# Effect of Deficit Irrigation and Furrow Methods on Yield and Water Productivity of Wheat at Ambo, Ethiopia

Kalkidan Degefa Desalegn

A Thesis Submitted to

The Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

February, 2024

Adama, Ethiopia

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Advisor: Dr. Boja Mekonnen

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Adama, Ethiopia

# DECLARATION

I hereby declare that this Master Thesis entitled "**Effect of Deficit Irrigation and Furrow Methods on Yield and Water Productivity Wheat at Ambo, Ethiopia**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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# RECOMMENDATION

I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Effect of Deficit Irrigation and Furrow Methods on Yield and Water Productivity Wheat at Ambo, Ethiopia**" prepared under my guidance by **Kalkidan Degefa Desalegn** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Water Resources Engineering, specialization in Irrigation Engineering.

Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedure.

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# APPROVAL SHEET

I, the advisor of the thesis entitled "**Effect of Deficit Irrigation and Furrow Methods on Yield and Water Productivity Wheat at Ambo, Ethiopia**" and developed by **Kalkidan Degefa Desalegn,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Kalkidan Degefa Desalegn** have read and evaluated the thesis entitled "**Effect of Deficit Irrigation and Furrow Methods on Yield and Water Productivity Wheat at Ambo, Ethiopia**" and examined the candidate during the open defence. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water Resource Engineering, specialization in Irrigation Engineering.

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# ACKNOWLEDGEMENT

Most of all, I am grateful to Almighty God, His beloved Mother, the Virgin Mary, and all the saints for their blessings, supply of strength, and compassionate support in all areas of my life.

I would especially like to express my gratitude to my advisor Dr. Boja Mekonnen, for his enthusiastic work, priceless guidance, moral support, great advice, and endless constructive comments for this research.

My sincere gratitude goes out to the Ethiopian Institute of Agricultural Research, Soil and Water Management Directorates for sponsoring and funding this master's program study. I also sincerely thank Adama Science and Technology University for its educational materials and information gathering.

In addition, I would like to thank Ambo Agricultural Research Centre, the Soil and Water Management Head, and the staff member for their invaluable help and encouragement throughout the data collecting and fieldwork phases. My special gratitude goes out to my colleague Selamawit Bekele for her initiation, unreserved support, guidance, encouragement, supervision, scientific advice, and comment on statistical analysis.

Finally, I would like to express my deepest gratitude to my family for their unwavering support and encouragement during every step of my study and my life.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| A | Area of Irrigable land |
| AFI | Alternate furrow irrigation |
| AGB | Above ground biomass |
| CFI | Conventional furrow irrigation |
| CIMMYT | International Maize and Wheat Improvement Center |
| CV | Coefficient of Variation |
| CWR | Crop Water Requirement |
| $CWU_E$ | Crop Water Use Efficiency |
| DAP | Diammonium Phosphate |
| DI | Deficit Irrigation |
| Eta | Actual Evapotranspiration |
| ETB | Ethiopian Birr |
| ETC | Crop Evapotranspiration |
| ETm | Maximum Evapotranspiration |
| FAO | Food and Agriculture Organization |
| FC | Field Capacity |
| FC | Fixed Cost |
| FFI | Fixed Furrow Irrigation |
| GIS | Geographical Information System |
| GY | Grain Yield |
| IWP | Irrigation Water Productivity |
| IWR | Irrigation Water Requirement |
| IWU | Irrigation Water Use |
| IWUE | Irrigation Water Use Efficiency |
| Ky | Yield response factor |
| LC | Labor Cost |
| LSD | Least Significant Difference |
| MRR | Marginal Rate of Return |
| MS | Mean Separation |
| NI | Net Income |

| | |
|---|---|
| NS | Non-Significant |
| NSPS | Number of Seeds per Spike |
| PH | Plant Height |
| RCBD | Randomized Complete Block Design |
| SL | Spike Length |
| SMC | Soil Moisture Content |
| SMD | Soil Moisture Depletion |
| SS | Sum of Squares |
| SW | Saved Water |
| TAW | Total Available Water |
| TC | Total Cost |
| TI | Total Income |
| TR | Total Return |
| TSW | Thousand Seed Weight |
| TVC | Total Variable Cost |
| USDA | United States Department of Agriculture |
| VC | Variable Cost |
| WP | Water Productivity |
| WUE | Water Use Efficiency |
| Ya | Actual Yield |
| Ym | Maximum Yield |

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# ABSTRACT

*Water is an essential component for global development. It plays a crucial role in various aspects of life. However, due to rising demand, it is becoming a scarce resource. To meet future water scarcity, the most optimal possible allocation, increased crop and water productivity (WP), and improved irrigation water management are needed. Applying furrow irrigation and deficit irrigation are essential alternatives for improving agricultural water use efficiency in areas with limited water resources. This study attempted to evaluate the effects of furrow irrigation methods and deficit irrigation levels on wheat production and water productivity. A Randomized Complete Block Design was used to arrange the experimental unit, and a pair of factors with three furrow irrigation methods (Alternate, Fixed and Conventional) and three deficit irrigation application levels (100%, 80%, and 60% ETc) with three replications were employed. A free statistical software R 4.3.1 was used to analyze the collected data. The results of the analysis on grain yield, yield component, water productivity and growth parameters indicate that there is a significant difference ($p<0.05$) in the furrow irrigation method and deficit irrigation levels. The interaction effect of deficit irrigation levels and irrigation method was non-significant. Different irrigation levels had a significant ($p<0.05$) impact on plant height. The reduction of irrigation level from 100% ETc to 60% ETc resulted in 4.0% decrease. The control treatment of (100% ETc) yielded the maximum grain production of (4531.25 kg/ha) and has no significant differences with irrigation applications of 80 % ETc treatment. The lowest grain production of (2543.75 kg/h) was recorded at 60% ETc application. The alternate furrow method yielded a maximum water productivity of 2.13 $kg/m^3$ which was statistically higher than conventional and fixed furrow systems at ($p<0.05$). Using the conventional furrow, the lowest water productivity of 1.11 $kg/m^3$ was obtained. The maximum yield response factor of 0.51 was obtained for 60% ETc with FFI that means sensitive to the water deficit level. The interaction effect of deficit irrigation and furrow irrigation method on yield and water productivity of wheat was not significant at ($p< 0.05$). Application of alternate furrow irrigation method and 80% ETc can improve water efficiency by saving 60% of water applied under conventional irrigation methods which is sufficient to irrigate 1.5-hectare additional wheat cropped land. Therefore, considering the maximum water productivity and water saved, non-significant yield reduction from full application of water and the economic benefit gained 80% ETc and AFI methods are recommended for our study area.*

**Keywords:** Deficit level, furrow method, yield, water productivity

# 1 INTRODUCTION

## 1.1 Background

The world's population has grown significantly, and the natural resource base is depleting (Page et al., 2020). To feed this growing population, there will undoubtedly be a need for increased global food production, particularly in developing countries (United Nations, 2019). As food production must expand in response to a changing climate, water shortages may become more prevalent (Scheierling et al., 2015). In light of the growing water crisis in developing countries, improving agricultural water management practices is essential to combating food insecurity. The future prospects of food security, poverty alleviation, and economic growth are significantly influenced by irrigated agriculture; for these reasons, efficient management of irrigation systems is critical.(Mozumdar, 2012). One of the best farming methods for increasing yield and productivity is irrigated agriculture (Terefe, 2021). However, current irrigation-based agriculture has difficulties due to the limited water supply (Belay et al., 2019). For current irrigated agriculture, water-saving and improving water productivity technologies are crucial (Tshenyego et al., 2019).

Many irrigation methods used in developing countries are traditional and rely on the knowledge of the local farmers(Beyene et al., 2018; Tsegay, 2012). As a result, farmers irrigate their fields when water is available without using any sort of gauge. Therefore, crops receive more water than they need(Beyene et al., 2018b). The majority of irrigation agriculture in Ethiopia is traditional and small-scale (Belete et al., 2011). Furrow irrigation is a popular technique for applying water during irrigation (Teshome, 2003). In furrow irrigation systems, there are various water application options. Farmers in Ethiopia and other developing nations frequently utilize a traditional form of furrow irrigation, conventional furrow irrigation (CFI) (Gebremedhin, 2017). According to Degefu & Kuli, (2020),an innovative method of deficit irrigation approach that increases water productivity by irrigating the furrows alternately rather than all of them simultaneously is called alternate furrow irrigation. While fixed-furrow irrigation involves only wetting the fixed furrows; the in-between furrows are left dry. Alternate furrow irrigation and Fixed furrow irrigation significantly lower the quantity of surface wetted area, which results in less evapotranspiration and deeper percolation. Water productivity can be improved by using fixed and alternate furrow irrigation methods with partial irrigation and deficit irrigation.

Applying irrigation water at levels that are purposefully less than what the plant needs is known as deficit irrigation. It can be used at specific times during the growing season of the crop or throughout the entire growing season (Fan et al., 2014). When irrigation is applied at a rate less than the plant's total water needs, the plant will withdraw water from the soil profile to make up the difference (Fereres & Soriano, 2007). Under deficit irrigation, the amount of irrigation is less than what is required to achieve maximum ET. This allows the need for irrigation water to be reduced and the water saved can be used for other purposes. DI can be an attractive option to increase WP and obtain comparable yields by using water-saving techniques and increasing irrigated areas (Asmamaw et al., 2021). Improved WP, less water required for irrigation, and lower production costs are potential advantages of DI ( Hashem et al., 2018). Deficit irrigation has been suggested as an alternate technique for maximizing the use of irrigation water. It offers a means of lowering water consumption without appreciably lowering yield. (Pereira et al., 2012).

Wheat (Triticumaestivum L.) is one of the cereal crops grown for the global market, which makes up 15% of all the areas used to sow cereal crops globally (Kiss, 2011). Global production of wheat grew by 18.63 million tons at an average annual rate of 2.40% from 763.49 million tons in the 2019/2020 production season to 775.82 million tons in the 2020/2021 production season (Muchie, 2022). It is one of the most important cereal crops in the world, second only to rice, and is traded internationally as both a food and industrial grain. (Falola et al., 2017).It is also a critical crop in sub-Saharan African countries that increases food security and agricultural earnings (Amentae et al., 2017). In Ethiopia, wheat is the second important cereal crop next to maize, making up 14% of total calories consumed, more than teff and "Enset"(Minot & Warner, 2015). Wheat cultivation, namely irrigated wheat production, is currently the main emphasis of Ethiopia's food security policy Irrigated wheat is the country's second staple crop and an important pillar of food security (Hordofa et al., 2022). Ethiopia is increasing its wheat consumption by 9.0 percent per year, while local production is growing at a rate of 7.8 percent per year. This results in annual demand for the crop exceeding its annual supply and, however, the country imports large quantities of wheat each year, with typical growth rates.

Numerous investigations have been carried out regarding the impact of deficit irrigation on crops of maize and vegetables (Degefu & Kuli, 2020; Setu et al., 2023; Yemane et al., 2018).

The impact of the deficit irrigation on the wheat crop, however, is not further examined. This study aims to determine the effects of a double deficit irrigation strategy on wheat crops while taking water limitation into account. This strategy includes partial root-zone drying combined with decreased irrigation depth.

## 1.2 Statement of the Problem

The scarcity of water is turning into a major issue in many parts of the world. Forecasts of rising temperatures and falling precipitation due to climate change will make water even more scarce (Fan et al., 2014). The growing global population has made increased agricultural production urgently necessary (Chen et al., 2011). Increasing agricultural production through irrigation is essential to meet growing global food needs (Jhon et al., 2018). However, the amount of freshwater that can be used for agricultural production has been steadily declining(Cai & Rosegrant, 2003). Traditional irrigation techniques are used by farmers in several regions of Ethiopia. Ethiopian farmers who use furrow irrigation experience uneven water distribution and extremely significant percolation losses (Tadese, 2018). These not only cause significant water losses but also contribute to salinity and waterlogging issues (Yadeta et al., 2022). The productivity of both water and crops is consequently low and steady (Hordofa et al., 2008). It is therefore essential to develop efficient furrow irrigation systems and irrigation water management techniques in order to increase water productivity. The sustainability of crop production and productivity can be compromised by proper irrigation water management (Subhan et al., 2021). It is proposed that better irrigation water management is the key to satisfying crop irrigation demands and minimizing future water constraint. Deficit irrigation is one of the irrigation management techniques that could lead to water savings (Hassen, 2022). It can be used in wheat production to achieve goals such as water conservation, improved grain quality, or increased water use efficiency. Wheat has been in high demand for the previous few decades and is predicted to stay in high demand. (Hordofa et al., 2022; Mann & Warner, 2015; Tadesse et al., 2022). The current wheat production is inadequate to meet the national demand, forcing the country to import 30–50% to fill the gap (Minot & Warner, 2015; Shikur, 2022). The demand for wheat is growing at an average annual growth rate of 9% in our country, and local production is only growing at an annual growth rate of 7.8%. This is primarily because of factors such as changing food preferences, growing population sizes, and occasional drops in crop productivity. But still, 90% of Ethiopia's wheat production is on small farms without irrigation (USDA and GAIN, 2020). The country's foreign exchange reserve is under pressure as a result of imports being used to cover the present demand gap for wheat in the nation. These days, the Ethiopian government is greatly increasing irrigated wheat farming across the nation to reduce the imbalance between the supply and demand for wheat. Compared to rain-fed wheat production, this allows for a higher harvest yield in irrigation farming systems (Muchie, 2022).Thus, in order to address the imbalance between supply and demand of wheat, effective irrigation technology is necessary to enhance production. In West Shewa, the impact of deficit irrigation combined with the most popular furrow irrigation method on wheat yield and water productivity is not assessed. Prior studies on deficit irrigation levels have mostly focused on vegetable and maize crops. Thus, the main objective of this study is to evaluate the effects of furrow irrigation techniques with deficit irrigation levels on wheat crop yield and water productivity.

## 1.3 Objective of the Study

### 1.3.1 General Objective

The general objective of this study is to evaluate the response of wheat crop yield and water productivity to deficit irrigation levels and furrow irrigation methods.

### 1.3.2 Specific Objectives

- ❖ To evaluate the effect of deficit irrigation levels on wheat yield and water productivity.
- ❖ To evaluate the effect of furrow irrigation methods on wheat yield and water productivity.
- ❖ To determine the interaction effect of deficit irrigation levels and furrow irrigation methods on the yield and water productivity of wheat.

## 1.4 Research Questions

- ❖ Which deficit irrigation levels provide the optimum yield and water productivity of wheat crops?
- ❖ Which type of furrow irrigation methods gives optimum yield and water productivity of wheat crops?
- ❖ What is the combined effect of deficit irrigation levels and furrow irrigation methods on the yield and water productivity of wheat crops?

## 1.5 Significance of the Study

The use of furrow irrigation and deficit irrigation are important techniques for increasing water production in regions with limited water resources. A major global issue is water scarcity, especially in arid and semi-arid areas. Efficient management of this scarce resource is crucial for sustainable agriculture. Deficit irrigation, which intentionally applies less water than the crop's full water requirements, can help optimize water use, address water scarcity challenges, and allow for better water resource allocation by using water more wisely. Alternate furrow irrigation, an optional irrigation technique, increased water productivity and economic gain while using less water and producing the same yield as conventional furrow irrigation. In areas where water resources are scarce, it could make more sense for a farmer to optimize crop water productivity than to harvest yield per unit of land. It is possible to irrigate more areas of irrigable land with the saved water or apply it for other purposes. Increasing agricultural water production is typically considered the most effective way to address water scarcity and environmental problems in arid and semi-arid countries. Therefore, the ideal strategy for dry farming systems is to maximize productivity per unit of water (WP). In general, studying the effects of deficit irrigation levels and furrow irrigation methods on crop yield and water productivity generates results that may be useful to academic institutions, global food security initiatives, farmers, policymakers, managers of water resources, and environmental conservation initiatives by offering insightful information and workable solutions to maximize water use in agriculture and improve the sustainability of water resources.

## 1.6 Scope of the Study

This study examines how wheat crop yield and water productivity are affected by deficit irrigation levels and furrow irrigation methods. It was carried out in an experimental setting in the Ambo Agricultural Research Centre in the west Shewa zone. The deficit irrigation levels and the irrigation methods are two factors in the experiment. Data on parameters related to water productivity, growth, yields, and yield components were gathered and examined. Treatments were established in the RCBD arrangement.

## 1.7 Expected Output

The expected outputs are: -

- ❖ The deficit irrigation level that provides relatively better yield and water productivity identified
- ❖ The effect of furrow irrigation methods on yield and water productivity of wheat crops determined
- ❖ The interaction effect of deficit level and furrow irrigation methods on yield and water productivity of wheat crops determined

# 2 LITERATURE REVIEW

## 2.1 Types of Furrow Irrigation Method

Furrow irrigation is the most popular surface irrigation method for irrigating agricultural land. A smaller initial investment is needed for this sort of irrigation, which is frequently employed in arid and semi-arid regions to supply water for crops, and less ongoing work is needed to maintain its maintenance and efficiency (Michael, 2007; Walker, 2003). Deep, somewhat permeable soils with a consistent level or mild slope of 0.1-0.5% are ideal for crops planted in rows, such as vegetables, maize, cotton, tomatoes, and potatoes (FAO, 1986). Furrows are particularly useful for irrigating crops that are prone to fungal root rot because they can stop water from ponding and coming into contact with the parts of the plant (Michael, 2008). Proper preparation of the land and effective water management techniques might result in moderate to high application efficiency. Without significantly changing the design of the layout or operational procedures, different crops can be grown one after the other. Furrow irrigation systems can use a variety of methods to apply water, making the initial investment relatively small on soils that do not require considerable land formation (FAO, 2002).

### 2.1.1 Conventional furrow irrigation

Conventional furrow irrigation (CFI) is a traditional form of furrow irrigation that is widely used by farmers in Ethiopia and other developing countries (Hassene & Seid, 2017). Every furrow is watered using this method, which is known to be less effective, especially in regions with a shortage of irrigation water. In conventional furrow irrigation (CFI), according to Karajeh et al. (2000), irrigation water has been used as follows: 51–54% of the total water supply was used to moisten the soil (saturation), 20–25% for infiltration within the temporary irrigation network and in the fields, 5-6% for the evaporation from the water surface, and 18–21% for surface runoff. A significant portion of the irrigation water supply is lost to infiltration and surface runoff, which results in a reduction in the amount of water available to irrigated lands, decreased agricultural production efficiency, and decreased drainage system dependability. The removal of organic materials and transportable forms of nutrients from the root zone has been accelerated by this irrigation technique, which has ultimately resulted in losses in soil fertility. Low application efficiency and distribution uniformities are typically the result of extremely deep percolation at the upper portion of the furrow, insufficient irrigation at the lower section, and significant runoff. According to the study of Yang et al, (2023) shows that the maximum thousand-grain weights, dry biomass and grain yield of maize were recorded under the CFI compared to the AFI method. However, the minimum irrigation water productivity was found with the CFI method compared to AFI method. From the study of Meskelu et al,(2018) maximum aboveground biomass 28.28 t/ha and grain yield 6.29 t/ha were observed in the conventional furrow irrigation water application method which was statistically superior to both alternate and fixed furrow methods. The minimum water use efficiency of 1.15 kg/$m^3$ was observed at the conventional furrow method and this was statistically inferior to both alternate and fixed furrow method during both seasons. According to earlier studies of Mekonen et al. (2022), Yemane et al.(2015) conventional furrow irrigation can reach a significant mean maximum yield, but it greatly reduces water use efficiency when compared to alternative and fixed furrow irrigation methods.

### 2.1.2 Alternate furrow irrigation

When irrigation involves watering one of every two adjacent furrows, this management strategy of irrigation is called an alternate furrow. It is an efficient way to increase water productivity without significantly lowering yield (Degefu & Kuli, 2020). The main difference between this method and CFI is that only the alternating furrows receive irrigation, leaving the areas between the furrows dry. This implies that just one side of each ridge receives water, and if the field's irrigation system permits this movement, the side that receives irrigation water may vary with each irrigation event. Alternate furrows encourage horizontal (lateral) water flow, which reduces water losses from deep percolation and runoff. Alternate furrow irrigation has been demonstrated to retain fertilizer in the soil for plant uptake, resulting in reduced nitrate leaching, in contrast to conventional furrow irrigation (Ebrahimian et al., 2012). This method leads to lower leaf transpiration and continuous stomatal inhibition. The root system was uniformly distributed across the soil during alternate-furrow irrigation drying, whereas more roots were in the wet and fewer in the dried zone during fixed root zone drying (Kang et al., 1998). According to studies by Asres et al. (2022); Kassaye et al.(2020), converting every furrow irrigation to alternate furrow irrigation (AFI) can improve the efficiency of water use. However, in some circumstances, crop yield may decrease (Yadeta et al., 2022). Both Kang et al. (2000) and Jarvis (2011) suggest that these practices have a favorable impact on how well plants absorb water and nutrients. Reduced soil water evaporation surface areas, higher water uptake rates for the roots that have access to soil water, promoted secondary root growth, and increased root activity are all ways to compensate for the roots that have limited access to water (dry zone). These actions improved nutrient uptake and nutrient recovery in plants. Many studies Kannan & Mulugeta, (2015), Meskelu et al.(2017), Nasri et al.(2010),Panigrahi et al.(2011) have demonstrated the ability to raise water production without appreciably lowering yield through the use of alternate furrow irrigation.

### 2.1.3 Fixed furrow irrigation

In comparison to alternate, fixed furrow irrigation (FFI) has shown a slight improvement in water conservation(Nur, 2018). Because less water is utilized and a higher economic return may be achieved, the every-other-furrow irrigation method has more advantages than any other irrigation technique, both environmentally and economically (Adugna et al., 2020). Except for just applying irrigation to specified furrows and leaving the spaces between them dry, this approach is essentially the same as conventional furrow irrigation (CFI). By irrigation just one side of the ridge during the irrigation season, irrigation water can be conserved greatly compared to CFI. However, there is also a chance that in some circumstances crop yield will decline (Hassene & Seid, 2017). The practice of selecting some adjacent furrows for irrigation and leaving other furrows unirrigated for the remainder of the season is known as fixed furrow irrigation (FFI), in which irrigation is fixed to one of the two neighboring furrows. It results in less salt buildup in the root zone than conventional furrow watering Ashraf & Saeed (2006). Studies of Akele ( 2019), Asres et al.(2022) Tadese (2018) found that fixed furrow irrigation had higher irrigation application efficiency when compared to conventional method. By using every other furrow irrigation (FFI), 20 to 30 percent of the reduced amount of water applied can be obtained. Infiltration should not be reduced by 50% when compared to watering every furrow due to increased lateral flow (Yonts et al., 2003).

## 2.2 Deficit Irrigation

According to the classic irrigation development paradigm, water must always be provided in appropriate quantities to prevent water shortages and maximize production(Fao, 1992). This paradigm is altering today due to limitations on the water supply (Bouman, 2007). Thus, achieving the goal of increasing food production while reducing water use would be difficult in the upcoming decades, especially in countries with limited water supplies, scarce land, and inappropriate water use (FAO, 2002). As a result, it's critical to create innovative irrigation scheduling techniques that don't necessarily rely on a crop's overall water needs. According to Costa et al.(2007), deficit irrigation is a technique that has been developed to lower yield losses, improve water productivity, and even enhance product quality. It involves watering the crop at periods of the growth season or at particular phenological stages when it is less susceptible to water stress (Galindo et al., 2018; Iniesta et al., 2009). Any yield reduction is expected to be insignificant in light of the advantages associated with water-saving. Deficit irrigation and furrow irrigation techniques of application are critical concerns for enhancing water production in areas with water constraints (Narayanan and Seid 2015). It is possible to significantly decrease irrigation water use without noticeably lowering crop yield by using deficit irrigation, which can save up to 30% of crop evapotranspiration. (Gebremariam, 2017). A proper grasp of agricultural ET, crop response to water deficits, particularly the identification of critical crop growth periods, and the economic consequences of yield reduction strategies are necessary for the implementation of DI. Conversely, deficit irrigation attempts to maintain yields rather than to increase yields (Zhang & Oweis, 1999). From the study of Degefu & Kuli,(2020) reported that there was significant difference between mean grain yields obtained from 100%ETc and 50%ETc treatments. The maximum and lowest grain yield of 9318.6 kg/ha and 7905.2 kg/ha was obtained from 100%ETc and 50%ETc respectively. There was 15.17 % significant yield reduction recorded through the application 50% deficit level as compared to full irrigation. According to Furgassa, (2017) study irrigation amount increased grain yield significantly ($P < 0.05$), producing higher grain yield of 4522.8 kg/ha with 100%ETc and significantly lower yield of 3668.8 kg/ha with 50% of ETc. However, WUE values ranged from 0.77 kg /$m^3$ to 1.37 kg /$m^3$ for 100% ETc and 50%ETc of irrigation depth of water applied respectively and the values decreased with increasing water use. The study of Adugna et al. (2020) reveled that grain yield is highest under satisfactory soil moisture than deficit irrigation. The maximum 6535.6kg/ha mean grain yield was obtained with irrigation level of 100%Etc while the minimum 4285.3kg/ha was observed with deficit of 50%Etc irrigation water application. And also, the deficit irrigation of 50%ETc provides the maximum 2.00 kg /$m^3$ water use productivity and the minimum was observed in 100%ETc irrigation level. Earlier studies of Jemal et al., (2019),Mahamed et al, (2011),and Meskelu et al, (2017) on wheat revealed that increase of deficit irrigation level can increase the water productivity of the wheat crop.

## 2.3 Yield Response to Water Deficit

The relationship between the amount of water given to a crop and the resulting increase in crop production is measured by a parameter called the yield response factor. It symbolizes the crop's susceptibility to changes in the amount of available water. How susceptible a crop is to water shortages and subsequent yield losses is shown by the magnitude of the yield reaction factor (Ky) value (Dirirsa et al., 2017). The method to calculate the ratio of relative yield drop to relative evapotranspiration decrease links actual yield (Ya), maximum yield (Ym), actual evapotranspiration (ETa), and maximum evapotranspiration (ETm) to the yield response factor (Ky) (Mubarak & Hamdan, 2018). Depending on the stage of growth, the crop-specific Ky values change during the growing season. There are three conditions. The first one is when water use is decreased due to stress, crops respond to water deficits particularly sensitively, with yield decreases that are proportionately higher and yield response factor become greater than one. The second is yield response factor becomes less than one means that crop has less proportionate production decreases with reduced water usage, is more resistant to water deficit, and has a partial recovery from stress. Finally, the decrease in yield is closely correlated with the decrease in water usage. When arranging limited supplies to get the maximum yield, yield responsiveness to water deficiency in various individual growth cycles is crucial. During emergence, blooming, and the early stages of yield development, crops are particularly vulnerable to water stress (Pershing et al., 1920). In wheat, the flowering period is more sensitive than the yield formation phase, and the yield formation phase is more sensitive than the vegetative period. Spring wheat is more sensitive than winter wheat. Determining the link between relative yield decline and relative evapotranspiration deficit, as provided by the empirically derived yield response factor, is important in order to evaluate the impact of water stress (Pershing et al., 1920). It is essential to understand how yield responds to a water deficit for farmers and researchers in managing water resources, optimizing irrigation strategies, and selecting drought-tolerant crop varieties. It helps inform decisions related to irrigation scheduling, water conservation, and crop management practices to minimize yield losses under limited water availability conditions.

## 2.4 Water Productivity

The yield of crops per unit of irrigation water is known as water productivity (WP), which measures how well irrigation water is applied Zhang et al (2003). Tons of crop output divided by irrigation water utilized during the production cycle is known as water use efficiency. Even though the output per hectare is high, utilizing excessive irrigation water to obtain that yield is a waste of a scarce resource. It is widely accepted that raising agricultural water production is the most efficient way to alleviate water scarcity and reduce environmental issues in arid and semiarid regions. It's not land but water that is the most limiting factor in raising crop yields in arid regions. Thus, it is preferable to optimize water productivity (yield per unit of water) for dry agricultural systems instead of land productivity (yield per unit of land) (English, 1990). Therefore, improving WP in irrigated agriculture is crucial. In dry regions, deficit irrigation has been thoroughly investigated as a profitable and environmentally friendly production technique (Pereira et al., 2002). This technique attempts to optimize water productivity and stabilize yield by restricting water application to stress tolerant development stages or throughout the growth cycle. Research findings show that deficit irrigation is productive in raising water productivity for different of crops without significantly reducing yields. However, it is necessary to guarantee a specific minimum level of seasonal moisture (Geerts & Raes, 2009). Given that water is scarce in many parts of the globe, agricultural researchers are interested in finding ways to use less water while producing more food. In this case, water productivity can be used to evaluate deficit irrigation techniques. Water productivity of crop is an essential factor in determining how well irrigated and rain-fed agriculture perform. Improving water productivity for sustainable irrigated agriculture is the fundamental challenge facing both rain-fed and irrigated agriculture. Application of a comparatively optimal furrow irrigation system showed success in improving the yield of fruits and water usage effectiveness. The amount of water required for transpiration, plant growth, soil evaporation, and drainage loss to produce one unit of dry-weight material is the indicator of water use efficiency (Ascough & Kiker, 2002; Baye, 2011). In developing countries, where water productivity varies greatly between and within fields depending on the circumstances in which the crop is grown, increasing water productivity can be a key path to reducing poverty (Derib et al., 2011). It is also an essential strategy for addressing the issue of future water shortage, which a growing population will make more serious (Dirirsa et al., 2017). In a recent review in Ethiopia, Asmamaw et al., (2021) showed that for saving 65% water, the yield penalty was 26%, while water productivity increased by 110% for wheat. In addition, by irrigating less water per unit area, the area under irrigation could be expanded. Water productivity was always highest under the lowest irrigation water regimes or the highest water saved and decreased linearly with more water being applied(Asmamaw et al., 2023).

## 2.5 Agronomic Characteristics of Wheat

Wheat (Triticum aestivum) is one of the most significant crops for Ethiopia's food security. It has an annual yield of 6.7 million tons of grain at an average productivity of 3.0 and 4.0 t/ha under rain-fed and irrigated conditions, respectively, it is grown on 2.1 million (1.7 million ha rain-fed and 0.4 million ha irrigated) hectares (Tadesse et al., 2022). Wheat can be successfully grown in most parts of Ethiopia on all soil types that are well-drained and productive. But wheat grows best in deep, well-drained, and fertile clay loam or sandy loam soils. The suitable depth of sowing for wheat is 4 cm for profuse tillering and strong crown root development. Wheat is one of the most widely adapted crops grown at different altitude ranges (Tadesse et al., 2022) Row spacing of wheat is suitable within the range of 20 to 25 cm for the target plant population and will produce the highest yield. Seed rates of 120 to 130 kg/ha produced the maximum grain yield in irrigated areas of Ethiopia. Irrigated wheat requires different amounts of water according to the variety, growth stage, canopy density, climate, irrigation, and crop management. A wheat crop grown in ideal conditions one that is uniform, disease-free, well-irrigated, and has an ideal canopy needs between 450 and 650 millimeters of water in total growing season in Ethiopia.

## 2.6 Effect of Deficit Irrigation on Crop Yield and Water Productivity

Deficit irrigation is a technique for reducing the consumption of irrigation water when resources are scarce (Zhuo & Hoekstra, 2017). The relationship between yield and irrigation amount can be viewed as linear in the ranges of irrigation regimes taken into consideration, and the resultant IWUE values fell within a narrow range (Ambachew et al., 2014). A deficit irrigation system can increase water productivity without significantly lowering bulb production, taking into account the crop's sensitive stage (Dirirsa et al., 2017). According to Meskelu et al.(2017) studies deficit irrigation levels have reportedly had a very high impact on wheat yield components, yield and growth parameters. The various deficit levels have likewise indicated a very highly significant impact on wheat WUE. The highest water use efficiency (1.86 $kg/m^3$) was found at 30% ETC treatment, while the lowest (1.08 $kg/m^3$) was found at 100% ETc. Studies by El-Shafei & Mattar, (2022) revealed that varying degrees of deficit watering had a very significant impact on the wheat crop's plant height, spike length, number of grains per spike, and grain yield. Water stress at different stages of growth also had a significant effect on wheat's water use efficiency. Various studies on wheat show that the deficit irrigation level impacts the water use efficiency of irrigated wheat (Pradhan et al.,2013). The study of Mohammadi, (2010) showed that the water use efficiency of wheat ranged from 0.66 to 1.34 kg/m$^3$ based on the irrigation regime. On the other hand, Hamid et al. (2012) discovered that irrigation of wheat below the optimum level can save 22% of irrigation water with only a minor yield loss. Additionally, according to Tavakoli & Moghadam, (2012), wheat can be watered to 66% of full irrigation with the right management, which increases water use effectiveness. Compared to full irrigation during the whole growing season, deficit irrigation decreased biomass, yield, and certain other attributes. As irrigation water increased, however, WUE and IWUE values decreased (Sincik et al., 2008).

## 2.7 Effect of Furrow Irrigation on Crop Yield and Water Productivity

Different furrow irrigation methods, In the study of Gebreigziabher,(2020), have a highly significant impact on the yield components of maize (plant height, cob length, grain yield, and above-ground dry biomass), as well as on water use efficiency. The study of Ahmee & Berhanu, (2020) demonstrated that the grain yield of maize produced per hectare has been highly significantly influenced by different furrow irrigation water management methods ($P < 0.001$). Based on the results, the conventional furrow irrigation water management method produced the highest yield 9003.8 kg/ha, which differs significantly from alternative and fixed furrow irrigation water management methods. Similarly, a very highly significant ($p<0.001$) influence was shown in water productivity. Results indicated that the water productivity of maize was higher under the alternate furrow irrigation method as compared with conventional and fixed furrow methods. The alternative furrow method yielded a maximum water productivity of 2.43 kg/m$^3$, which was statistically higher than that of the conventional and fixed furrow systems. During growing seasons, the conventional furrow approach yielded the lowest water productivity 1.64 kg/m$^3$, which was statistically lower than that of the alternative and permanent furrow systems. The study of Ahmee & Berhanu,(2020) showed that the water management techniques used in furrow irrigation had a highly significant ($p<0.001$) impact on the aboveground biomass of maize. The highest aboveground biomass of 47.70 t/ha was obtained from the conventional furrow method (100% ETC), which was statistically significantly superior to both alternate and fixed furrow irrigation methods. On the other hand, the fixed furrow irrigation method produced a minimum aboveground biomass of 36.68 t/ha, which was statistically comparable to the alternate furrow irrigation method. When compared to the fixed furrow irrigation approach, the application of the conventional furrow irrigation method increased maize total biomass by 30.2%.

## 2.8 Effect of DI and Furrow Irrigation on Crop Yield and Water Productivity

Studies of Gebreigziabher, (2020) reported that the interaction effect of irrigation deficit levels and furrow methods on maize grain yield showed that it was very significant ($p<0.001$) and significant ($p<0.05$) on above-ground dry biomass production. On the water use efficiency (WUE) of maize, there was also a significant variation as a result of the application of different furrow irrigation techniques and irrigation deficit levels at 0.1% and 1% significant levels, respectively. According to Adugna et al.(2020), there were considerable differences in the furrow irrigation techniques and irrigation levels, with maize water productivity ranging from 0.22 $kg/m^3$ to a maximum of 3.99 $kg/m^3$.The study of Yang et al, (2023) reported that the interaction effect of water stress and furrow irrigation methods was non-significant in the growth parameters of maize but there was significant interaction effect in grain yield ,biomass ,harvest index and water productivity of maize crop.

# 3 MATERIALS AND METHODS

## 3.1 Description of the Study Area

The experiment was conducted in West Shewa Zone, Ambo at Ambo Agricultural Research Center. Ambo is a town in west-central Ethiopia located in the West Shewa Zone of Oromia Region, west of Addis Ababa. It is the capital city of the West Shewa zone. Ambo is known for its mineral water, bottled outside of town; it is reportedly the most popular brand in Ethiopia. The experimental site's geographical location is at 38° 07'E ,8° 57'N, and 2144 a.s.l altitude located in (Figure 3.1). The area experienced bimodal rainfall with a mean annual precipitation of 1029 mm. The mean maximum and minimum temperature of the area is 26.4°C and 10.3°C respectively. The soil texture of the experimental site has been classified as clay soil with 67.1%, 16.5 %, and 16.4 % clay, silt, and sand respectively.

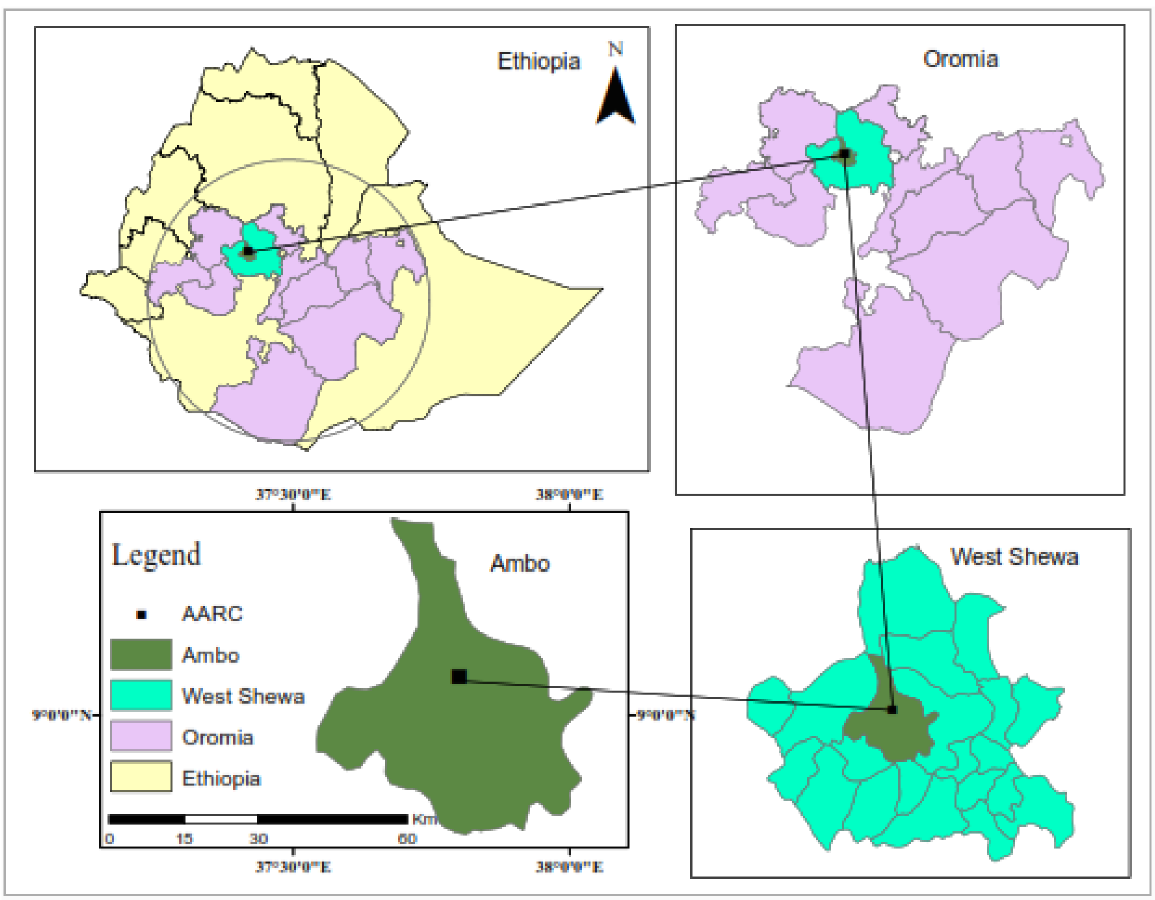



Figure 3.1.Location map of the study area

## 3.2 Experimental Design

The experiment was a two-factor factorial experiment arranged in a Randomized Complete Block Design (RCBD) with three replications. The two factors were deficit irrigation level and furrow irrigation method. According to Fereres & Soriano,(2007) it has been argue that the level of irrigation supplied under deficit irrigation should be between 60% and 100% of the full crop water requirement to enhance water productivity. The deficit irrigation levels are 60% ETc,80% ETc, and 100% ETc whereas the irrigation methods are conventional, alternate, and fixed. The treatment combinations of the experiment are given in the (Table3.1) below:

Table 3.1Treatment combination

| Factors | | Treatment combination | Trt. No |
|---|---|---|---|
| Deficit irrigation (DI) | Furrow Irrigation (FI) | | |
| 100%ETc (0 Deficit) | Conventional Furrow (CF) | 100% ETc with CF | 1 |
| | | 80% ETc with CF | 2 |
| | | 60% ETc with CF | 3 |
| 80%ETc (20% Deficit) | Alternate Furrow (AF) | 100% ETc with AF | 4 |
| | | 80% ETc with AF | 5 |
| | | 60% ETc with AF | 6 |
| 60%ETc(40%Deficit) | Fixed Furrow (FF) | 100% ETc with FF | 7 |
| | | 80% ETc with FF | 8 |
| | | 60% ETc with FF | 9 |

## 3.3 Experimental Field Layout

The experimental field was divided into 27 plots and each plot was a size of 3 m x 2.8m which consists of 5 ridges spaced at 60 cm. The seed was sown in a double row on the ridge with a spacing of 20 cm (Tewabe et al., 2020).The distance between plots and blocks was 2meters and 3meters respectively to control the lateral movement of water. The width and length of the layout was 16.4 meter and 47 meters respectively. The source of irrigation water in the study area was the Huluka River. The predetermined amount of water was applied by a 2-inch Parshall flume to each plot.

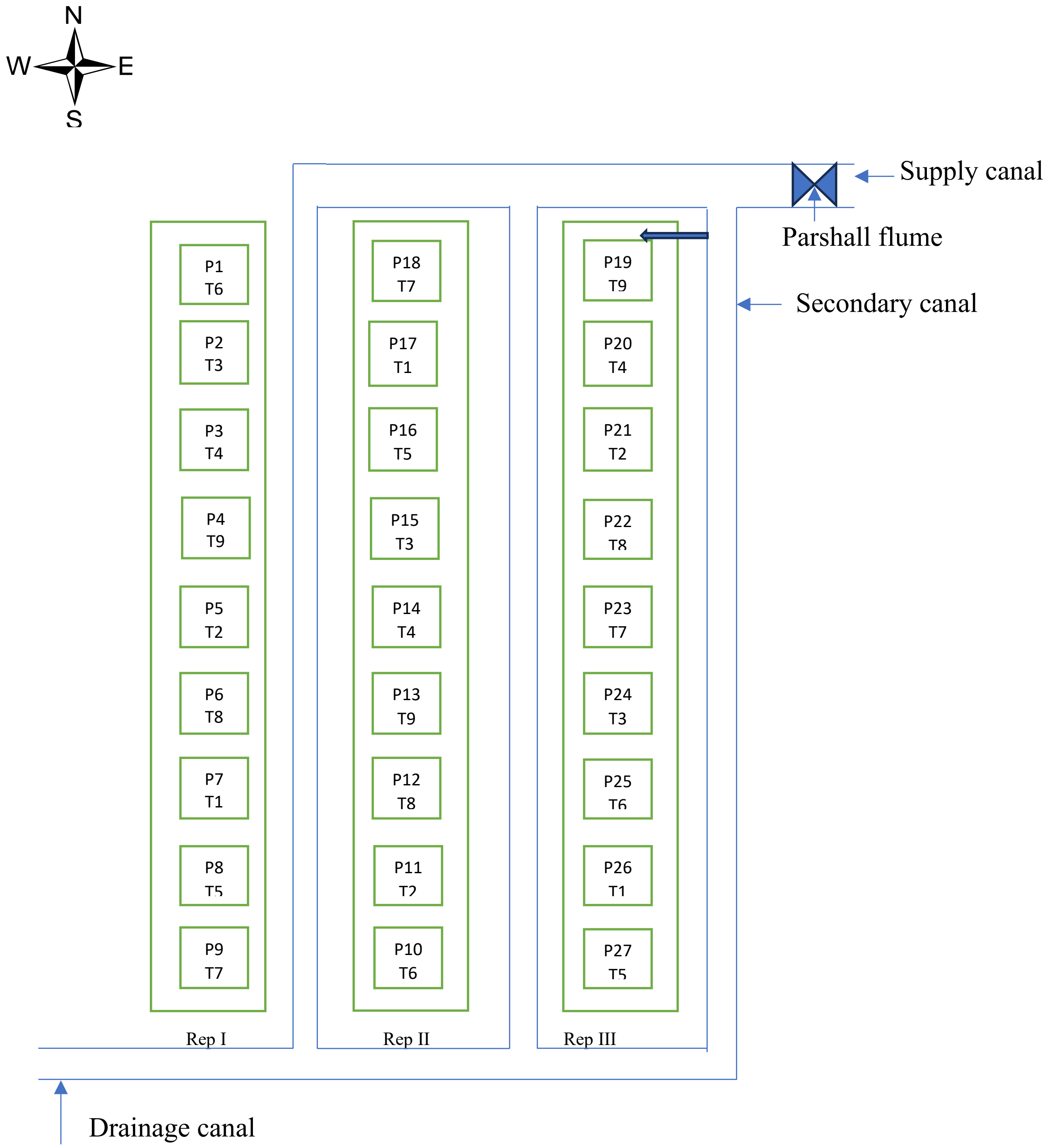



Figure 3.2.Field layout

P =Plot

T =Treatment

## 3.4 Materials

The material used to conduct this study were listed in the tables below

Table 3.2.Material used

| No | Material | Activities performed by materials |
|---|---|---|
| 1 | Tractor | To plow and level the land of the experimental site |
| 2 | Measuring meter | To prepare the layout of the experimental site |
| 3 | Hammer | To prepare the layout |
| 4 | Stick | To fence every plot size |
| 5 | Spade | To prepare the Furrow and ridge of the plots |
| 6 | Hoe | To compact the soil |
| 7 | Balance | To measure the seed and fertilizer |
| 8 | Seed | The recommended level of seed will be sowed in each plot |
| 9 | Fertilizer | The recommended level of fertilizer will be added to each treatment |
| 10 | Parshall flume | To measure the water applied |
| 11 | Stopwatch | To control the time for applied water in the furrow in each plot |
| 12 | Ruler | To measure the spike length of wheat |
| 13 | Meter | To measure the plant height of wheat |
| 14 | Hard paper and color | To prepare tags for the plots |
| 15 | Sickle | To harvest the wheat |
| 16 | Sacks | To collect data yield |
| 17 | Auger | To take a soil sample |

The software used to conduct this study were listed in the tables below

Table 3.3.Software used

| No | Software used | Purpose |
|---|---|---|
| 1 | CROPWAT 8.0 | To estimate ETo and ETc |
| 2 | Arc-GIS 10.4 | To map the study area |
| 3 | Statistical software (R 4.3.1 for windows) | To statistically analyze the data |

## 3.5 Determination of Soil Physical Properties

### 3.5.1 Soil texture and bulk density

For soil textural class analysis, disturbed composite soil samples were collected from (0-20 cm, 20-40 cm, 40-60cm, and 60-90cm), depth using a soil auger at three locations with three distances of the representative site of the experiment, because of the maximum root depth of the crop. The hydrometer method was used for analyzing particle size distribution and the textural class was assigned using the USDA textural triangle. The soil bulk density was determined from undisturbed soil samples using a core sampler of size 5 cm in diameter and 5 cm in height. The samples were dried in an oven at 105°C for 24 hours and the bulk density was determined by the equation given by(Hillel & Hatfield, 2005).

$$pb = \frac{Ws}{Vs} \tag{3.1}$$

Where: $\rho_b$ is soil bulk-density (g/ cm$^3$),

$W_s$ is mass of dry soil (g) and

$V_s$ is the volume of soil in the core (cm$^3$)

### 3.5.2 Field capacity and permanent wilting point

Soil sample for the determination of moisture content at field capacity (FC) and permanent wilting point (PWP) was collected at (0-20 cm, 20-40 cm, 40-60cm, and 60-90cm) depth from different locations along with the representative place of the experimental site. The soil sample was saturated for two to three days before being it in a pressure plate apparatus with plastic rings. Then, the pressure plate was closed properly and the gauge from the compressor was adjusted at 1/3 and 15 bars for FC and PWP, respectively. The pressure was provided until no further change in soil moisture content was observed. Then the samples were collected, weighed, and oven-dried for 24 hours at 105°C at Melkassa Agricultural research center. Then TAW was determined using the equation

$$\mathrm{TAW} = (\mathrm{FC} - \mathrm{PWP}) * \mathrm{Dz} * pb \qquad (3.2)$$

Where: TAW is Total available moisture (mm),

FC is Moisture content at Field capacity (%),

PWP is Moisture content at Permanent wilting point (%),

$pb$ is density of soil(g/cm$^3$) and

$D_z$ is root depth(mm)

Readily available moisture (RAW) is the fraction of the total available moisture that a crop can extract from the root zone without suffering water stress. It is the permissible soil moisture depletion level and can be determined by using the equation

$$\mathrm{RAW} = \rho \times \mathrm{TAW} \qquad (3.3)$$

Where: RAW is the readily available moisture(mm),

ρ is Allowable depletion level (%) and

TAW is Total available moisture (mm)

The depletion fraction of wheat crop is 0.55(Savva & Frenken, 2002).

The soil moisture depletion for each treatment at any time will be computed from the expression:

$$\mathrm{SMD} = (\mathrm{FC} - \mathrm{SMC}) \times pb \times \mathrm{D_z} \qquad (3.4)$$

Where: SMD is the soil moisture depleted in mm,

FC is moisture content at field capacity in %,

SMC is soil moisture content at the time of sampling in %,

$pb$ is the bulk density in gm/cm$^3$ and

$\mathrm{D_z}$ is effective depth of root zone in mm.

## 3.6 Irrigation Scheduling

### 3.6.1 Determination of crop water requirement

Monthly reference evapotranspiration was computed using Crop wat model version 8.0 based on the 25-year long-term climate data. Maximum and minimum temperature, relative humidity, sunshine hour, and wind speed were collected from Ambo Agricultural Research Center meteorology station. Crop water requirement (ETc) was determined by multiplying reference evapotranspiration ETo with the crop coefficient Kc (Kassam & Smith, 2001). The crop coefficient of the wheat crop for each growth stage and monthly reference evapotranspiration were used to determine the crop water requirement.

Table 3.4.Parameters for crop water requirement determination

| | Growth stage | | | | |
|---|---|---|---|---|---|
| Parameters | Initial | Development | Mid | Late | Total |
| Growth stage(days) | 15 | 25 | 50 | 30 | 110 |
| Crop coefficient (Kc) | 0.4 | 0.8 | 1.15 | 0.5 | |
| Depletion fraction(ρ) | 0.55 | 0.55 | 0.55 | 0.55 | |

Sources:(Kassam & Smith, 2001)

The accuracy of determination of crop water requirements was largely dependent on the type of climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Muturi et al., 1992).The growth and yield of any crop was related to the amount of water used. The variable amount of water contained in a soil and its energy state are important factors affecting the growth of plants(Hillel, 2003).The calculation can be done using the CROPWAT model. Reference evapotranspiration ($ET_o$) is calculated based on the FAO Penman-Monteith method(FAO,1992) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34U_2)} \quad (3.5)$$

$$es = \frac{e°T\ max + e°T\ min}{2}$$

$$ea = \frac{RH\ mean}{100} \times es$$

$$\Delta = \frac{4.098\left[0.6108exp\left\{\frac{17.27T}{T + 237.3}\right\}\right]}{(T + 237.3)^2}$$

$$Rn = Rns - Rni$$

Where, $ET_o$ is reference evapotranspiration (mm/day),

Rn is net radiation at the crop surface ($MJ/m^2/day$),

G is soil heat flux density ($MJ/m^2/day$),

T is mean daily air temperature at 2 m height (°C),

$U_2$ is wind speed at 2 m height (m/s),

$e_s$ is saturation vapor pressure (kPa),

$e_a$ is actual vapor pressure (kPa),

es - ea is saturation vapor pressure deficit (kPa),

Δ is slope of the vapor pressure curve (kPa/°C) and

ϒ is psychrometric constant (kPa/ °C).

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity, and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water. The updated values of crop coefficients are determined from(Pereira, 1998).

$$ETc = ETo * Kc \qquad (3.6)$$

Where, ETc is crop evapotranspiration,

Kc is crop coefficient and

$ET_o$ is reference evapotranspiration

### 3.6.2 Determination of effective rainfall

The portion of rainfall that can effectively be used by plants, to sustain their growth is known as Effective rainfall. The rain which is available to the crops is not all the failing. when some are lost through runoff and deep percolation. An empirical formula was developed in the Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance), and estimated losses due to runoff and deep percolation using Cropwat 8.0. Calculation according to:

$$Pe = 0.8\,P - 25 \quad \text{if } P > 70\ \text{mm/month} \tag{3.7}$$

$$Pe = 0.6\,P - 10 \quad \text{if } P < 70\ \text{mm/month} \tag{3.8}$$

Where P is monthly dependable rainfall (mm) and

Pe is monthly effective rainfall (mm)

### 3.6.3 Net irrigation depth

The net depth of irrigation supplied at any time is obtained from a simplified water balance equation:

$$I_n = ET_c - P_e \tag{3.9}$$

Where: In is net irrigation depth in mm,

ETc is crop water requirement and

Pe is effective rainfall

### 3.6.4 Gross irrigation depth

Considering conveyance and other losses for a surface furrow irrigation system, an application efficiency of 60% was assumed (Chandrasekaran et al., 2010). The gross irrigation requirement is obtained as:

$$I_g = \frac{I_n}{E_a} \tag{3.10}$$

Where: Ig = gross irrigation depth in mm,

In =net irrigation depth in mm and

Ea is the furrow application efficiency (%).

### 3.6.5 Irrigation interval

The irrigation interval is the length of time between each irrigation event in agriculture. It indicates how often crops are watered through irrigation systems to satisfy their water needs and sustain appropriate soil moisture levels for optimal growth and productivity.

$$T = \frac{I_n}{ET_c} \tag{3.11}$$

Where: T is Irrigation interval (days),

$I_n$ is the net irrigation depth (mm) and

ETc is Crop water requirement (mm/day).

### 3.6.6 Time of application

The time required to deliver the desired depth of water into each furrow is calculated using the equation:

$$t = \frac{I_g \times w \times l}{6Q} \tag{3.12}$$

Where: Ig is gross depth of water applied (cm),

t is application time (min),

l is furrow length (m),

w is furrow width (m), and

Q is flow rate (l/s)

### 3.6.7 Parshall flume installation

Based on Parshall flume standard guides, the flume was sett up in the upstream of the canal, close to the experimental field to measure irrigation water used to the experimental field. The Parshall flume was skillfully installed along the main canal at a distance of 4 meters from the closest plot so there could be no bypass. The flume was positioned on the straight section of the channel such that its longitudinal axis was parallel to the channel and the direction of water flow. The entry section's floor level was checked using a spirit level. To prevent the flume from becoming submerged, the entry section was elevated by around 3 cm above the channel bed. The head of water entering in the Parshall flume was measured by the measuring unit of the flume in converging zone. The throat width of the installed Parshall flume was 2 inches. By using the throat width of the Parshall flume and head of water the discharge of water could be determined. By using the plot area and the discharge of water the time taken for irrigating each plot was also determined. The table used to determine the discharge of the irrigated water is presented below.

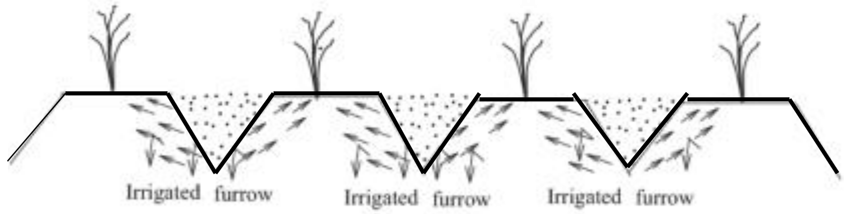
Table 3.5 Free flow discharge values for different sizes of Parshall flumes

| Head (cm) | Throat width (inches) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 6 | 9 |
| | Discharge (l/s) | | | | |
| 2 | 0.140 | 0.281 | | | |
| 3 | 0.263 | 0.526 | 0.772 | 1.496 | 2.504 |
| 4 | 0.411 | 0.822 | 1.206 | 2.357 | 3.889 |
| 5 | 0.581 | 1.162 | 1.705 | 3.354 | 5.471 |
| 6 | 0.771 | 1.541 | 2.261 | 4.473 | 7.232 |
| 7 | 0.979 | 1.957 | 2.872 | 5.707 | 9.155 |
| 8 | 1.205 | 2.407 | 3.532 | 7.047 | 11.231 |
| 9 | 1.446 | 2.889 | 4.239 | 8.489 | 13.448 |
| 10 | 1.702 | 3.402 | 4.991 | 10.027 | 15.801 |

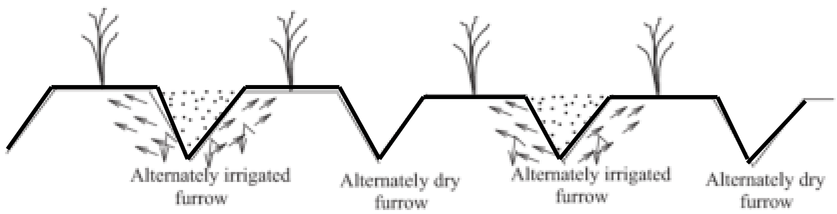
Source:(Meters, 2007)

### 3.6.8 Furrow irrigation application method

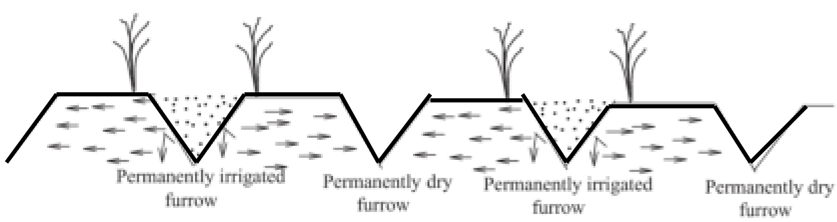
Each plot was formed in double five rows of wheat crop. The outer two rows were used as buffer rows to control border effects. In the conventional furrow method, every furrow was irrigated throughout the irrigation season. In alternate furrow irrigation, one of the consecutive furrows irrigated and the adjacent was remained dry until the next event of irrigation. In the fixed furrow irrigation, irrigation water is applied to a fixed furrow and the adjacent remains dry throughout the growing season. The three different furrow irrigation methods are presented in Fig (3) below.




Conventional furrow irrigation (CFI)




Alternate furrow first irrigation (AFI)




Fixed furrow irrigation (FFI)

Figure 3.3.Furrow irrigation methods

### 3.6.9 Crop Management

Before sowing, the experimental land was plowed by a tractor, and the furrow and ridge were prepared manually. After pre-irrigation seed was sown on the prepared experimental field at 0.20 m row-to-row spacing (Tewabe et al., 2020).A total of five double rows was kept on each plot. Each plot and block were separated by 2m and 3m respectively. Each plot was given the recommended dosage of DAP (150 kg/ha) and urea (about 200 kg/ha) to suit the nutritional needs of the wheat crop. The fertilizers were applied manually. DAP was applied at sowing time while urea was applied by split application. the first one was in sowing and the next was 45 days after sowing. The crop water requirement was computed by using meteorological data from the meteorology station and crop input data from FAO 33 by using the Cropwat 8.0 software version. The amount of irrigation water to be applied for each plot was measured using a Parshall flume. It has a 2-inch throat width. It was set in a straight and uniform section of the main canal away from 4 m from the nearest plot. The wheat variety "Wane" was used for the experiment. It is an improved variety that was released in 2016 by CYMMYT(Tadesse et al., 2022). Other important agronomic practices like hoeing, weeding, disease, and insect pest control were applied uniformly for all experimental plots as often as required.

### 3.6.10 Water productivity

Water productivity was determined based on the ratio of economical yield of wheat (grain yield per hectare) to the gross irrigation depth applied from germination to harvest expressed as kg/ha of grain yield per $m^3$ /ha of water. It was calculated based on the following formula for water use efficiency(Chandrasekaran et al, 2010).

$$WP = \frac{Y}{I_g} \tag{3.13}$$

Where; WP is Water productivity (kg/ $m^3$),

Y is yield (kg/ ha) and

$I_g$ is gross irrigation ($m^3$/ha)

### 3.6.11 Yield and yield components

To determine the effect of treatments on wheat yield, samples were collected from central three ridges to control border effects. Data on plant height, spike length, number of seeds per spike was recorded from five randomly selected plants for each experimental plot, and the same plant was used for subsequent measurement. Data on aboveground biomass and grain yield from each experimental plot was collected excluding the border of the plot.

### 3.6.12 Yield response factor

The yield response factor (Ky) of wheat which relates relative yield decrease to relative ET deficit under this study was estimated using the following equation which was formulated by (Kassam & Smith, 2001). It describes the relationship between the relative yield decreases produced by relative evapotranspiration deficit in a given irrigation scheduling protocol. The formulation relates four parameters (Ya, Ym, ETa, and ETm) to a fifth: Ky, the yield response factor as:

$$1 - \frac{Y_a}{Y_m} = K_y \left[1 - \frac{ET_a}{ET_m}\right] \quad (3.14)$$

Where: Ya is actual yield (kg/ha), ETm is maximum evapotranspiration (mm),

Ym is maximum yield (kg/ha), Ky is yielding response factor and

ETa is actual evapotranspiration (mm),

### 3.6.13 Economic analysis

Economic analysis was calculated by considering the general relationship between crop water use and crop yield per hectare of land at the different deficit irrigation application levels using the partial budget analysis. Net income (NI) in Birr/ha, generated from the wheat crop, was computed by subtracting the total cost (TC) in Birr/ha from the total return (TR) in Birr/ha obtained from Wheat sale as:

$$\mathrm{NI} = \mathrm{TR} - \mathrm{TC} \quad (3.15)$$

Where: NI is Net income (Birr/ha),

TR is Total return (Birr/ha) and

TC is Total cost (Birr/ha)

TC is the sum of FC and VC. Fixed costs (FC) are those that do not vary between irrigation treatments, i.e. wheat seeds, fertilizer, pesticides, land rent, and farm implements. Variable costs, on the other hand, are those that do vary between irrigation treatments, i.e., irrigation water and labor. The marginal rate of return (MRR) in % measures the percentile increase in net income ΔNI which will generated by each additional unit of expenditure (ΔTVC) and will be calculated by:

$$\mathrm{MRR} = \frac{\Delta \mathrm{NI}}{\Delta \mathrm{VC}} \times 100\% \quad (3.16)$$

Where: MRR is Marginal rate of return (%),

ΔNI is Increase in net income (Birr) and

ΔTVC is Total variable cost (Birr)

The amount of water to be saved (SW) per hectare of land from irrigation deficit was computed by subtracting deficit water application levels from the irrigation treatment that used the highest irrigation water level, i.e., 100%ETc. The extra irrigable land area (A) in hectare which was served by the saved irrigation water was determined by dividing the total saved water per hectare of land (SW) in $m^3$ by the irrigation water use for a hectare of land (IWU) in $m^3$/ha as:

$$A = \frac{SW}{IWU} \quad (3.17)$$

Where: A is Irrigable land area (ha),

SW is Saved water ($m^3$) and

IWU is irrigation water use($m^3$/ha)

The net income from saved water ($NI_{sw}$) in Birr that was obtained from irrigating extra land of area (A) in hectares is expressed as:

$$NI_{sw} = \Delta NI \times A \quad (3.18)$$

Where: $NI_{sw}$ is Net income from saved water (Birr),

$\Delta$NI is Increase in net income (Birr/ha) and

A is irrigable land area(ha)

## 3.7 Statistical Analysis

The data was analyzed by using R statistical software and if there was a significant difference among the treatments mean separation was made using the Least Significant Difference (LSD) method.

# 4 RESULTS AND DISSCUSIONS

## 4.1 Soil Physical Properties

The physical properties of the soil laboratory results showed that the average composition of sand, silt, and clay percentages were 16.7, 16.5, and 66.7, respectively. According to the USDA soil texture categorization, the soil at the experimental site was classified as heavy clay soil. The soil bulk density result varies slightly in the experimental field due to variation of the depth of the soil. According to Hazelton & Murphy (2019), the bulk density of the clay soil ranges between 1.0-1.4g/cm$^3$. The bulk density of the study site was 1.2 g/cm$^3$ which was in the range. The average moisture content on the mass basis at FC (-0.33 bar) and PWP (-15 bar), was 32.66% and 18.36%, respectively.

Table 4.1.Physical properties of the soil

| Soil property | Soil depth(cm) | | | |
|---|---|---|---|---|
| | 0-20 | 20-40 | 40-60 | 60-90 |
| Particle size distribution | | | | |
| Sand | 15.9 | 16 | 17.3 | 17.7 |
| Silt | 18.0 | 17.1 | 14.4 | 16.8 |
| Clay | 66.1 | 66.9 | 68.3 | 65.5 |
| Texture class | Clay | Clay | Clay | Clay |
| Bulk density | 1.09 | 1.12 | 1.13 | 1.16 |
| FC (%) | 40.5 | 35.6 | 29.7 | 24.8 |
| PWP (%) | 21.5 | 17.7 | 17.7 | 16.5 |
| TAW (mm) | 41.2 | 40.1 | 27.2 | 25.5 |

## 4.2 Soil Chemical Properties

The pH of the soil was determined to be at its ideal level (7.1), meaning that wheat and other crops can grow in this soil which is neutral. In general, normal soil is defined by the USDA as having a pH within the range of 7- 8. The electrical conductivity was less than 2.0 dS/m at 25°C. Slightly saline soils have EC within the range of (0.0 - 2.0 dS/m) which is low salt concentration and are generally suitable for most crops without causing significant negative impacts on plant growth and yield. Thus, the research area's soil was suitable. The soil had a weighted average organic matter level of roughly 3.47%. According to Staney and Yerima (1992), the soil's organic matter content is classified as medium. According to (Table 4.2) the average amount of accessible phosphorus and nitrogen was found to be 8.9% and 0.13 percent, respectively.

Table 4.2.Chemical properties of the soil

| Soil chemical properties | Tested results |
|---|---|
| Ph | 7.10 |
| Organic matter content (%) | 3.47 |
| Available nitrogen (%) | 0.13 |
| Available phosphorus(ppm) | 8.90 |
| Electric conductivity(dS/m) | 0.18 |

## 4.3 Reference Evapotranspiration

Long-term climate data of maximum and minimum temperature, sunshine hour, humidity, and wind speed were collected from the Ambo Agricultural Research Center to determine the reference evapotranspiration (ETo) of the study area. The average reference evapotranspiration of the experimental site was computed by CROPWAT 8 software and found to be 3.66mm/day.

Table 4.3.Climate data and ETo of the experimental site

| Month | Min Temp °C | Max Temp °C | Humidity % | Wind m/s | Sun Hours | Rad MJ/m²/day | ETo mm/day |
|---|---|---|---|---|---|---|---|
| January | 11.6 | 27.5 | 50 | 0.7 | 8.2 | 19.7 | 3.66 |
| February | 12.8 | 28.9 | 49 | 0.7 | 9.5 | 22.8 | 4.32 |
| March | 13.4 | 28.9 | 50 | 0.8 | 7.9 | 21.5 | 4.39 |
| April | 13.7 | 28.1 | 57 | 0.8 | 7.4 | 20.9 | 4.28 |
| May | 12.8 | 27.2 | 61 | 0.6 | 6.8 | 19.5 | 3.94 |
| June | 12.6 | 24.9 | 71 | 0.5 | 6.0 | 17.9 | 3.46 |
| July | 12.7 | 22.8 | 79 | 0.4 | 4.1 | 15.3 | 2.93 |
| August | 12.8 | 22.3 | 80 | 0.3 | 3.9 | 15.3 | 2.89 |
| September | 11.8 | 24.0 | 75 | 0.3 | 4.5 | 16.2 | 3.04 |
| October | 11.3 | 26.0 | 59 | 0.5 | 7.8 | 20.5 | 3.74 |
| November | 11.0 | 26.3 | 54 | 0.6 | 8.2 | 19.8 | 3.60 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| December | 11.2 | 26.5 | 51 | 0.7 | 8.6 | 19.7 | 3.61 |
| **Average** | **12.3** | **26.1** | **61** | **0.6** | **6.9** | **19.1** | **3.66** |

## 4.4 Crop Water Requirement of Wheat

Wheat's crop water requirement for the growing season was calculated using crop, soil, and climatic data by the CROPWAT 8 program. Long year mean climate data was obtained from Ambo Agricultural Research Center meteorological station and soil data for the study area was obtained from soil laboratory analysis result. Crop data like crop coefficient, total growing period, depletion level and other crop data used for CROPWAT model were accessed from FAO 33 paper. According to the table 4.3 the site's average reference evapotranspiration (ETo) was determined to be 3.66 mm/day. The seasonal crop water requirement of wheat as reported by (Doorenbos, 1986) ranges from 450-650 mm and the net irrigation depth computed with CROPWAT model agreed within the range stated by FAO. During the experimental season for months from February to May there was rainfall. The effective rainfall was calculated by using CROPWAT software on daily based and obtained to be 86mm depth throughout the growing season. The irrigation water requirement was calculated by subtracting the effective rain fall from crop water requirement.

Table 4.4.Crop water requirement and irrigation requirement of wheat crop

| Treatment | Factor 1<br>Deficit levels | Factor 2<br>Furrow method | Total CWR<br>(mm) | Irrigation<br>requirement (mm) |
|---|---|---|---|---|
| Treat 1 | 100%ETc | CFI | 452.52 | 356.52 |
| Treat 2 | 80% ETc | CFI | 362.01 | 266.01 |
| Treat3 | 60% ETc | CFI | 271.51 | 175.51 |
| Treat4 | 100% ETc | AFI | 226.26 | 130.26 |
| Treat5 | 80% ETc | AFI | 181.01 | 85.01 |
| Treat 6 | 60% ETc | AFI | 135.76 | 39.76 |
| Treat 7 | 100% ETc | FFI | 271.51 | 175.51 |
| Treat 8 | 80% ETc | FFI | 217.21 | 121.21 |
| Treat 9 | 60% ETc | FFI | 162.91 | 66.91 |

Note: 100%ETc is 0% deficit level,80%ETc is 20% deficit level, and 60% ETc is 40% deficit level

## 4.5 Irrigation Water Amount

The usual recommended values for furrow irrigation application efficiency for well-designed and managed systems are 50–70%, while they can be higher depending on the type of soil and management techniques (Griffiths, 2007). The CROPWAT model was used to compute the net and growth irrigation depth with the assumption of 60% application efficiency value for furrow irrigation. The gross irrigation depths of water for three furrow irrigation methods (CFI, AFI, and FFI) were 754.2mm,377.1mm, and 452.52mm respectively.

Table 4.5.Gross irrigation depth of different furrow irrigation methods

| Date | Gross irrigation water applied(mm) | | |
|---|---|---|---|
| | CFI | AFI | FFI |
| 12-Feb | 27.3 | 13.65 | 16.38 |
| 20-Feb | 45.5 | 22.75 | 27.30 |
| 28-Feb | 60.4 | 30.20 | 36.24 |
| 8-Mar | 65.8 | 32.90 | 39.48 |
| 16- Mar | 68.4 | 34.20 | 41.04 |
| 24- Mar | 71.7 | 35.85 | 43.02 |
| 3-Apr | 74.5 | 37.25 | 44.70 |
| 13-Apr | 72.6 | 36.30 | 43.56 |
| 23-April | 70.4 | 35.20 | 42.24 |
| 3-May | 68.3 | 34.15 | 40.98 |
| 13-May | 65.4 | 32.70 | 39.24 |
| 23-May | 63.9 | 31.95 | 38.34 |
| | 754.2 | 377.1 | 452.52 |

Note: CFI is conventional furrow irrigation, AFI is alternate furrow irrigation and FFI is fixed furrow irrigation.

The gross irrigation depths for the case of conventional furrow irrigation method under full crop water requirement (100% ETc) and two irrigation levels 80% ETc and 60% ETc (20% and 40% deficit levels respectively) were 754.2mm,603.4 mm, and 452.5mm respectively as presented in (Table 4.6) below.

Table 4.6.Gross irrigation depth of conventional furrow with deficit levels

| Date | Day | Stage | Gross Irrigation depth (mm) | | |
|---|---|---|---|---|---|
| | | | 100%ETc | 80%ETc | 60%ETc |
| 12-Feb | 7 | Init | 27.3 | 21.84 | 16.38 |
| 20-Feb | 15 | Init | 45.5 | 36.40 | 27.30 |
| 28-Feb | 23 | Dev | 60.4 | 48.32 | 36.24 |
| 8-Mar | 31 | Dev | 65.8 | 52.64 | 39.48 |
| 16-Mar | 39 | Dev | 68.4 | 54.72 | 41.04 |
| 24-Mar | 47 | Mid | 71.7 | 57.36 | 43.02 |
| 3-Apr | 57 | Mid | 74.5 | 59.60 | 44.70 |
| 13-Apr | 67 | Mid | 72.6 | 58.08 | 43.56 |
| 23-Apr | 77 | Mid | 70.4 | 56.32 | 42.24 |
| 3-May | 87 | Mid | 68.3 | 54.64 | 40.98 |
| 13-May | 97 | End | 65.4 | 52.32 | 39.24 |
| 23-May | 107 | End | 63.9 | 51.12 | 38.34 |
| | | Total | 754.2 | 603.4 | 452.5 |

## 4.6 The Effects of DI on Yield and Water Productivity of Wheat Crop

### 4.6.1 The effects of deficit irrigation on growth parameters of wheat

**Plant height**

The Analysis of variance on deficit irrigation levels show a significant ($P < 0.05$) effect on plant height of wheat (Appendix Table 1). The result of plant height revealed that application of 100 % ETc levels gave a maximum value of 83.74 cm which is statistically similar with the result obtained at 80 % ETc level, and significantly superior with the result obtained from the application of 60 % ETc levels as described in (Table 4.7). There was 4.9 % significant plant height reduction as the application of irrigation depth decreased from 100 % ETc to 60 % ETc levels. This result is consistent with the findings of Meskelu et al.( 2017), who found that applying irrigation water with an optimal irrigation treatment resulted in a maximum plant height of 87.5 cm, which was statistically equivalent to 85% ETc and 70% ETc. While plant height of 81 cm was attained with 60% ETc of irrigation water which was a statistically significant difference from full irrigation application. According to a study by Maqbool et al.(2015) on the response of three wheat varieties to water stress at different growth stages, the highest plant height was attained in the control treatment (full application of irrigation water). Plant height was reduced in different wheat varieties by water stress at different stages. The result clearly showed that water stress significantly reduced plant height at critical times. According to this research findings plant height and amount of irrigation have a direct relationship in which the plant height value increase as the application of irrigation depth increased. This might be due to deficit irrigation levels effect on the meristematic growth of plants by inhibiting the promotion of cell elongation and division which directly affect plant height of the crop. Generally, the findings of this research in lined with earlier research findings on wheat who stated that plant height of wheat increase with increasing in the application of irrigation depth(El Hwary & Yagoub, 2011; Negassa et al., 2013).

**Spike length**

The analysis result on spike length wheat shows that application of different irrigation depth had no significant effect on spike length of wheat at 5% significance level (Appendix Table 2). However, the highest spike length value of 6.6 cm was recorded from the treatment receiving 100 % ETc levels, and the lowest spike length value of 6.43 cm obtained through the application of 60% ETc levels with a non-significant spike length reduction (Table 4.7). This result agrees with Meskelu et al. (2017)'s findings, which showed that applying irrigation water with the optimal irrigation treatment produced the longest spike length of 8.3 cm and that there were no significant differences between irrigation applications of 85, 70, and 60% ETc. This finding is consistent with (Jemal et al., 2019b).

Table 4.7.The effect of deficit irrigation level on growth parameters of wheat

| Deficit level | Plant height (cm) | Spike length(cm) |
|---|---|---|
| 100% ETc | 83.74[a] | 6.60 [ns] |
| 80% ETc | 81.58[ab] | 6.53 [ns] |
| 60% ETc | 79.64[b] | 6.43 [ns] |
| LSD $_{(0.05)}$ | 2.54 | 0.23 |
| CV (%) | 3.11 | 3.5 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance ns=non-significant at 5% level;

### 4.6.2 The effect of deficit irrigation on yield components of wheat crop

**Seed per spike**

The analysis of the result showed that deficit irrigation application levels had a significant effect on the result of seed per spike of wheat at ($p<0.05$) as described in (Appendix Table 3). The maximum and minimum seed per spike value 43.46 and 41.76 were obtained from the application of 100% ETc and 60% ETc respectively. The number of seeds per spike significantly reduced by 4 % when the irrigation water amount was decreased from 100% ETc to 60% ETc (Table 4.8). This might be the result of plants experiencing stress and the soil becoming less moist, which would have an impact on the plant's ability to absorb nutrients, carry out photosynthesis, move food, and generate seeds. According to the study of Maqbool et al.(2015) higher number of grains per spike was counted in the control (full irrigation level) treatment, while the number of grains per spike decreased under induced water stress. This might be due to the dehydration of pollen grains. Moreover, pollen grains germination tube growth down to the ovary and ovule was badly affected and finally, the number of grains per spike was reduced. Khanzada et al. (2001) reported that water stress at vegetative and reproductive stages caused a significant decrease in number of grains per spike in wheat. Comparable results on wheat have been documented by (El Hwary & Yagoub, 2011; Jemal et al., 2019a; Meskelu et al., 2017).

**Thousand seed weight**

The different irrigation levels on wheat have shown a significant ($p<0.05$) influence on thousand seed weights (Appendix Table 4). The highest thousand seed weight 35.0 g was observed at 100% ETc and has no significant differences with irrigation applications of 80% ETc. The minimum thousand seed weight 33.3 g was observed at 60% ETc (Table 4.8). Maqbool et al (2015), Stated higher 100-grain weight was weighted in the control treatment. The discovery of higher 100-grain weight with full irrigations might be due to the more translocation of photosynthates towards grain due to the sufficient amount of water in the root zone. On the other hand, plants having a limited supply of water had produced lighter grain which might be due to the less availability of nutrients from soil solution. Additionally, according to the study of (Kazmi et al. 2003) water stress shriveled the grains and its degree depends on variety and water stress conditions. Different studies reported similar findings(Maqbool et al., 2015; Meskelu et al., 2017).

**Aboveground biomass**

The different irrigation levels on wheat showed also a significant ($p<0.05$) influence on aboveground total biomass (Appendix Table 5). The maximum and minimum above-ground total biomass of 10663.9 kg/ha and 9165.9 kg/ha was scored at 100% ETC and 60% ETC, respectively (Table 4.8). The reduction of irrigation water amount from 100% ETc to 60 ETc% reduced the biomass production by 38.26%. According to Meskelu et al.(2017) the maximum above ground biomass of 12473.4 kg/ha was scored at 100% and the reduction of irrigation water depth reduced the biomass production. When the stress level increases the above ground biomass was decreased. This might be the depth of water which is the main component of photosynthesis for plants to produce their food. Supplying adequate water might lead to an increase in above-ground biomass and grain yield. The study of Makino (2011),reported that more than 90% of plant biomass is derived from photosynthesis products, whose main input is water. The finding of different researchers reported similar results on wheat was in line with the result of this work (Maqbool et al., 2015; Negassa et al., 2013).

Table 4.8.The effect of deficit irrigation level on yield components

| Deficit level | Number of seeds per sike (number) | Thousand seed weight (g) | Aboveground biomass (Kg/ha) |
|---|---|---|---|
| 100% ETc | 43.46$^{a}$ | 35.00$^{a}$ | 10663.9$^{a}$ |
| 80% ETc | 42.70$^{ab}$ | 33.90$^{ab}$ | 9889.4$^{ab}$ |
| 60% ETc | 41.76$^{b}$ | 33.30$^{b}$ | 9165.9$^{b}$ |
| $LSD_{(0.05)}$ | 1.03 | 1.25 | 914.71 |
| CV (%) | 2.44 | 3.68 | 9.23 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance

### 4.6.3 The effect of deficit irrigation on the yield of wheat crop

**Grain yield**

Different irrigation levels on wheat have shown a significant ($p<0.05$) influence on grains yield per hectare production (Appendix Table 6). The highest grain yield 4531.25kg/ha was obtained at a control treatment 100% ETc. The mean maximum grain yield of 3809.6 kg/ha was observed at 100%ETc which is non-significant with 80 %ETc and significantly different from 60%ETc (Table 4.9). This result showed that wheat yield decreased with an increase in levels of water deficit. The highest grain is obtained from full crop water requirement. This could be because there is enough water in the grain for the process of grain filling, which is the transfer of nutrients and carbohydrates to the growing grains. It also contributes to improved photosynthesis, which raises the production of assimilates, including carbohydrates, which are crucial for the development of grain yields. Stage wise deficit irrigation study of Jemal et al.(2019a) on wheat reported that the highest grain yield 29.93 qt/ha was obtained at a treatment of irrigation of all stages (no stress) and the minimum grain yield 9.72 qt/ha was obtained at a treatment of irrigation only at maturity stage. The grain yield of wheat is reduced with increased deficit level, whereas the water productivity increased with deficit irrigation level increased. The reduction of irrigation water from the optimum irrigation level reduced grain yield production per hectare by percent depend on the deficit irrigation level. Different studies conducted on wheat reveal deficit irrigation level affects grain yield production of irrigated wheat (Negassa et al., 2013; Tavakoli & Moghadam, 2012).

Table 4.9.The effect of deficit irrigation level on grain yield of wheat

| Deficit levels | Grain yield (Kg/ha) |
|---|---|
| 100% ETc | $3809.6^{a}$ |
| 80% ETc | $3642.8^{ab}$ |
| 60% ETc | $3284.7^{b}$ |
| $LSD_{(0.05)}$ | 369.1 |
| CV (%) | 10.32 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance

### 4.6.4 The effect of deficit irrigation on water productivity of wheat crop

Deficit irrigation levels show significant difference among treatment at 5% significance level. The Maximum and minimum water productivity of 2.28 kg/m$^3$ and 0.8 kg/m$^3$ were obtained from 60% ETc with FFI and 100% ETc with CFI respectively. The mean maximum water productivity of 1.89 was observed on 60% ETc while the mean minimum was obtained from

100% ETc (Table 4.10).According to this, water productivity was higher in the 60%ETc treatment than in the 100%ETc treatment Application of lower irrigation water depth resulted in a lower yield water productivity of 100% ETc treatments had a significant difference from the other two deficit level treatments. This is because the amount of water applied in the full irrigation treatment was significantly higher than the deficit treatment and reduced the yield of wheat in the deficit treatment. Treatment 60%ETc with the smallest irrigation depth and smaller yield has the greatest IWP values, while the smallest IWP corresponds to full crop water requirement treatment 100%ETc. This finding was consistent with the findings of (Rop et al., 2016), who found that irrigation water usage efficiency values decreased as water application levels increased, rising at 50%ETc and declining at 100%ETc. This outcome also agreed with (Ismail, 2010) finding that deficit irrigation often results in more water being used efficiently. By increasing the area under irrigation, DI may be an effective strategy for increasing water productivity (Asmamaw et al., 2021b). Compared to full irrigation, deficit irrigation increased water productivity and decreased irrigation and production expenses (Hashem et al., 2018). Applying DI can save a large quantity of water and increase water production without significantly affecting yields.

Table 4.10.The effect of deficit irrigation level on water productivity of wheat

| Deficit level | Water productivity (Kg/$m^3$) |
|---|---|
| 100% ETc | 1.28$^c$ |
| 80% ETc | 1.54$^b$ |
| 60% ETc | 1.89$^a$ |
| LSD $_{(0.05)}$ | 0.19 |
| CV (%) | 12.03 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance

### 4.6.5 The effect of deficit irrigation on the harvest index of wheat crop

The different irrigation levels on wheat have shown no significant ($p>0.05$) influence on harvesting index (Appendix Table 8). However, average harvesting index varies from 35.62 to 36.92% this might be as the amount of irrigation amount reduced, both grain yield and aboveground biomass production reduced similarly(Table 4.11). According to Khakwani et al.(2011) finding on the study of different varieties and stress levels, although different varieties show significant variation.

Table 4.11.The effect of deficit irrigation level on harvest index of wheat

| Deficit level | Harvest index (%) |
|---|---|
| 100% ETc | 36.92$^{ns}$ |
| 80% ETc | 35.80 $^{ns}$ |
| 60% ETc | 35.62 $^{ns}$ |
| LSD $_{(0.05)}$ | 2.04 |
| CV (%) | 5.65 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance ns=non-significant at 5% level;

## 4.7 The Effect of Irrigation Method on Yield and Water Productivity of Wheat Crop

### 4.7.1 The effects of the furrow irrigation method on the growth parameters of wheat

**Plant height**

The analysis of variance revealed that plant height was highly significantly ($p<0.05$) influenced due to different types of irrigation water management methods (Appendix Table 1). Maximum plant height of 83.8 cm was observed for the conventional furrow method, whereas the minimum plant height 78.7 cm was observed for the fixed furrow method (Table 4.12). The maximum plant height recorded at conventional furrow method was statistically superior to fixed furrow methods. On the other hand, the shorter plant height was observed at the fixed furrow method and this was statistically significant with both of conventional and alternate furrow irrigation water management method. The finding of Ahmee & Berhanu, (2020) on maize reported that the maximum plant height of 245.43 cm was obtained for conventional furrow method, while the minimum plant height 177.19 cm was gained at fixed furrow method. Stage wise deficit study on maize by Bayisa et al. (2021), reported that the plant height was affected by soil moisture stress. The maximum plant height of 227.93 cm was gained from non- stressed treatment whereas the smallest plant height was obtained from stressing all stages except initial stages. According to the study of Meskelu et al.(2018) maximum plant height was observed for conventional furrow method, whereas the minimum was observed at fixed furrow method. This was consistent with studies by Furgassa, (2017),Kannan & Mulugeta (2015) found higher plant heights are caused by conventional furrow irrigation, followed by alternate and fixed furrow, respectively.

**Spike length**

The analysis of variance revealed that the different types of irrigation water management methods significantly ($p<0.05$) influenced parameter spike length (Appendix Table 2). Longest spike length 6.7 cm was observed at conventional furrow irrigation water application method and the shortest spike length was observed at fixed furrow irrigation method (Table 4.12). The maximum spike length observed at conventional furrow method was statistically superior to fixed furrow methods. The shorter spike length 6.4 cm was observed when irrigation was applied using fixed furrow irrigation method. The minimum value recorded was statistically similar with that of alternate furrow method. According to the finding of Meskelu et al.(2018) the longest cob length 17.1 cm and higher cob diameter 4.7cm were observed at conventional furrow irrigation water application method. Contrary to this, shorter cob length 14.7 cm and lower cob diameter 4.3 cm were observed when irrigation water applied using fixed furrow irrigation method. This might be due to highest soil moisture content in the root zone due to high irrigation water depth in conventional furrow method which leads to favorable growth condition. This leads to improve growth parameters like plant height, cob length and cob diameter. This result in line with finding of (Ahmee & Berhanu, 2020).

Table 4.12.The effect of the furrow irrigation method on the growth parameters of wheat

| Furrow irrigation method | Plant height (cm) | Spike length(cm) |
|---|---|---|
| CFI | $83.83^{a}$ | $6.7^{a}$ |
| AFI | $82.38^{a}$ | $6.5^{ab}$ |
| FFI | $78.76^{b}$ | $6.4^{b}$ |
| $LSD_{(0.05)}$ | 2.54 | 0.23 |
| CV (%) | 3.11 | 3.5 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance

### 4.7.2 The effect of the furrow irrigation method on yield components of wheat crop

**Seed per spike**

The analysis of variance revealed that number of seeds per spike was highly significantly ($p<0.05$) influenced due to different types of furrow irrigation water management methods (Appendix Table 3). The highest number of seeds per spike 44 was obtained at the conventional furrow method and it was statistically similar to that of the alternate furrow method. On the other hand, the minimum number of seeds per spike 40 was obtained at fixed furrow method which was statistically inferior to both conventional and alternate furrow methods (Table 4.13). According to the study of Furgassa (2017) on maize the highest seed weight per cob 134.33 gm was recorded on irrigation level of 85%ETc and the lowest value 118.78 gm was observed in 70%ETc of water applied.

**Thousand seed weight**

The analysis of variance revealed that thousand seed weight was highly significantly ($p<0.05$) influenced due to different types of furrow irrigation water management methods (Appendix Table 4). The highest 35.5g thousand seed weight was obtained at the conventional furrow method and it was statistically superior to fixed furrow method. The minimum 32.2 g thousand seed weight was obtained at fixed furrow conditions which was statistically inferior to both conventional and alternate furrow methods (Table 4.13). The maximum thousand seed weight due to conventional furrow irrigation methods was 11.4 % higher than that observed under the fixed furrow method. This study supports the findings of Nasri et al.(2010), who found that grain yield and thousand seed weight increased in response to an increase in water content. In the same direction, Meskelu et al.(2017) found that when wheat is irrigated, a reduced irrigation depth results in lighter seed weight.

**Aboveground biomass**

The different types of furrow irrigation water management methods on wheat have shown a very highly significant ($p<0.05$) influence on aboveground biomass production (Appendix Table 5). The highest aboveground biomass 10879.8 kg/ha was observed at the conventional furrow method 100% ETc. The maximum aboveground biomass obtained at conventional furrow method was statistically superior to fixed furrow method. The minimum aboveground biomass 8775.4 kg/ha was obtained with the fixed furrow irrigation method (Table 4.13). The minimum aboveground biomass obtained at fixed furrow was statistically inferior to both of the conventional and alternate furrow irrigation method. The highest aboveground biomass of wheat obtained at the conventional furrow irrigation method was increased by 19.34 % from the fixed furrow method. Wheat physiological and photosynthetic processes benefit from the high soil moisture content in the root zone created by the standard furrow method's deep irrigation water depth. According to Makino (2011), 90% of plant biomass comes from the products of photosynthesis, of which water is the primary ingredient. According to Jien et al.(2012), plants under moisture stress have a reduced ability for photosynthesis because of a decrease in chlorophyll concentration and damage to the photosystem's reaction center. Similar study on maize Narayanan & Mulugeta (2015), showing that compared to the alternate and fixed furrow irrigation method, the conventional furrow irrigation method produced the maximum aboveground biomass and grain yield, with irrigation water application meeting 100% of crop water need.

Table 4.13.The effect of furrow irrigation method on yield components of wheat

| Furrow irrigation methods | Number of seeds per spike (number) | Thousand seed weight (g) | Aboveground biomass (Kg/ha) |
|---|---|---|---|
| CFI | 44.00[a] | 35.52[a] | 10879.8[a] |
| AFI | 43.44[a] | 34.44[a] | 10064.0[a] |
| FFI | 40.46[b] | 32.23[b] | 8775.4[b] |
| LSD $_{(0.05)}$ | 1.04 | 1.25 | 914.71 |
| CV (%) | 2.44 | 3.68 | 9.24 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance

### 4.7.3 The effect of the furrow irrigation method on the yield of wheat crop

**Grain yield**

Different types of furrow irrigation water management methods have highly significantly influenced the grain yield of wheat per hectare production at 5% significance level (Appendix Table 6). The result showed that highest yield was scored 3923.6 kg/ha from conventional furrow irrigation water management method and it has a significant difference with fixed furrow irrigation water management methods (Table 4.14). The minimum grain yield 3101 kg/ha was obtained at the fixed furrow irrigation method. The minimum grain yield obtained at the fixed furrow irrigation water management method was statistically inferior to both of the conventional and alternate furrow irrigation method. The yield was least affected by water application in alternate furrow irrigation treatments, while most yield was reduced by water application in fixed furrow irrigation treatments. The grain yield decrease by 21% due to changing the irrigation application of water from a conventional furrow to a fixed furrow method. The result of Gebreigziabher (2020), on maize reported that conventional furrow irrigation with 100% crop evapotranspiration (ETc) gave the highest grain yield 7323.3 kg/ha and dry biomass yield 19.69 t/ha followed by alternate furrow irrigation with 100% crop evapotranspiration ETc to be 6714.8 kg/ha and 14.18 tons/ha respectively. The minimum in grain yield 2647.5 kg/ha and dry biomass yields 9.31t/ha was obtained from fixed furrow irrigation at 50% of crop evapotranspiration (ETc). The result of this study line with earlier studies on maize (Mahamed et al., 2011; Tadese , 2018).

Table 4.14.The effect of furrow irrigation method on grain yield of wheat

| Furrow irrigation methods | Grain yield (Kg/ha) |
|---|---|
| CFI | 3923.6[a] |
| AFI | 3712.3[a] |
| FFI | 3100.7[b] |
| LSD $_{(0.05)}$ | 369.1 |
| CV (%) | 10.32 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance;

### 4.7.4 The effect of the furrow irrigation method on water productivity of wheat crop

The different types of furrow irrigation water management methods on wheat have shown a very highly significant ($p<0.05$) influence on water productivity (Appendix Table 7). Results indicated that the water productivity of wheat was higher under the alternate furrow irrigation method as compared with conventional and fixed furrow methods. Maximum water productivity 2.13kg/m$^3$observed at the alternate furrow method was statistically superior to both conventional and fixed furrow methods. The minimum water productivity 1.11 kg/$m^3$ was observed at the conventional furrow method and this was statistically inferior to both alternate and fixed furrow methods during growing seasons (Table 4.15). Compared to the conventional furrow, the alternative furrow irrigation water application method produced a higher water productivity. Lower water productivity may be the result of evaporation losses that reduce the amount of water available for plant uptake, thus lowering water productivity. Higher irrigation water application amounts are linked to lower water productivity, while lower irrigation water application amounts are linked to higher water productivity. According to the study of Kannan & Mulugeta (2015), the highest and the lowest WUE of 2.06 kg/$m^3$ and 0.911 kg/$m^3$ was obtained by FFI at 50% ETc and CFI respectively. AFI and FFI have indicated better performances in terms of WUE.The finding of this study is comparable with (Ahmee & Berhanu, 2020; Gebreigziabher, 2020).

Table 4.15.The effect of the furrow irrigation method on water productivity of wheat

| Furrow irrigation method | Water productivity (Kg/$m^3$) |
|---|---|
| CFI | $1.11^{b}$ |
| AFI | $2.13^{a}$ |
| FFI | $1.48^{b}$ |
| $LSD_{(0.05)}$ | 0.19 |
| CV (%) | 12.03 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance;

### 4.7.5 The effect of furrow irrigation method on the harvest index of wheat crop

The furrow irrigation methods on wheat have shown no significant ($p>0.05$) influence on harvesting index (Appendix Table 8).The average harvesting index varies from 36.91 to 35.34%. The highest harvest index was gained in alternate furrow irrigation even though there was no significance difference with both of furrow irrigation method (Table 4.16). This might be AFI produce more grains per unit of biomass, resulting in increased productivity. Similar finding by Meskelu et al. (2018), Furgassa (2017) on the study of different furrow irrigation methods on maize show non-significant variation.

Table 4.16.The effect of furrow irrigation method on the harvest index of wheat

| Furrow irrigation method | Harvest index (%) |
|---|---|
| CFI | 36.10$^{ns}$ |
| AFI | 36.91$^{ns}$ |
| FFI | 35.34 $^{ns}$ |
| LSD $_{(0.05)}$ | 3.53 |
| CV (%) | 5.65 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance ns=non-significant at 5% level;

## 4.8 The Interaction Effect on Yield and Water Productivity of Wheat

### 4.8.1 The interaction effect on growth parameters of wheat

The analysis of variance of revealed that there was no significant interaction effect between deficit irrigation and furrow irrigation on growth parameters of wheat. In the study of Gebreigzibher (2020) the interaction effect of furrow irrigation method and deficit irrigation level on plant height of maize was non-significant at ($p<0.05$).

Table 4.17.Interactive effect of deficit and furrow irrigation on growth parameter

| Treatment | Plant height | Spike length |
|---|---|---|
| CFI with 100%ETc | 85.53$^{ns}$ | 6.80 $^{ns}$ |
| CFI with 80%ETc | 84.07 $^{ns}$ | 6.73 $^{ns}$ |
| CFI with 60% ETc | 81.90 $^{ns}$ | 6.47 $^{ns}$ |
| AFI with 100%ETc | 83.50 $^{ns}$ | 6.50 $^{ns}$ |
| AFI with 80%ETc | 82.53 $^{ns}$ | 6.47 $^{ns}$ |
| AFI with 60%ETc | 81.13 $^{ns}$ | 6.57 $^{ns}$ |
| FFI with 100%ETc | 82.20 $^{ns}$ | 6.53 $^{ns}$ |
| FFI with 80%ETc | 78.17 $^{ns}$ | 6.40 $^{ns}$ |

| | | |
|---|---|---|
| FFI with 60%ETc | 75.90 ns | 6.27 ns |
| LSD $_{(0.05)}$ | 4.4 | 0.39 |
| CV (%) | 3.11 | 3.5 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance ns=non-significant at 5% level;

### 4.8.2 The interaction effect on yield and yield components of wheat

The result of analysis revealed that there was no significant interaction effect between deficit irrigation and furrow irrigation on yield and yield components of wheat. The mean maximum grain yield was obtained from 100% ETc combined with CFI is 4374.3kg/ha which is statistically non-significant with 80%ETc.The application of alternate furrow irrigation combined with three irrigation level didn't show significant difference at ($p>0.05$).

Table 4.18.Interactive effect of deficit and furrow irrigation on yield and yield component

| Treatment | NSPS | TSW | AGB | GY |
|---|---|---|---|---|
| CFI with 100%ETc | 44.70 ns | 36.57 ns | 12167.8 ns | 4374.3 ns |
| CFI with 80%ETc | 44.00 ns | 34.90 ns | 11202.6 ns | 4042.4 ns |
| CFI with 60% ETc | 43.30 ns | 35.10 ns | 9268.9 ns | 3354.2 ns |
| AFI with 100%ETc | 44.33 ns | 36.07 ns | 10730.7 ns | 3868.7 ns |
| AFI with 80%ETc | 43.57 ns | 34.13 ns | 9890.1 ns | 3663.9ns |
| AFI with 60%ETc | 42.43 ns | 33.13 ns | 9571.1 ns | 3604.2 ns |
| FFI with 100%ETc | 41.33 ns | 32.37 ns | 9093.2 ns | 3222.2 ns |
| FFI with 80%ETc | 40.53 ns | 32.67 ns | 8657.8 ns | 3184 ns |
| FFI with 60%ETc | 39.53 ns | 31.67 ns | 8575.4 ns | 2895.8 ns |
| LSD $_{(0.05)}$ | 1.8 | 2.17 | 1584.3 | 639.29 |
| CV (%) | 2.44 | 3.68 | 9.23 | 10.32 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance ns=non-significant at 5% level; NSPS is number of seeds per spike, TSW is thousand seed weight, AGB is above ground biomass, and GY is grain yield

### 4.8.3 The interaction effect on water productivity and harvest index of wheat

The result of analysis revealed that there was no significant interaction effect between deficit irrigation and furrow irrigation on water productivity and harvest index of wheat. The maximum water productivity of 2.65 kg/m$^3$ was observed at alternate furrow irrigation with 60% ETc and the minimum water productivity of 0.97 kg/m$^3$ was obtained from the control treatment (CFI with 100%ETc). AFI combined with 100% ETc provide the maximum water productivity which is statistically non-significant with AFI with 80%ETc.

Table 4.19.Interaction effect of DI and furrow irrigation on WP productivity and harvest index

| Treatment | Water productivity | Harvest index |
|---|---|---|
| CFI with 100%ETc | 0.97 $^{ns}$ | 35.96 $^{ns}$ |
| CFI with 80%ETc | 1.12 $^{ns}$ | 36.12 $^{ns}$ |
| CFI with 60% ETc | 1.24 $^{ns}$ | 36.23 $^{ns}$ |
| AFI with 100%ETc | 1.71 $^{ns}$ | 36.04 $^{ns}$ |
| AFI with 80%ETc | 2.03 $^{ns}$ | 37.02 $^{ns}$ |
| AFI with 60%ETc | 2.65 $^{ns}$ | 37.68 $^{ns}$ |
| FFI with 100%ETc | 1.17$^{ns}$ | 34.87 $^{ns}$ |
| FFI with 80%ETc | 1.48 $^{ns}$ | 37.63 $^{ns}$ |
| FFI with 60%ETc | 1.78 $^{ns}$ | 33.52 $^{ns}$ |
| LSD $_{(0.05)}$ | 0.32 | 3.53 |
| CV (%) | 12.03 | 5.65 |

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation. Means in columns followed by the same letters are not significantly different at a 5% level of significance ns=non-significant at 5% level;

## 4.9 Correlation Between Growth, Yield and Yield Components

The correlation analysis of wheat in the (Table4.20) below showed that there was positive correlation between growth parameters (plant height and spike length) and grain yield of wheat and also a strong association between yield components and grain yield. The results indicate that the application of deficit irrigation combined with furrow method treatments affects the important growth parameters and yield components of the wheat crop. The positive and significant correlation observed among the yield components (number of seeds per spike, thousand seed weight, aboveground biomass) and yield of wheat. Plant height has shown positive and strong correlation with thousand seed weight, above ground biomass and grain yield. The strongest and positive correlation observed between above ground biomass and grain yield. Water productivity correlates negatively with growth parameters, yield components and yield of wheat.

Table 4.20.Correlation of growth parameters, yield components, and yield of wheat

| | PH | SL | NSPS | TSW | AGB | GY | WP |
|---|---|---|---|---|---|---|---|
| PH | 1 | | | | | | |
| SL | 0.26 | 1 | | | | | |
| NSPS | 0.42 | 0.54 | 1 | | | | |
| TSW | 0.70 | 0.37 | 0.72 | 1 | | | |
| AGB | 0.65 | 0.40 | 0.56 | 0.65 | 1 | | |
| GY | 0.71 | 0.35 | 0.57 | 0.66 | 0.94 | 1 | |
| WP | -0.21 | -0.28 | -0.22 | -0.28 | -0.16 | -0.04 | 1 |

*PH is plant height, SL is spike length, NSPS is number of seeds per spike, TSW is thousand seed weight, AGB is above ground biomass, GY is grain yield and WP is water productivity

## 4.10 Economic Analysis of Deficit Level and Irrigation Method of Wheat Crop

Economic analysis was done using partial budgeting and benefit-cost ratio under the prevailing market pricing of expenses and returns. According to CIMMYT (1988), the adjusted grain yield was computed from the average grain yield by reducing it by 10%. The total costs considered for the economic study were the cost of the labor required for irrigating the experimental site, assuming that all other expenses incurred were uniform for each treatment. The total return is the cost of returning from the adjusted grain yield output at the market price of wheat during harvesting. During the experimental period the average cost of labor daily was 95.00 ETBirr, while the price of wheat during the harvesting time was 55.00 ETBirr per kg taken for analysis. All costs and returns were computed in Ethiopian Birr per hectare (ETBirr/ha). Therefore, the cost of labor required to cover a 1 ha area for the control treatment (CFI with 100 %ETc) was 112,648.00 ETBirr. The cost of labor required to cover 1 ha for each of the treatments was calculated. In the case of alternate furrow irrigation combined with 60% ETc, 0.8 hours (48minute) was required for one irrigation event, and the cost of labor for a hectare of land was

45059.00 ET Birr (Table4.18). There was no other cost considered in economic analysis rather than labor cost.

Table 4.21.Economic analysis of the deficit levels and irrigation methods

| Treatments | Time of Irrigation (hr) | Time for the whole irrigation season(hr) | Time for whole irrigation per Working Day Day/plots | Time for whole irrigation per Working Day/ha | VC (ET birr) | AY (kg/ha) | TI (ETBirr) | NI (ETbirr) | B/C ratio |
|---|---|---|---|---|---|---|---|---|---|
| T1 | 2 | 24 | 3 | 1186 | 112648 | 3937 | 216528 | 103880 | 0.92 |
| T2 | 1.6 | 19.2 | 2.4 | 949 | 90119 | 3638 | 200097 | 109978 | 1.22 |
| T3 | 1.2 | 14.4 | 1.8 | 711 | 67589 | 3019 | 166031 | 98442 | 1.46 |
| T4 | 1 | 12 | 1.5 | 593 | 56324 | 3482 | 191503 | 135179 | 2.40 |
| T5 | 0.9 | 10.8 | 1.35 | 534 | 50692 | 3298 | 181363 | 130671 | 2.58 |
| T6 | 0.8 | 9.6 | 1.2 | 474 | 45059 | 3244 | 178406 | 133347 | 2.96 |
| T7 | 1.2 | 14.4 | 1.8 | 711 | 67589 | 2866 | 157609 | 90020 | 1.33 |
| T8 | 1.1 | 13.2 | 1.65 | 652 | 61957 | 2900 | 159500 | 97544 | 1.57 |
| T9 | 1 | 12 | 1.5 | 593 | 56324 | 2606 | 143344 | 87020 | 1.54 |

Note: VC is variable cost AY is actual yield TI is total income NI is net income B/C is cost benefit ratio

Where: T1 CFI with 100%ETc

T2 CFI with 80%ETc

T3 CFI with 60% ETc

T4 AFI with 100%ETc

T5 AFI with 80%ETc

T6 AFI with 60%ETc

T7 FFI with 100%ETc

T8FFI with 80%ETc

T9 FFI with 60%ETc

## 4.11 Yield Response Factor

The result reveals that lower yield response factor was associated with lower stressed treatments. The sensitivity of yield increased as deficit level increased. According to FAO (2002), yield response factor of different crops and different stress condition varies from 0.20 for tolerant crops to 1.15 for sensitive crops. The yield response factor Ky, which indicates the level of tolerance of a crop to water stress, approaching unity when yield declines proportionally to ET deficit (the greater Ky the lower the tolerance), was higher fixed furrow compared alternate and conventional furrow. This indicates a yield reduction was due to water shortage in the fixed furrow irrigation methods. In this respect, Ky may be a valuable tool for water deficit tolerance and, thus, for deficit irrigation adaptability evaluation in crop production. Different studies revealed that yield response factor varies for different crop types and stress conditions. However, yield response factors are dependent on locations. The result of the experimental site indicated that the effect of furrow irrigation and deficit irrigation level treatments influence wheat yield. When Ky> 1, the crop response is very sensitive to water deficit with proportional larger yield reductions; Ky< 1, the crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use; Ky = 1, the yield reduction is directly proportional to reduced water use (Doorenbos, 1979). The result among the treatments showed as the deficit level increased the sensitivity of yield reduction.

Table 4.22.Yield response factor of each treatment

| Treatment | Yield (Kg/ha) | Eta (mm) | ETa/ETm | Ya/Ym | 1-Ya/Ym | 1-Eta/ETm | Ky=1-(Ya/Ym) / 1-(ETa/ETm) |
|---|---|---|---|---|---|---|---|
| 100%ETc*CFI | 4374.31 | 452.52 | 1 | 1 | 0 | 0 | |
| 80%ETc*CFI | 4042.36 | 362.01 | 0.80 | 0.92 | 0.08 | 0.20 | 0.38 |
| 60%ETc*CFI | 3354.17 | 271.51 | 0.60 | 0.77 | 0.23 | 0.77 | 0.30 |
| 100%ETc*AFI | 3868.75 | 226.26 | 0.50 | 0.88 | 0.12 | 0.88 | 0.13 |
| 80%ETc*AFI | 3663.89 | 181.01 | 0.40 | 0.84 | 0.16 | 0.84 | 0.19 |
| 60%ETc*AFI | 3604.17 | 135.76 | 0.30 | 0.82 | 0.18 | 0.82 | 0.21 |
| 100%ETc*FFI | 3184.03 | 271.51 | 0.60 | 0.73 | 0.27 | 0.73 | 0.37 |
| 80%ETc*FFI | 3222.22 | 217.21 | 0.48 | 0.74 | 0.26 | 0.74 | 0.36 |
| 60%ETc*FFI | 2895.83 | 162.91 | 0.36 | 0.66 | 0.34 | 0.66 | 0.51 |

## 4.12 Irrigation Water Saved and the Additional Area Gained

The amount of water saved under each irrigation method compared with the control treatment (conventional furrow irrigation with 100 % ETc) as described in (Table 4.20) showed that all deficit application levels saved different amount of irrigation water and irrigated additional farm land. The conventional furrow irrigation combined with 80%ETc saved 1509 $m^3$/ha water and with amount 0.25 ha of land can be irrigated. Additional yield gained from this treatment was 1010.67kg/ha. Considering the yield loss due to the deficit level 678.67 kg net yield can be obtained. Conventional furrow irrigation combined with 60% ETc saved 3017 $m^3$/ha of water applied compared with the control treatment. This amount of water can be used to irrigate 0.67 ha. The additional yield and net yield gained from this treatment was 2236.15kg/ha and 1216.01 kg. Similarly, fixed furrow irrigation methods combined with 60 % ETc saved 4827 $m^3$/ha of water applied under control treatment which can be used to irrigate 1.78 ha of additional land for wheat production. Alternate furrow and fixed furrow irrigation received different amounts of irrigation water, in the case of the furrow number used for the experiment. The number of furrows was five so the alternate furrow irrigation received 50% of the water applied in the conventional one whereas fixed furrow irrigation received 60% of the water depth of the conventional furrow irrigation. Alternate furrow irrigation combined with 40% deficit level saved 5280 $m^3$/ha of water applied compared with the conventional furrow irrigation method combined with full irrigation level which can be used to irrigate 2.33 ha of additional land. Moreover, applying an alternate furrow irrigation method combined with 20% deficit level increased water productivity and saved 4525.2 $m^3$/ha (60%) of water saved compared with the control one. This amount of water was sufficient to irrigate 1.5 hectares of wheat-cropped area using alternate furrow irrigation techniques that can earn better economic returns as compared to every furrow irrigation method.

Table 4.23.Irrigation water saved and the additional area gained

| Furrow irrigation methods | DI Levels | Water applied (m3/ha) | Grain yield (Kg/ha) | Yield Loss (Kg/ha) | Water saved (m3/ha) | Additional area gained (ha) | Additional yield gained (kg) | Net yield gain(kg) |
|---|---|---|---|---|---|---|---|---|
| CFI | 100%ETc | 7542 | 4374 | 0 | 0 | 0 | 0 | 0 |
| | 80%ETc | 6034 | 4042 | 332 | 1509 | 0.25 | 1010.67 | 678.67 |
| | 60%ETc | 4525 | 3354 | 1020 | 3017 | 0.67 | 2236.15 | 1216.01 |
| AFI | 100%ETc | 3771 | 3869 | 506 | 3771 | 1.00 | 3868.75 | 3363.19 |
| | 80%ETc | 3017 | 3664 | 710 | 4525 | 1.50 | 5495.74 | 4785.57 |
| | 60%ETc | 2263 | 3604 | 770 | 5279 | 2.33 | 8409.36 | 7639.19 |
| FFI | 100%ETc | 4525 | 3184 | 1190 | 3017 | 0.67 | 2122.72 | 932.44 |
| | 80%ETc | 3620 | 3222 | 1152 | 3922 | 1.08 | 3490.72 | 2338.63 |
| | 60%ETc | 2715 | 2896 | 1478 | 4827 | 1.78 | 5147.99 | 3669.51 |

Additional area gained= Water saved /Water applied

Additional yield gained= Additional area gained*Grain yield

Net yield gain= Additional yield gained-Yield loss

The grain yields of wheat obtained by the the application of three furrow irrigation methods is presented in Figure4.2 below

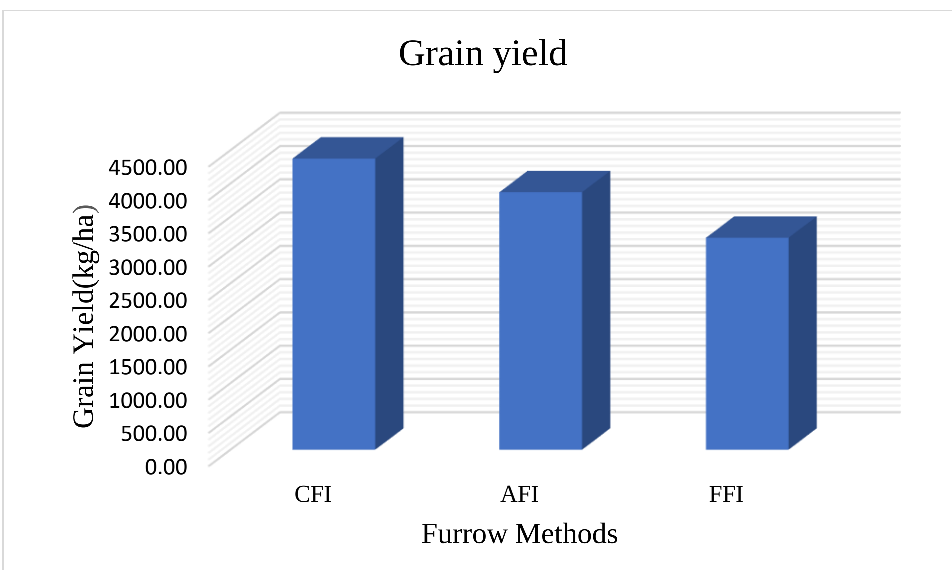



Figure 4.1. Grain yield of wheat under three furrow irrigation methods

The quantity of water saved for each treatment by applying a double deficit was displayed in (Figure 4.2). The maximum amount of water was applied during conventional furrow irrigation; combined with 100% ETc treatment one which, no water was saved during this treatment. The maximum quantity of water can be saved by treatment number six, which combines 40% deficit level with alternate furrow irrigation

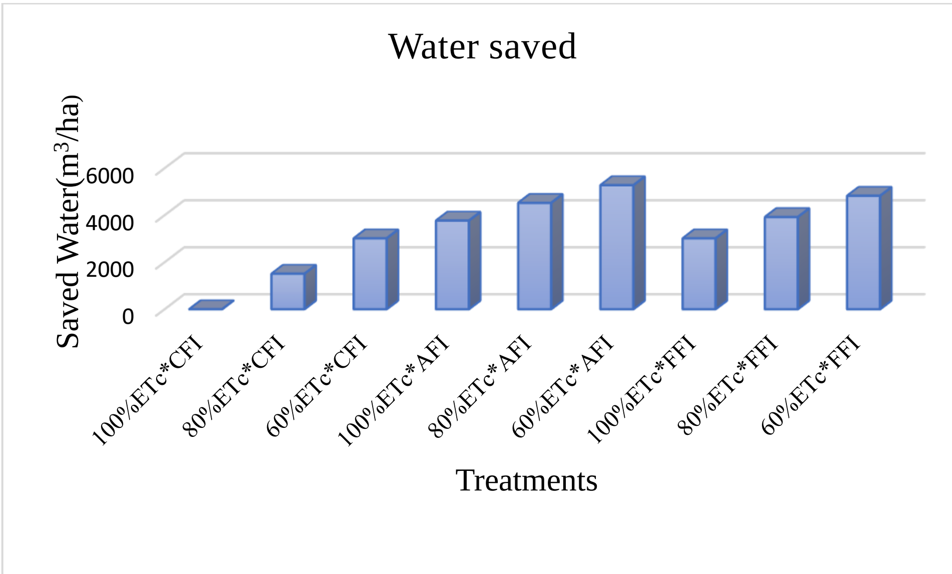



Figure 4.2. Amount of water saved from each treatment

The relationship of gross water applied with their respective water productivity of each treatment is presented in the figure 4.4 below

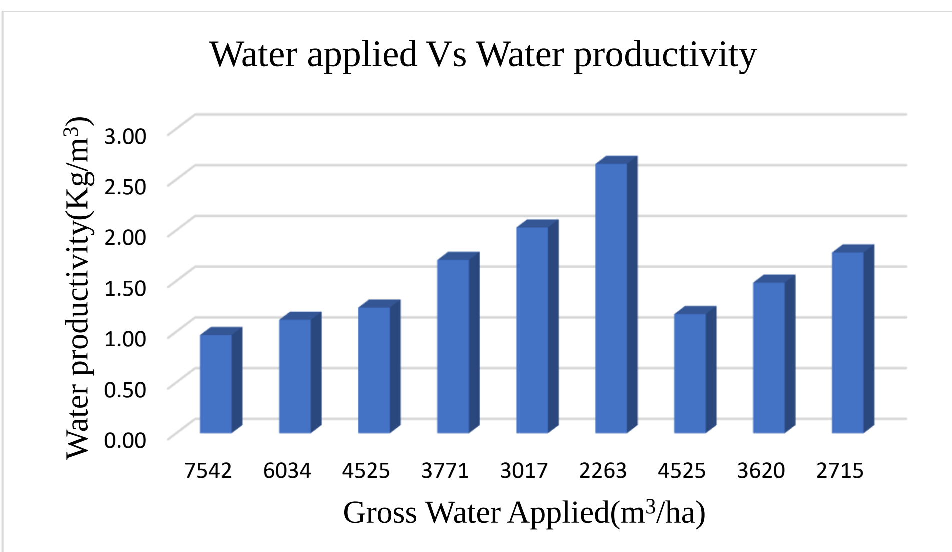



Figure 4.3. Relationship of gross Water applied and water productivity

# 5 CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Water is necessary for the development of the entire world. But as demand grows, it's turning into a scarce resource. The most efficient distribution, higher crop and water productivity (WP), and better irrigation water management are required to meet future water scarcity. In regions with limited water resources, enhancing agricultural water usage efficiency through furrow irrigation and deficit irrigation is essential. This study attempted to assess the effects of furrow irrigation technique and deficit irrigation level on wheat production and water productivity. The different irrigation level had a significant effect on yield, yield component of wheat crop at ($p<0.05$). The different types of furrow irrigation water management methods had very highly significant ($p<0.05$) influence on plant height, yield component and yield of wheat crop production. On the other hand, interaction effect of deficit irrigation levels and furrow irrigation methods didn't show significant variation in wheat growth parameter yield components and grain yield production. Water productivity has shown highly significant difference ($p<0.05$) on different irrigation levels and irrigation methods of wheat crop. The study results confirmed that alternate irrigation strategy preferable to increase water productivity and save significant depth of water for irrigation without significant yield reduction. On the other hand, 20% deficit irrigation level is the best one in water saving and gaining comparable yield with full irrigation level. From this result, it can be concluded that applying alternate furrow irrigation method and 80% ETc can improve water efficiency by saving 60% of water applied under conventional irrigation methods which is sufficient to irrigate 1.5-hectare additional wheat cropped land.

## 5.2 Recommendations

Based on the result of the study the following recommendations are suggested.

- Water is a scarce resource in high land area of western Shewa zone of Ethiopia. It is recommended to apply deficit irrigation of 80% ETc to save significant amount of water of which has no significant yield reduction compared to full irrigation application.
- For improved production and water consumption efficiency in our research area, considering grain yield, water productivity, water saved and economic benefit alternative furrow irrigation (AFI) and 80 % ETc irrigation level is recommended.
- Using water-saving techniques during a period of water scarcity (double deficit irrigation) benefits smallholder farmers economically because it reduces production costs for labor used for irrigation water application, and the water saved may increase farm income that can be used to irrigate new areas.
- A comparable additional study conducted at a different location and season should be relevant to derive the strongest conclusion and best recommendations.

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# APPENDICES

Appendix Table 1.Analysis of variance for plant height

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 27.53 | 13.76 | | |
| Deficit | 2 | 75.71 | 37.86 | 5.85 | 0.0124 |
| Furrow | 2 | 123.21 | 61.60 | 9.53 | 0.0019 |
| Deficit*Furrow | 4 | 13.92 | 3.48 | 0.54 | 0.7098 |
| Error | 16 | 103.48 | 6.46 | | |
| Total | 26 | 343.86 | | | |

Appendix Table 2.Analysis of variance for spike length

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 0.06 | 0.03 | | |
| Deficit | 2 | 0.12 | 0.06 | 1.21 | 0.3242 |
| Furrow | 2 | 0.32 | 0.16 | 3.12 | 0.0418 |
| Deficit*Furrow | 4 | 0.18 | 0.04 | 0.89 | 0.4916 |
| Error | 16 | 0.84 | 0.05 | | |
| Total | 26 | 1.54 | | | |

Appendix Table 3.Analysis of variance for the number of seed per spike

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 7.38 | 3.68 | | |
| Deficit | 2 | 13.06 | 6.52 | 6.03 | 0.0112 |
| Furrow | 2 | 64.98 | 32.49 | 30.01 | <.0001 |
| Deficit*Furrow | 4 | 0.24 | 0.06 | 0.06 | 0.9935 |
| Error | 16 | 17.32 | 1.08 | | |
| Total | 26 | 102.98 | | | |

Appendix Table 4.Analysis of variance for thousand seed weight

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 0.69 | 0.34 | | |
| Deficit | 2 | 13.38 | 6.69 | 4.24 | 0.0333 |
| Furrow | 2 | 50.60 | 25.30 | 16.03 | 0.0002 |
| Deficit*Furrow | 4 | 6.511 | 1.62 | 1.03 | 0.4213 |
| Error | 16 | 25.25 | 1.58 | | |
| Total | 26 | 96.44 | | | |

Appendix Table 5.Analysis of variance for above-ground biomass

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 98900.86 | 49450.43 | | |
| Deficit | 2 | 10101496.82 | 5050748.41 | 6.03 | 0.0112 |
| Furrow | 2 | 20262307.06 | 10131153.53 | 12.09 | 0.0006 |
| Deficit*Furrow | 4 | 5590176.50 | 1397544.12 | 1.67 | 0.2063 |
| Error | 16 | 13405080.43 | 837817.53 | | |
| Total | 26 | 49457961.67 | | | |

Appendix Table 6.Analysis of variance for grain yield

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 90590.24 | 45295.12 | | |
| Deficit | 2 | 1292266.59 | 646133.29 | 4.74 | 0.0242 |
| Furrow | 2 | 3287639.36 | 1643819.68 | 12.05 | 0.0006 |
| Deficit*Furrow | 4 | 638798.20 | 159699.55 | 1.17 | 0.3606 |
| Error | 16 | 2182645.40 | 136415.338 | | |
| Total | 26 | 7491939.79 | | | |

Appendix Table 7.Analysis of variance for water productivity

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 0.02 | 0.01 | | |
| Deficit | 2 | 1.14 | 0.56 | 24.93 | <.0001 |
| Furrow | 2 | 1.18 | 0.58 | 25.85 | <.0001 |
| Deficit*Furrow | 4 | 0.16 | 0.04 | 1.83 | 0.1731 |
| Error | 16 | 0.36 | 0.02 | | |
| Total | 26 | 2.87 | | | |

Appendix Table 8.Analysis of variance for harvest index

| Sources | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep. | 2 | 5.38 | 2.68 | | |
| Deficit | 2 | 8.88 | 4.44 | 1.07 | 0.3678 |
| Furrow | 2 | 11.16 | 5.58 | 1.34 | 0.2904 |
| Deficit*Furrow | 4 | 21.67 | 5.42 | 1.30 | 0.3123 |
| Error | 16 | 66.75 | 4.17 | | |
| Total | 26 | 113.85 | | | |

Appendix Figure 1.Furrow and ridge preparation

Appendix Figure 2.Pre-irrigation

Appendix Figure 3.Sowing time

Appendix Figure 4.Initial growth stage

Appendix Figure 5.Developmental stage

Appendix Figure 6.Mid stage of wheat crop

Appendix Figure 7.Harvesting at late stage

Appendix Figure 8.Threshing and Sorting of grain from straw

Appendix Figure 9.Data recording