mengiste, 2007. Evaluation of the effect of deficit irrigation on water use efficiency and yield of furrow irrigated maize at Dire Dawa, MSc. Thesis, Department of Irrigation Engineering, Haramaya University, Ethiopia.

Yonts, C. D., D. E. Eisenhauer and D. Varner, 2003. Managing furrow irrigation system, G97-1338- A. Cooperative extension, Institute of Agriculture and Natural Resources. University of Nebraska-Lincoln.

Zhang, J., S. Kang, Z. Liang., Y. Z. Pan, P. Shi, Y. H. Pan, Z. S. Liang, X. T. Hu, 2000. Soil water distribution, uniformity and water use efficiency under alternate furrow irrigation in arid areas. Irrig. Sci. 19: 181-190.

Zwart, S.J., and Bastiaanssen, W.G.M., (2000). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agric. WaterManage* 69, 115-133.

7. APPENDIXES

7.1. Appendix Tables

Appendix Table 1: Long-term meteorological data of the study area (2002 – 2016)

Month	Max T °C	Min T °C	RF(mm)	WRU (m/s)	RH (%)	SS (hours)
Jan	27.83	18.87	2.92	1.44	59.47	8.55
Feb	28.98	19.91	0.57	1.50	56.71	9.18
Mar	31.89	22.35	7.86	1.45	53.32	8.76
Apr	33.60	24.25	28.83	1.40	51.41	9.58
May	35.68	25.85	2.89	1.14	45.27	9.88
Jun	35.78	26.37	2.19	1.28	37.15	8.31
Jul	36.85	25.98	33.43	1.51	46.23	7.59
Aug	36.05	25.14	63.48	1.35	50.14	7.88
Sep	34.98	24.39	16.80	1.06	47.03	7.44
Oct	31.58	21.99	2.61	1.18	49.02	9.41
Nov	30.47	18.92	3.39	1.17	51.94	9.59
Dec	29.01	17.75	4.83	1.14	55.45	9.11

Appendix Table 2: Periodic meteorological data and Reference evapotranspiration (ETo) based on Penman-Monteith method

Day	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun Hours	Rad MJ/m^2/day	ETo mm/day
2-Feb	14.6	36	75	1.5	11	23.8	5.17
3-Feb	16.5	36.5	74	1.2	11	23.9	5.13
4-Feb	12.3	36	67	2.5	10.9	23.8	5.91
5-Feb	12.5	35.4	55	1.8	11.2	24.3	5.68
6-Feb	19.5	38	42	2.4	11	24	6.94
7-Feb	12.5	36.2	51	2.3	10.5	23.4	6.21
8-Feb	11	38.6	49	1.4	10.3	23.2	5.61
9-Feb	10	37	55	1.4	10	22.8	5.34
10-Feb	14.5	36.5	50	2.2	10.1	23	6.17
11-Feb	13.6	36.9	48	1.5	10.5	23.6	5.65
12-Feb	14	36.5	52	1.4	11	24.4	5.57
13-Feb	13	40	52	1.5	10.5	23.7	5.97
14-Feb	19.5	37	54	1.9	10.9	24.4	6.15
15-Feb	16.5	38.3	57	2	9.9	23	6.1
16-Feb	13.3	36.3	55	1.5	10	23.2	5.47
17-Feb	15	39.3	58	1.6	10.1	23.4	5.91
18-Feb	16	37.3	55	2	11.2	25.1	6.31
19-Feb	17.9	33.5	56	1.2	11	24.8	5.25
20-Feb	17.4	34.9	60	1	10.8	24.6	5.16
21-Feb	17.2	35.4	62	1.1	9.2	22.3	4.94
22-Feb	20.2	34.3	59	0.8	10	23.5	4.91
23-Feb	19.5	35.5	65	0.9	10.2	23.9	5.1
24-Feb	18.5	37.2	61	0.8	10.5	24.4	5.23
25-Feb	17	36	63	1	10.3	24.1	5.2
26-Feb	18.1	39.1	66	1.2	10.6	24.6	5.75
27-Feb	15.5	40	60	1.6	11	25.3	6.3

28-Feb	14.7	40.2	57	1.4	11.1	25.5	6.2
1-Mar	20	38.6	59	2.1	11	25.4	6.64
2-Mar	19	39.5	77	2.6	11	25.5	6.51
3-Mar	19.8	39	66	2.5	11	25.5	6.78
4-Mar	16.8	38.9	58	2.3	10.2	24.3	6.68
5-Mar	19.1	39	41	2.2	10.2	24.4	7.09
6-Mar	19.7	38.9	56	1.9	10.3	24.6	6.48
7-Mar	12.5	38.6	47	1.7	10	24.2	6.28
8-Mar	15.5	38.6	47	1.7	11	25.7	6.52
9-Mar	17.5	41.5	40	2.2	9.5	23.5	7.33
10-Mar	19	39.8	47	1.7	9.9	24.2	6.51
11-Mar	12	40.5	52	1.5	9.4	23.4	6.14
12-Mar	18	40.6	54	1.9	11	25.9	6.94
13-Mar	14	41	45	1.8	10	24.4	6.79
14-Mar	18	40.6	54	1.9	11	26	6.96
15-Mar	12.3	40	49	2.3	10.2	24.8	7.2
16-Mar	16	41.5	55	2.1	9.9	24.4	7.01
17-Mar	14.5	39.5	54	1.6	10.1	24.7	6.32
18-Mar	19.1	35	58	1.1	10.3	25.1	5.5
19-Mar	19	37.2	56	0.8	9	23.1	5.15
20-Mar	21	37	51	1	9.3	23.6	5.47
21-Mar	21.3	37.5	46	0.8	10	24.7	5.48
22-Mar	18.5	38	43	1.2	10.6	25.6	6.04
23-Mar	19.3	38	43	1.2	10.6	25.7	6.07
24-Mar	20.1	37	41	1.1	10.9	26.2	5.96
25-Mar	21	39.5	45	1.1	9	23.2	5.78
26-Mar	19	39.1	42	1.3	9.8	24.5	6.14
27-Mar	17	40.2	39	1.5	10.2	25.1	6.58
28-Mar	19.8	39.9	43	0.9	10.5	25.6	5.9
29-Mar	21.6	37	45	1.8	10.8	26.1	6.73

30-Mar	21.4	39.1	44	1.1	10.9	26.3	6.22
31-Mar	20	38	41	1	10.7	26	5.92
1-Apr	20.5	40	49	1.3	10.4	25.5	6.38
2-Apr	22.5	40	45	1.5	10.5	25.7	6.72
3-Apr	19.2	40.2	51	1.8	10.6	25.9	6.93
4-Apr	20.5	41.5	46	1.9	10.1	25.1	7.2
5-Apr	20	39.8	38	2.2	10	25	7.47
6-Apr	20.6	40.5	40	1.4	10.8	26.2	6.72
7-Apr	18.5	41.4	39	1.4	9.5	24.2	6.5
8-Apr	15.5	41.5	48	1.6	9.9	24.8	6.72
9-Apr	18.8	40.7	53	2	10.3	25.5	7.09
10-Apr	18	42	45	1.7	9.4	24.1	6.86
11-Apr	20.5	41	48	1.4	11	26.5	6.78
12-Apr	20	43	46	1.9	9.7	24.5	7.3
13-Apr	18.6	41.6	45	2	10.2	25.3	7.34
14-Apr	19.5	42.2	49	2	10.3	25.5	7.39
15-Apr	18.3	42.7	51	1.4	10.8	26.2	6.85
16-Apr	19.7	42	48	1.6	10.1	25.1	6.89
17-Apr	22	41.5	56	1.7	10	25	6.83
18-Apr	23.2	38.9	54	0.9	10.3	25.4	5.95
19-Apr	23.9	39	50	0.9	8.7	23	5.58
20-Apr	24.3	39.4	52	1.5	10	25	6.54
21-Apr	23.3	40.6	49	0.7	9.5	24.2	5.65
22-Apr	19.7	42	48	0.9	10.2	25.3	6.07
23-Apr	22	41	44	1.2	10.5	25.7	6.48
24-Apr	18.8	41.6	43	1	11	26.5	6.31
25-Apr	18	41	46	1.3	11.2	26.8	6.66
26-Apr	20.5	42.6	41	1.6	10.5	25.7	7.13
27-Apr	20	41.6	45	2	10.6	25.8	7.45
28-Apr	20.6	42.8	42	2.1	10.7	25.9	7.82

29-Apr	18.5	42.7	47	2.4	10.9	26.2	8.05
30-Apr	17.5	42.2	44	1.9	11	26.4	7.48
1-May	21.2	41	40	2	10	24.8	7.36
2-May	22	41.5	41	2.1	9.8	24.5	7.49

Appendix Table 3: Factorial ANOVA Table for Stand Count

Source	DF	SS	MS	F	P
REP	2	1.556	0.7778		
IL	2	89.556	44.7778	4.62	0.0861^{ns}
IS	2	29.556	14.7778	1.52	0.2478^{ns}
IL*IS	4	14.889	3.7222	0.38	0.8169^{ns}
Error	16	155.111	9.6944		
Total	26	290.667			
Grand Mean	537.78				
CV	0.58				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 4: Factorial ANOVA Table for Plant Height

Source	DF	SS	MS	F	P
REP	2	0.1618	0.0809		
IL	2	49.0649	24.5325	159.06	0**
IS	2	3.6212	1.8106	11.74	0.0007**
IL*IS	4	1.1799	0.295	1.91	0.1574^{ns}
Error	16	2.4677	0.1542		
Total	26	56.4955			
Grand Mean	43.3				
CV	0.91				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 5: Factorial ANOVA Table for Bulb Height

Source	DF	SS	MS	F	P
REP	2	4.586	2.293		
IL	2	120.653	60.327	41.09	0.0000**
IS	2	315.761	157.880	107.53	0.0000**
IL*IS	4	14.291	3.573	2.43	0.0899^{ns}
Error	16	23.492	1.468		
Total	26	478.783			
Grand Mean	49.941				
CV	2.43				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 6: Factorial ANOVA Table for Bulb Diameter

Source	DF	SS	MS	F	P
REP	2	0.767	0.3835		
IL	2	50.656	25.3281	20.19	0.00**
IS	2	113.455	56.7274	45.23	0.00**
IL*IS	4	11.671	2.9178	2.33	0.1007^{ns}
Error	16	20.067	1.2542		
Total	26	196.616			
Grand Mean	52.543				
CV	2.13				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 7: Factorial ANOVA Table for Average Bulb Weight

Source	DF	SS	MS	F	P
REP	2	1.323	0.6614		
IL	2	146.724	73.3622	159.87	0.00**
IS	2	101.786	50.8931	110.91	0.00**
IL*IS	4	5.706	1.4265	3.11	0.0452*
Error	16	7.342	0.4589		
Total	26	262.881			
Grand Mean	59.328				
CV	1.14				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 8: Factorial ANOVA Table for Total Bulb Yield

Source	DF	SS	MS	F	P
REP	2	0.999	0.5		
IL	2	54.351	27.175	58.18	0.00**
IS	2	278.385	139.193	298.01	0.00**
IL*IS	4	9.147	2.287	4.9	0.009**
Error	16	7.473	0.467		
Total	26	350.355			
Grand Mean	21.508				
CV	3.18				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 9: Factorial ANOVA Table for Marketable Yield

Source	DF	SS	MS	F	P
REP	2	0.258	0.129		
IL	2	267.5	133.75	236.9	0.00**
IS	2	121.664	60.832	107.74	0.00**
IL*IS	4	11.228	2.807	4.97	0.0085**
Error	16	9.034	0.565		
Total	26	409.683			
Grand Mean	18.67				
CV	4.02				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 10: Factorial ANOVA Table for WUE

Source	DF	SS	MS	F	P
REP	2	0.108	0.0539		
IL	2	97.798	48.8989	573.21	0.00**
IS	2	91.819	45.9093	538.16	0.00**
IL*IS	4	9.208	2.3019	26.98	0.00**
Error	16	1.365	0.0853		
Total	26	200.297			
Grand Mean	8.7007				
CV	3.36				

DF = Degree of freedom SS = Sum square MS = Mean square ns = no significant different

**** = significant different ** = highly significant different***

Appendix Table 11: Free flow discharge values for 2 inches of Parshall flumes

Head (cm)	**Discharge (l/s)**
2	0.281
3	0.526
4	0.822
5	1.162
6	1.541
7	1.957
8	2.407
9	2.889
10	3.402
11	3.943
12	4.513
13	5.109
14	5.731
15	6.377
16	7.048
17	7.743
18	8.460
19	9.200
20	9.961
21	10.744
22	11.547
23	
24	

7.2. Appendix Figures

Appendix Figure 1: Onion on nursury site

Appendix Figure 2: Plot preparation

Appendix Figure 3: During transplantation

Appendix Figure 4: Partial flume setup