

**RESPONSE OF ONION (*Allium cepa* L.) TO DEFICIT IRRIGATION
UNDER DIFFERENT FURROW IRRIGATION METHODS**

Getachew Wandifra Boru



**A Thesis Submitted to the Department of Water Resources Engineering,
School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment 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

**Adama
October, 2020**

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Advisor

Andinet Kebede (PhD)

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We, the undersigned, members of the Board of Examiners of the final open defense by Mr. **Getachew Wandifra Boru** have read and evaluated his thesis entitled “**RESPONSE OF ONION (*allium cepa l.*) TO DEFICIT IRRIGATION UNDER DIFFERENT FURROW IRRIGATION METHODS**” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master’s in Water Resources Engineering (Specialization in Irrigation Engineering)

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I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis/ dissertation have been duly acknowledged.

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To: Water Resources Engineering Department

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This is to certify that the thesis entitled “**Response of Onion (*Allium Cepa L.*) to Deficit Irrigation under Different Furrow Irrigation Methods**” submitted in partial fulfillment of the requirements for the degree of Master’s in Irrigation Engineering, the Graduate program of the department of Water Resources Engineering, and has been carried out by Getachew Wandifra. Id. No PGR/18038/11, under my supervision.

Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Name of major Advisor

Signature

Date

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TABLE OF CONTENTS

	PAGE
APPROVAL OF BOARD OF EXAMINERS.....	i
DECLARATION.....	ii
ADVISOR'S APPROVAL SHEET	iii
ACKNOWLEDGMENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF APPENDIX TABLES.....	x
LIST OF APPENDIX FIGURES.....	xi
LIST OF ABBREVIATIONS AND ACRONYMS.....	xii
ABSTRACT	xiv
1. INTRODUCTION.....	1
1.1. Background	1
1.2. Statement of the Problem	3
1.3. Objectives of the Study	4
1.3.1. General objective.....	4
1.3.2. Specific objectives.....	4
1.4. Research Questions	4
1.5. Significance of the Study	4
1.6. Delimitations	5
2. LITERATURE REVIEW.....	6
2.1 Water Resources Potential and Its Scarcity.....	6
2.2. Irrigation Water and Its Advantages	8
2.3. Irrigation Water Management in Ethiopia.....	9
2.4. Surface Irrigation Systems	10
2.5. Advantage of Furrow Irrigation over Other Surface Irrigation Methods	11
2.6. Concept of Alternate, Fixed and Conventional Furrow Irrigation Methods	11
2.6.1. Alternate furrow irrigation	11
2.6.2. Fixed furrow irrigation.....	12
2.6.3. Conventional furrow irrigation.....	13
2.7. Deficit Irrigation and Its Advantages	13
2.8. Irrigation Scheduling.....	14
2.9. Water Productivity	15
2.10. Crop Water Requirement	15
2.11. Onion Response to Deficit Irrigation	16

2.12. Agronomy and Productivity of Onion Crop under Irrigation.....	17
3. MATERIALS AND METHODS.....	19
3.1. Description of the Study Area.....	19
3.2. Materials Used	20
3.3. Treatments and Experimental Design	21
3.4. Soil Sampling and Analysis	23
3.4.1. Soil physical properties	23
3.4.2. Soil chemical properties	24
3.5. Experimental Procedures for Crop Management Practices.....	25
3.6. Crop Water Requirements.....	25
3.7. Irrigation Scheduling and Management	26
3.8. Gross Irrigation Water Requirement and Discharge Measurement	27
3.9. Data Collection.....	28
Agronomic data	28
3.10. Water Productivity	29
3.10.1. Crop water use efficiency.....	29
3.10.2 Irrigation water use efficiency.....	30
3.11. Statistical Data Analysis.....	30
4. RESULTS AND DISCUSSIONS	30
4.1. Physical, Chemical and Infiltration Characteristics of the Soil.....	30
4.1.1. Soil physical properties	30
4.1.2. Soil chemical properties	31
4.1.3. Infiltration characteristics of the soil.....	32
4.2 Crop Water Requirement and Irrigation Water Management	33
4.3. Response of Onion Growth, Yield and Yield Parameters to Deficit Irrigation and Furrow Irrigation Methods.....	34
4.3.1 Onion growth parameters	35
4.3.2 Yield and yield component parameters of onion.....	41
4.4 Water Productivity	51
4.4.1 Crop Water Use Efficiency	51
4.4.2. Irrigation Water Use Efficiency	53
4.5. Yield and Applied Water Relationship	54
4.6. Relative Water Saved and Yield Reduction as Influenced by Deficit Irrigation.....	56
4.7. Present Simple Correlation Coefficient of Growth and Yield Parameters.....	57
5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	60
5.1 Summary and Conclusions.....	60

5.2. Recommendations	61
REFERENCES	61
APPENDICES	76

LIST OF TABLES

TABLE	PAGE
Table 1: Materials used for the experimental work.....	20
Table 2: Treatment arrangements of irrigation levels and furrow irrigation methods	22
Table 3: Randomization of treatments at each plot within the replications.....	23
Table 4: Physical properties of the soil at the experimental site	30
Table 5: Chemical properties of the soil at the experimental site	32
Table 6: Crop water requirement (mm/period) of onion at experimental site for full irrigation level (100% ETC).....	34
Table 7: Effect of irrigation level and furrow irrigation method on plant height of onion at each stage	37
Table 8: Effect of irrigation level and furrow irrigation method on number of leaves per plant at each growth stage.....	40
Table 9: Effect of furrow irrigation methods and irrigation levels on bulb diameter and bulb height of onion.....	43
Table 10: Effects of interaction of irrigation levels and furrow irrigation methods on bulb weight of onion.....	44
Table 11: Effects of interaction of irrigation levels and furrow irrigation methods on dry weight of bulb of onion.....	46
Table 12: Effects of interaction of irrigation levels and furrow irrigation methods on marketable bulb yield of onion.....	47
Table 13: Effect of irrigation levels and furrow irrigation methods on yield component parameters of onion	48
Table 14: Effects of interaction of irrigation levels and furrow irrigation methods on total bulb yield of onion.....	51
Table 15: Effects of interaction of irrigation levels and furrow irrigation methods on crop water use efficiency of onion	52
Table 16: Effects of interaction of irrigation levels and furrow irrigation methods on irrigation water use efficiency of onion	53
Table 17: Irrigation water saved and corresponding yield reduction as influenced by deficit irrigation.....	56
Table 18: Pearson's correlation coefficient (r) of growth and yield parameters of onions ..	59

LIST OF FIGURES

FIGURE	PAGE
Figure 1: Location map of the study area.....	20
Figure 2: Layout of the experimental field.....	22
Figure 3: Soil infiltration rate and cumulative infiltration curves of experimental site	33
Figure 4: The relationships between (A) total applied water and total bulb yield of onion and (B) irrigation water use efficiency and total bulb yield of onion	55

LIST OF APPENDIX TABLES

APPENDIX TABLE	PAGE
Appendix Table 1: Infiltration rate measurement of the experimental soil data using double ring infiltrometer.....	76
Appendix Table 2: Climatic condition and reference evapotranspiration rate of the study area for long term (2008-2019).....	77
Appendix Table 3: Climatic condition and reference evapotranspiration rate of the study area during study period.....	77
Appendix Table 4: Net and gross irrigation water requirement of onion at experimental site for all irrigation levels.....	78
Appendix Table 5: Mean squares analysis of variance (ANOVA) for plant height at initial, development, mid-season and late-season stages of onion	79
Appendix Table 6: Mean squares analysis of variance (ANOVA) for leaf number per plant at initial, development, mid-season and late-season stages of onion	79
Appendix Table 7: Mean squares analysis of variance (ANOVA) for bulb diameter and bulb height of onion.....	80
Appendix Table 8: Mean squares analysis of variance (ANOVA) for bulb weight and dry weight of bulb of onion.....	80
Appendix Table 9: Mean squares analysis of variance (ANOVA) for marketable bulb yield, unmarketable bulb yield and total bulb yield of onion	81
Appendix Table 10: Mean squares analysis of variance (ANOVA) for crop water use efficiency and irrigation water use efficiency	81

LIST OF APPENDIX FIGURES

APPENDIX FIGURE	PAGE
Appendix Figure 1: Infiltration rate measurement of the experimental site soil.....	82
Appendix Figure 2: During land preparation and layout of the experimental site.....	82
Appendix Figure 3: During field management of the experimental site.....	83
Appendix Figure 4: During data collection and recording of growth and yield parameters.....	84

LIST OF ABBREVIATIONS AND ACRONYMS

ABA	Absciscic Acid
AFI	Alternate Furrow Irrigation system
ANOVA	Analysis of Variance
ATVET	Agricultural Technical and Vocational Education Training
CFI	Conventional Furrow Irrigation
CWUE	Crop Water Use Efficiency
DAP	Di-ammonium phosphate
dS/m	deci Siemens per Metre
EARO	Ethiopian Agriculture Research Organization
ECe	Electrical Conductivity of Saturated extract
ECw	Electrical Conductivity of water
Ea	Application Efficiency
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization Statistical
FC	Field Capacity
FFI	Fixed Furrow Irrigation
GTP	Growth and Transformation Plan
ICID	International Commission on Irrigation and Drainage
IRg	Gross Irrigation Requirement
IRn	Net Irrigation Requirement
IWUE	Irrigation Water Use Efficiency
LSD	Least Significance Difference
Kc	Crop Coefficient
MARC	Melkassa Agricultural Research Centre
MoA	Minister of Agriculture
MoWIE	Ministry of Water, Irrigation and Electricity
OC	Organic Carbon

OM	Organic Matter
Pe	Effective Rainfall
pH	Power of Hydrogen
PWP	Permanent Wilting Point
RAW	Readily Available Water
SAS	Statistical Analysis System
TAW	Total Available Water
WP	Water Productivity
WUE	Water Use Efficiency
USDA	United State Department of Agriculture

ABSTRACT

Scarcity of water is a major constraint for development of agriculture in arid and semi-arid areas. Deficit irrigation and use of appropriate irrigation systems are considered as means to improve water use efficiency without significant yield loss. A field experiment was conducted with the objective of identifying the levels of deficit irrigation and different furrow irrigation methods that provide optimum onion yield and per unit of water under limited water condition at Alage Agricultural Technical and Vocational Education Training College. The experimental plots were designed as split plot in randomized arrangement with three replications having 12 treatments. The treatments included are three furrow irrigation methods as a sub-plot; namely, alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and convectional furrow irrigation (CFI) methods and four irrigation levels as a main plot of 90, 75 and 50% of the water requirement (ETc) and a control irrigation of 100% ETc depth. Crop water requirement was determined by using CRPWAT 8.0 and a discharge was measured by using Parshall flume. The collected data's were analyzed by analysis of variance (ANOVA) using 'gen stat' statistical software. Furrow irrigation methods and deficit irrigation levels were significantly ($P < 0.05$) affected onion growth, yield parameters and water productivity. The interaction of deficit irrigation level and furrow irrigation method also significantly ($P < 0.01$) affected the bulb weight, dry weight of bulb, marketable bulb yield, total bulb yield, crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE). The maximum and minimum total bulb yield of 33098 and 27275 kg ha⁻¹ were obtained from 100 and 50% ETc. The total bulb yield of onion was maximum at 34812 kg ha⁻¹ from the treatment irrigated with CFI method with 100% ETc depth, followed by the treatment irrigated with AFI method with 100% ETc depth that resulted in comparable total bulb yield of 33784 kg ha⁻¹. The minimum total bulb yield of 25922 kg ha⁻¹ was attained from the treatment irrigated with 50% ETc depth with FFI method. The highest IWUE of 15.34 kg m⁻³ was obtained from treatment receiving 50% ETc irrigation level with AFI method. The least IWUE of 4.82 kg m⁻³ was attained from the treatment irrigated with 100% ETc depth with CFI method. The result of AFI method with 100% ETc irrigation level showed only 2.95% yield reduction and 50% efficiency in terms of IWUE when compared to CFI method with 100% ETc irrigation level. However, greater yield reduction was encountered for FFI method, compared to the CFI and AFI methods. In the study areas water is a limiting factor, as a result, AFI method with 90% ETc irrigation level was found to be better for such water scarce area. Therefore, it can be recommended that farmers and commercial growers produce Bombay Red onion by applying combination of 90% ETc irrigation level with alternate furrow irrigation method.

Key Words: Alternate furrow irrigation, Conventional furrow irrigation, Deficit irrigation, Fixed furrow irrigation, Onion (*Allium cepa* L)

1. INTRODUCTION

1.1. Background

The ever-increasing world population and the demand for additional water supply by industrial, municipal, and agricultural sectors exert a lot of pressure on renewable water resources (Valipour, 2014). With such rapid economic and population growth, many water sources have become depleted. Therefore, water has become one of the scarce goods (Ahmad *et al.*, 2010). Roughly 70% of the world freshwater withdrawals are for agricultural use (FAO, 2010). The increasing need for crop production due to the growing population in the world is requiring a rapid expansion of irrigated agriculture throughout the world. Irrigated agriculture accounts for 20% of the total cultivated land but contributes 40% of the total food produced worldwide (FAO, 2011). However, the water resources used for irrigation have been declining to meet the demands of the ever-increasing population posing a challenge to seek for efficient management solutions. This increasing global demand for food and other agricultural products calls for urgent measures to increase water use efficiency.

In the arid and semi-arid areas of Ethiopia, water is the most limiting factor for crop production. In these areas, where the amount and distribution of rainfall is not sufficient to sustain crop growth and development, an alternative approach is to make use of the rivers and underground water for irrigation.

To overcome the shortage in water required for crop production and minimize the impact of drought on crop performances, supplemental water from these sources are provided in the form of irrigation. Irrigation enhances crop production and household income which in turn improves the livelihood of the rural people, as water and food security are closely related (FAO, 2003). Hence, irrigated agriculture is the core issue of the food security strategy of the Ethiopian Government, that is, expansion of small scale irrigation and less dependent on rain-fed agriculture is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of the country (GTP, 2010).

But, the question is which type of irrigation technology should be employed, from the broad categories of irrigation such as surface (flood, basin, border, and furrows), and pressurized (sprinkler, and drip) methods based on application of water in the field. Among the above methods, sprinkler and drip irrigation methods are known to be efficient in maximizing water

utilization, but their initial investment cost is often expensive and not affordable by the majority of smallholders' farmers.

Under such circumstances, less precise and yet least capital-intensive irrigation systems have to be considered. In this regard, furrow irrigation method is the most widely used in Ethiopia in almost all-large and small irrigation schemes (FAO, 2002). It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface methods of irrigation, especially by furrow system in farmer's fields and majority of the commercial farms. Furrow irrigation usually causes excessive deep percolation at the upper part of the furrow, insufficient irrigation at the lower part and considerable runoff, resulting in low application efficiencies and distribution uniformities. Therefore, proper furrow irrigation practices can minimize water application and irrigation costs, save water, control soil salinity build up and result in higher crop yields (Booher, 1974). Furrows are particularly suitable for irrigating row crops such as vegetables, cotton, sugar beet, maize, tomatoes and potatoes planted on raised beds, which are subject to injury if water covers the crown or stems of the plants (Michael, 2008).

However, as irrigated land under vegetables and other irrigated crops by commercial private farms are increasing in the country, the pressure on the available water is increasing, leading to shortage of water during the most important stages and hampering yield of crops. Many strategies are available to improve water productivity, including proper selection of irrigation system and proper use of irrigation scheduling (timing and quantity of water applied) and the choice of the best crop management with regards to the soil and climate conditions (Mancosu *et al.*, 2015). Hence, efficient application methods should be used to allocate available water during the most important stages without affecting the production and at the same time saving the most precious resource for extra production.

Deficit irrigation has widely been reported as a valuable strategy for arid and semi-arid regions to optimize crop yields and productivity where water is the limiting factor to crop production (Geerts and Raes, 2009; David *et al.*, 2016). Different furrow irrigation application systems are developed that are believed to improve water application efficiency, distribution uniformity and storage efficiency. These are conventional, fixed and alternate furrow irrigation methods.

In central Rift valley, increasing population pressure and economic developments put an increasing claim on the precious fresh water resources (Hengsdijk and Jansen, 2006). Onion

(*Allium Cepa L.*) is one of the most irrigated vegetables crops in the study area. It is important horticulture and commercial crop categorized under root crops (Olani and Fikre, 2010). Of the vegetable crops, onion ranks second after tomatoes in terms of total annual world production (FAO, 2005). There is scarcity of water at the study area (Alage) and the farmers use traditional irrigation methods such as wild flooding, furrow and basin, application methods which at times lead farmers to under-irrigate. This results in high water losses and low irrigation efficiency. Under such conditions understanding the response of deficit irrigation on onion crop production would be useful to enhance crop productivity through improved water use.

Therefore, this study was taken up intended to evaluate the different furrow irrigation methods with different deficit irrigation levels on onion production.

1.2. Statement of the Problem

The competing uses for water, domestic, industrial, and environmental, and the increasing demand for food due to a rapidly growing world population require an urgent improvement of productivity per unit of water consumed in agriculture (FAO, 2002). About 90% of the irrigated land of the world is cultivated using relatively inefficient surface irrigation methods (Tiercelin and Vidal, 2006)

In Ethiopia as in different parts of the country traditional surface irrigation methods (basin, border and furrow) are widely used to irrigate crops. Onion is being grown extensively in different parts of the country. In Alage district onion is one of the major irrigable vegetable crops its high domestic and export markets and high yield per unit area. Bombay Red cultivar is most preferred by the growers due to its early maturing character and requirement of less production cost and time than the rest of cultivars (Nega *et al.*, 2015).

But as the crop is very sensitive to moisture stress, water shortage in the area is hampering the productivity and reducing yields. Most of the farmers in the study area use furrow irrigation and water resources are limited to benefit from irrigation practice. Hence, there is a need to achieve optimal crop production and productivity from limited water resources thereby adopting the use of techniques and practices that save irrigation water and minimize unwanted waste.

Seeking for efficient irrigation methods that are economical, easy to install and operate, and which are readily acceptable to the farming community is necessary. In this study, Deficit irrigation under different furrow irrigation methods were used to improve irrigation water

productivity and optimize crop yields, where water is the limiting factor to crop production. Because furrow irrigation is a well-known, simple and economical method of irrigation, farmers are likely to be ready to adopt new approaches that are practical improvements of their current practices and that result in improved water use efficiency (WUE).

1.3. Objectives of the Study

1.3.1. General objective

The general objective of the study was to investigate the response of onion to deficit irrigation and furrow irrigation methods.

1.3.2. Specific objectives

- i. To determine the effects of different furrow irrigation methods on yield and yield component and water productivity of onion.
- ii. To determine the level of deficit irrigation that allows achieving optimum onion yield and yield component.
- iii. To evaluate the interaction effects of different furrow irrigation methods and deficit irrigation levels on yield and yield component and water productivity of onion.

1.4. Research Questions

The study addressed the following research questions:

- a. Which furrow irrigation method gives optimum yield and yield component and water productivity of onion?
- b. What level of deficit irrigation allows to achieve optimum onion yield and yield component?
- c. Which interaction effect of furrow irrigation method and deficit irrigation level gives highest yield and yield component and water productivity of onion?

1.5. Significance of the Study

At present water is a scarce resource due to its use for different purposes. This study is, therefore, vital because it will provide baseline information on saving water lost due to poor water application method and thus will create opportunity for optimized use of a limited supply of irrigation water. This in turn will increase the number of farmers irrigating their command area without causing a substantial drop in the yield of onion crop. It is also

essential to transfer this knowledge to the farmers to develop optimal deficit irrigation strategies to minimize unproductive water loss and improve crop productivity.

1.6. Delimitations

The study considered to identify the efficient furrow irrigation methods, among alternate, conventional and fixed furrow, by applying different deficit water level on onion crop at Alage Agricultural Technical and Vocational Education Training (ATVET) College demonstration site. This study has focused on evaluation of growth and yield parameters, water productivity, relative water saved and yield reduction, yield and applied water relationship and growth and yield parameters relationship.

Due to shortage of time the study considered only one onion variety and one season for alternate, fixed and conventional furrow irrigation methods.

2. LITERATURE REVIEW

2.1 Water Resources Potential and Its Scarcity

Water covers about two-thirds of the Earth's surface, but it is a scarce resource as most of it is unavailable and too salty for use. Only 2.5% of the world's water is not salty, and two-thirds of that is locked up in the icecaps and glaciers. About 20% of the fresh water is not accessible, and much of it arrives at the wrong time and place, as monsoons and floods. Currently, less than 0.08% of all the Earth's water is available for human use. Nevertheless, of this small proportion of available water more than two-third is used for agriculture (FAO, 2000).

Ethiopia constitutes 99.3 % of land area and the remaining 0.7 % is covered with water bodies (Melesse *et al.*, 2014). Ethiopia has 12 river basins that provide an estimated annual run-off of 125 billion m³, with the Abay basins accounting for 45 percent of this amount. While much of this run-off could be used for irrigation or other purposes, Ethiopia has limited water infrastructure to use this surface water. The country has also, barely exploited its groundwater resources, especially for agriculture (Awulachew *et al.*, 2010). The preliminary estimated amount of yearly groundwater recharge of the country is about 28 billion m³ (MoWIE, 2014).

The food production principally depends on availability of water and an increase in production necessarily requires more water to be set aside for the agriculture sector. However, it is estimated that between 2000 and 2025, the global average annual water availability per capital will fall from 6,600 m³ to 4,800 m³. Besides, due to uneven distribution of water resources, some 3 billion people will live in countries entirely or partially arid to semi-arid having less than 1,700 m³ per capital per year water availability (ICID, 2002).

Irrigation development is an important means for achieving food self-sufficiency in many arid and semi-arid countries, including Ethiopia, as the main challenge for achieving food security is caused by water scarcity. Water is becoming an economically scare resource not only in arid and semi-arid areas but also in regions where rainfall is abundant. Water scarcity concerns quantity of resource available and the quality of the water because degraded water resources become available for more stringent requirements. Water scarcity may be due to different causes, nature produced and man-induced (Pereira, 1990).

Agriculture is the backbone of Ethiopia's economy, contributing more than 40% to GDP and providing a livelihood to about 80% of the population (Makombe *et al.*, 2017). There is not enough water for most farmers to produce more than one crop per year (Awulachew, 2005). Furthermore, more than one-third of total water used in the irrigation projects is wasted, because of low irrigation efficiencies (Hanks, 1983). Therefore, improving the efficiency of the irrigation application is a key strategy for water savings in agriculture (Mancosu *et al.*, 2015).

The major agricultural use of water is used for irrigation, which, thus, is affected by decreased supply (Burt and Styles, 1999). Hence, irrigation development should be an important component of a diversification and expansion strategy to strengthen food security for the future and innovations are needed to increase the efficiency of use of the water that is available. Better management of agricultural water for increased productivity and efficiency," More crop per drop", are of vital importance.

The major water source for crop production in Ethiopia is rainfall. However, the trend of rainfall amount is decreasing and the distribution is erratic especially in arid and semi-arid areas of the country. Due to moisture stress during growing season, yield reduction is common in the country as the rainfall is erratic (Woldeamlak, 2009).

Accurate water accounting and water balance studies, to minimize the negative impacts of the ever-decreasing water availability and to save considerable amount of water for future crop production need to be emphasized at a global scale (FAO, 2015a). Therefore, the great challenge for the coming decades will be the task of increasing food production with less water through improving water productivity. This will reduce competition for scarce water resources, mitigate environmental degradation and enhance food security, simply by producing more food with less water and rewards the saved water to other uses (FAO, 2015b).

To minimize water scarcity in crop production and utilization of water resource in sustainable manner, different technologies and management options are being under use. These options minimize the water wastage and enhance the production of grain per drop of water than only concerning on yield per land area. Therefore, innovations are required in irrigation water management to utilize water resources efficiently. Moreover, as the higher water user and the most inefficient sector, enhancing the efficiency of irrigation water

management implies saving higher amount of water. The saved water could be available for other sectors or used to irrigate additional cropland (Pereira *et al.*, 2009).

Therefore, agriculture under unfavorable climatic conditions and limited water resources cannot be profitably practiced unless on-farm water management techniques are designed to meet the present growing demands of water for increased food production (Oad *et al.*, 2001). There should also be a need to identify crops and irrigation techniques which could give higher returns to scarce water and overall investment.

2.2. Irrigation Water and Its Advantages

The growing world population and developing industries are today involved in a competitive struggle with the agriculture sector, the major water consumer compared to industries and municipalities (Rijsberman, 2006). These days about 70% of the available water we have on earth is used for agriculture and by 2020 additional 17% more water is needed than is available now if we are to feed the world (Sleper *et al.*, 2007). Three basic requirements of agricultural production are soil, seed, and water. Besides, fertilizers, insecticides, suitable atmospheric temperature, and human labor are also needed. Of all these, water appears to be the most important requirement of agricultural production. It is among the main limiting factors for productivity of agriculture worldwide, which is majorly due to the temporal and spatial variation of rainfall distribution and low amount of water available especially in arid and semi-arid areas (FAO, 2003). This shows that we cannot afford to depend exclusively on rainfall. Irrigation is therefore, required when rainfall is insufficient to compensate for the water lost by evapotranspiration.

Irrigation is the supply of water to crops by artificial means, designed to permit farming in arid and semi-arid regions and to offset the effect of drought in these regions. Even in areas where total seasonal rainfall is adequate on average, it may be poorly distributed during the year and variable from year to year. In areas where the amount and distribution of rainfall is not sufficient to sustain crop growth and development, an alternative approach set by the Ethiopian Government is to make use of the rivers, underground water and micro dams for irrigation in order to maintain crop growth so as to enhance crop production (MoA, 2010). Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production (FAO, 1997).

A reliable and suitable irrigation water supply can result in vast improvement of agricultural production and assure the economic vitality. A general comparison made by FAO (2002)

between irrigated and rain fed agriculture for food production revealed that irrigated agriculture has been an extremely important means of food production over recent decades. It was also reported that highest yields obtained from irrigation were more than double of the highest yields obtained from rain fed agriculture. Irrigation in arid areas of the world besides providing moisture supply to plant growth which also transports essential nutrients, it supplies water to leach or dilute salts in the soil. Therefore, irrigation plays an increasingly important role now and in the future both to increase the yield from already cultivated land and to permit the cultivation of marginal or unusable land due to moisture deficiency

2.3. Irrigation Water Management in Ethiopia

According to U.S Bureau of Reclamation (2010), “irrigation water management” means management of irrigation water on the farm through the act of timing and regulating irrigation water application in a way that will satisfy the water requirement of the crop without washing water, soil and plant nutrients. The objectives of any irrigation system are to deliver irrigation water in the right amount (size, frequency, and duration), at the right place and at the right moment. Management activity is a major component of success for any irrigation scheme (Depeweg, 1999).

Irrigation development is increasingly implemented in Ethiopia more than ever. The main objectives are to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that agriculture plays the role of driving the economic development of the country. Expansion of irrigated area combined with the efficient management of water will enhance the attainment of food security and poverty alleviation goals of the country. The expansion of irrigated agriculture is to feed the ever-increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand.

The management of irrigation systems aims to achieve optimal crop production and efficient water use or in other term a reliable, predictable and equitable irrigation water supply to farmers. A good management, proper and timely application of water may result in better yield and reduction in drainage problems (Vidhya *et al.*, 2002). It is widely known that the performance of irrigation systems is below their expectation and potential. Farmers are not sure when and how much water they can expect, which leads to very little cooperation and involvement in irrigation management and limited contribution to operation and maintenance costs (Wil and Vander, 1994).

Research effort has focused on developing new techniques to achieve high returns from restricted supply of water. Previous findings (Hanks, 1983) suggest that new innovations can be used to improve traditional irrigation practices and thereby increase effective use of water. For example, it has been reported that exposing field crops to water stress at specific growth stages may not cause significant yield reduction and therefore irrigation during these stages can be omitted. Well managed irrigation application systems have better water productivity compared to that of the traditional irrigation practices in the country (Tsegay *et al.*, 2015; Kifle and Gebretsadikan, 2016).

2.4. Surface Irrigation Systems

Depending on the mode of water application in the field, irrigation methods are categorized into, surface, sprinkler and drip. Surface irrigation is accomplished by impounding water on the land surface, or causing the water to flow over the surface. It involves the application of water directly to the soil surface from a channel located along a higher ground on the upper side of the field. For this method of water distribution, means must be provided for controlling the water such that the required depth may enter the soil to supply moisture as per the need of the crop. In surface irrigation, gravity is the major driving force to spread water over the area to be irrigated. The basic flow characteristics are much the same for all surface irrigation methods, the exception being the difference in channel geometry and boundary conditions.

Surface irrigation, including furrows, borders, and basins, is the dominant type among the types of irrigation evolved (Jensen, 1983). Further, it is the least efficient user, as it is generally based on less advanced techniques. Even in countries like Egypt where irrigation has been practiced for centuries and is the dominant type of agriculture, 90% of the irrigated lands is under surface irrigation.

Emphasis should be given for evaluation of surface irrigation, as it will continue to be the major type of irrigation in the future. This practice is true, in particular in the developing world, where high technology is not easy to adopt, and where low value crops are grown (Strekoff *et al.*, 1999).

Border irrigation is a method where the field is divided into several strips, ranging from 10 to 20 m in width, and 100 to 400 m in length, depending on the topography, bonded by low ridges or borders. In this method irrigation water is led into each strip, from where it advances along the strip and infiltrates into the soil down to the root depth (Hasen, *et al.*,

1980). The method is typically used in soils such as loams that have moderate infiltration rates for irrigating close growing crops.

Basin irrigation is a surface irrigation system in which the land is divided into level rectangular areas bounded by ridges or dykes. During irrigation water is turned into each basin at one or more points until the design amount fills the basin and the water remains ponding until it fully infiltrates into the soil. The method is applied for close growing as well as row crops, on soils with infiltration rates ranging from medium (2.0 to 6.0 cm/hr) to low (0.1 to 0.5 cm/hr) (Michael, 1978). The method is adapted especially to soils having infiltration rates varying from moderate to low. It is used for growing deep rooted and closely space crops (Walker and Skogerboe, 1987).

Furrow irrigation, is most common type of surface irrigation method which is carried out using small channels that run along or across the contour depending on the principal slope of the land. The water that is conveyed by the furrows infiltrates into the soil both laterally and vertically, the process that makes the method unique from the other methods. Furrows are suitable for irrigation of row crops (James, 1988) and they are the most widely used irrigation methods in the world as they provide better on farm water management and flexibility under many surface conditions (Walker and Skogerboe, 1987).

2.5. Advantage of Furrow Irrigation over Other Surface Irrigation Methods

Furrow irrigation method is one of surface irrigation methods in which small channels direct water across the field. Furrows are particularly well adapted to irrigating crops, which are susceptible to water contact with plant part (Michael, 1997). Furrow irrigation may be adapted on a wide range of natural slopes without causing erosion by designing the furrows across the slope rather than down the slope. The method reduces labour requirements in the land preparation and irrigation. Most crops can be irrigated by furrow method except those grown in ponded water such as rice. The furrow method is particularly suitable for irrigating crops subject to injury if water covers the crown or stem of the plants, as the crops may be planted on ridge between furrows.

2.6. Concept of Alternate, Fixed and Conventional Furrow Irrigation Methods

2.6.1. Alternate furrow irrigation

Alternate furrow irrigation (AFI) is a furrow irrigation system in which one of the two neighbouring furrows interchangeably irrigated during consecutive watering. By irrigating

alternative furrows, half of root is exposed to wet soil condition and the other half is exposed to dry soil condition. A drier soil condition stimulates the creation of phytohormone known as Absciscic Acid (ABA) in shoots. ABA is a primary regulator of the stomatal opening in water stressed plants. Closure of stomata in leaf with related decrease in the evaporative water loss is initiated by ABA. AFI offers opportunity for reducing size of irrigation and permits irrigating a field in a shorter time with a given water supply. This irrigation system may supply water in a manner that greatly reduces the amount of surface wetted leading to less evapotranspiration and less deep percolation. Deep percolation can be reduced because the lower wetted surface with alternate furrow results in lower infiltration. It has been suggested that the reduced evapotranspiration in the alternate furrow irrigation method is due to a reduction for wet soil surface compared to that in other furrow irrigation (Stone *et al.*, 1979).

According to Karajeh *et al.* (2000), application of alternate furrow irrigation system improves irrigation water use. Under this furrow irrigation system, 56.7-72% of the water supply is used to replenish soil moisture, 12-21.1% for infiltration within the temporary irrigation network and 11.3-17.8% for surface runoff.

According to Zhang *et al.* (2000), alternate furrow irrigation method uses less irrigation water but can maintain the same grain yield production as that of conventional furrow irrigation with high irrigation amounts.

Alternate furrow irrigation and early termination of irrigation are two simple deficit irrigation strategies that would result in water conservation (Fernandez, 1996). The success of deficit irrigation relies upon the fact that when plants are exposed to water deficit, they conserve water by limiting leaf area growth and closing stomata. When the supply of water is limited, irrigation is applied through alternate furrows. This system saves quite a good amount of water and is very useful and crucial in areas of water scarcity (Majumdar, 2002). Total water use efficiency and net irrigation water use efficiency were larger in alternate furrow irrigation than in conventional furrow irrigation and fixed furrow irrigation with the same irrigation amount (Kang *et al.*, 2000).

2.6.2. Fixed furrow irrigation

Fixed furrow irrigation (FFI) is a method in which irrigation is fixed to one of the two neighbouring furrows. FFI system supplies water to one side of each furrow ridge throughout irrigation seasons. Usually, FFI method applies water to more area in a given amount of time

than conventional furrow irrigation. Research findings indicate that fixed furrow irrigation method also uses less irrigation water. Irrigation water application may be reduced 20% to 30% by implementing FFI. In general, FFI method is a trade-off between lower yield and higher WUE (Kang *et al.*, 2000).

2.6.3. Conventional furrow irrigation

Conventional furrow irrigation (CFI) is a means of traditional irrigation where every furrow is irrigated. Under CFI option, irrigation water is used in the form that: 51-54% of the total water supply was used to moisturise soil (saturation), 20-25% for infiltration within the temporary irrigation network and in the fields, 5-6% for the evaporation from water surface, and 18-21% for surface runoff (Karajeh *et al.*, 2000). Significant quantities of irrigation water losses by infiltration and surface runoff (about 40% of total water supply) reduce water supply to the irrigated lands and decrease the efficiency of agricultural production as well as the reliability of drainage systems.

This irrigation system has speed up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, brought to soil fertility losses (Karajeh *et al.*, 2000). As reported by Graterol *et al.* (1993), the great evapotranspiration and deep percolation in the CFI system do not increase yields. This may be so because a greater portion of the evapotranspiration and deep percolation could be due to non-productive water losses arising from the higher amount of wet soil surface.

2.7. Deficit Irrigation and Its Advantages

Deficit irrigation is one way of maximizing water use efficiency for higher yields per unit of irrigation water used in agriculture (Nagaz *et al.*, 2012). The crop is exposing to a certain level of water stress either during a particular stage or throughout the whole growing season (English and Raja, 1996). In other words, deficit irrigation aims at stabilizing yield and at obtaining maximum water productivity rather than maximizing the yields (Zhang and Oweis, 1999).

So the advantage of deficit irrigation is that it maximizes water productivity. Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Smith *et al.*, 2002). Agronomic measures such as varying tillage practices, mulching etc, can reduce the demand for irrigation water. Another option is deficit irrigation, with plants exposed to certain levels of water stress during either a particular growth period or throughout the whole growth season, without significant reduction in yields (Kirda, 2002).

Deficit irrigation can improve the water productivity without significantly reducing the bulb yield of onion, considering the sensitive stage of the crop (Dirirsa *et al.*, 2017). Although a certain reduction in yield is observed, the quality of the yield (e.g. sugar content, grain size) tends to be equal or even superior to rain-fed or full irrigation (Cui *et al.*, 2008; Hueso and Cueva, 2008).

The other is that irrigated yields can be stabilized at the particular level, guaranteeing stable income for the farmer and allowing economic planning. An additional advantage is that deficit irrigation creates a less humid environment around the crop than full irrigation, decreasing the risk of fungal disease (Cicogna *et al.*, 2005).

Different experiments show that DI can increase water use efficiency without severe yield reductions in different crops. According to the findings of Kumar *et al.*, (2007), applying 80 and 60% of ET_c of onion resulted in yield decreases of 14 and 38% and saved 18 and 33% of irrigation water, respectively when compared to full irrigation. Bekele and Tilahun (2007) indicated also that deficit irrigation throughout the growing season with 50 and 75% ET_c application reduced yields from full irrigation and resulted in the highest water saving and crop water use efficiency.

2.8. Irrigation Scheduling

The main objective of irrigation scheduling for crops is to decide when to irrigate and how much to irrigate depending on the crop water needs (FAO, 1989). Optimal irrigation scheduling leads to maximum yields and good bulb quality. Under-irrigation stresses the crop causing losses in total yield and marketability while over-irrigation causes soil erosion, bulb disease susceptibility, water loss, extra energy costs for pumping, nitrogen leaching leading to ground water pollution, and increased crop nitrogen needs. For this reason irrigation scheduling and management should be carried out carefully.

The irrigation water management was carried out following regular soil moisture monitoring before and after irrigation so that the crop water use and soil moisture condition could be known. The rate of water uptake starts to reduce when about 25 percent of the total available soil water has been depleted ($p = 0.25$, where p is the fraction of soil water depletion) (FAO, 2012). The crop requires light and frequent irrigations which are applied when about 25 percent of available water in the soil depth has been depleted by the crop.

2.9. Water Productivity

Water productivity (WP) refers to the ratio between output derived from water use and the water input (volume or value of water depleted or diverted) (Clement *et al.*, 2011). WP is a measure of a crop capacity to convert water into plant biomass or grain. It is widely believed that an increase in agricultural water productivity is the key approach to mitigate water shortage and to reduce environmental problems in arid and semiarid regions.

In agricultural production systems water productivity is focused on producing more food with the same water resources or producing the same amount of food with less water resources. Increasing water productivity is particularly important where water is scarce compared with other resources involved in production (Drechsel *et al.*, 2015). Crop WP expressed in kg/m³ is an efficiency term, expressing the amount of marketable product (e.g. kilograms of grain) concerning the amount of input needed to produce that output (cubic meters of water) (Kijne *et al.*, 2003).

Usually, water productivity is defined as a mass (kg), monetary (\$) or energy (calorific) value of produce per unit of water evapotranspired (Molden *et al.*, 2010), and, as such, it is a measure of the ability of agricultural systems to convert water into food.

2.10. Crop Water Requirement

The term crop water requirement is defined as the amount of water required to compensate for the evapotranspiration loss from the cropped field. Crop water requirement refers to the amount of water that needs to be supplied for the crops, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al.*, 1998). For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference evapotranspiration (ET_o) and the effect of crop characteristics (K_c) are important (FAO, 1977).

The growth and yield of any crop is related to the amount of water used. The amount of water contained in a soil and its energy state are important factors affecting growth of plants (Hillel, 2004). The Penman Monteith equation has been adopted as the globally best performing method of estimating evapotranspiration (Smith and Mulins, 1991). The ET_o is calculated based on the FAO Penman-Monteith method (Allen *et al.*, 1998) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2.1)$$

where, E_{To} is reference evapotranspiration (mm/day), R_n is net radiation at the crop surface (MJ/m²/day), G is soil heat flux density (MJ/m²/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 vapour pressure (kPa), $e_s - e_a$ is saturation vapor pressure deficit (kPa), Δ is slope of vapor pressure curve (kPa/°C), γ is psychrometric constant (kPa/°C). The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. Then E_{Tc} is computed as;

$$E_{Tc} = E_{To} \times K_c \quad (2.2)$$

Where, E_{Tc} = crop evapotranspiration; K_c = crop coefficient; E_{To} = reference evapotranspiration

The gross water requirement was then computed assuming 60% of application efficiency as suggested by FAO (1989).

2.11. Onion Response to Deficit Irrigation

Onion is a vegetable crop widely cultivated in the world. Onion production is dependent on adequate irrigation, well-distributed and well-spaced throughout the growing season. Onions are shallow rooted crop that need to maintain relatively higher water potential for optimum yield and economic return since these plants show little capacity for reducing leaf water potential by osmotic adjustment to compensate for reduced water availability (Shock *et al.*, 2004). Onions are most sensitive to water deficit during the yield formation period, particularly during the period of rapid bulb growth and transplantation. However, the crop appears to be relatively less sensitive to water deficits during the vegetative (Doorenbos and Kassam, 1979; Kadayifci *et al.*, 2005) and maturity period (Kadayifci *et al.*, 2005). Water deficit of 50-75% during the total growing season at the yield formation period caused a large decrease in bulb yield (Kadayifci *et al.*, 2005). Further, they suggested that to achieve large bulb size and high bulb weight, water deficits especially during the yield formation (bulb enlargement) should be avoided. Under limited water supply small water savings can be made during the vegetative period and maturity period (Doorenbos and Kassam, 1979; Bazza and Taya, 1999). However, too much water shortage during these periods could result in higher percentage of small- sized bulbs (Martin de Santa Olalla *et al.*, 2004).

Kebede (2003) indicated that bulb yield and mean bulb weight were higher at irrigation levels of 75 than at 50 or 25% available soil moisture and total weight of bulbs were highest at irrigation level of 75 and least at 25% available soil moisture. The best irrigation water

use efficiency was obtained with irrigation at 50% available soil moisture (Kebede, 2003). Similarly, Shock *et al.* (1998) showed that bulb yields were more improved when plants were irrigated at 75% available soil moisture than at 50% or 25% available soil moisture and onion yields were more affected when the available soil moisture in the surface topsoil dropped below 60-80%. However, frequent irrigation delays onion bulb maturation, encourages ripening and bulb splitting (Brewster, 1990a).

2.12. Agronomy and Productivity of Onion Crop under Irrigation

Onion (*Allium cepa* L.) is since ancient times a valuable vegetable crop for people all over the world (Jaims and Fernando, 2008). Nowadays one can find onions with different colors, tastes, and bulb shapes, making the crop an important ingredient in all types of dishes around the world. On the list of worldwide cultivated vegetable crops, onions rank second only preceded by tomatoes (FAOSTAT, 2006).

Onions have a wide range of climatic, soil adaptation, and they are cultivated under both irrigation and rain fed conditions (Rabinowitch and Currah, 2002). Proper irrigation is critical for onion production. Optimal irrigation management leads to steady plant growth, uniform bulb size, maximum yields, and superior bulb quality. Under-irrigation results in a reduction of yield and quality. However, over-irrigation increases disease susceptibility, nutrient leaching, and inefficient water use. For ideal bulb development, a consistent moisture supply throughout the season is necessary. Different irrigation methods are commonly used to irrigate onions, each with different management considerations. Historically, furrow irrigation was the method of choice. Even though Furrow irrigation results in large fluctuations in soil moisture, nutrient leaching, and low water use efficiency when compared to drip irrigation, properly managing irrigation water is resulting in a high yield and maximize water use efficiency.

Temperature is one of the most important environmental factor that affect onion bulb development and production. The crop grows in mild climate without extremes in temperature and excessive rainfall. The initial growth period, cool weather and adequate water is advantageous for proper crop establishment, whereas during ripening, warm, dry weather is beneficial for high yield of good quality. The optimum mean temperature for onion development varies between 15°C and 20°C (Kalb and Shanmugasundaram, 2001). The length of growing period varies with climate but in general 130–175 days are requiring from sowing to harvesting (FAO, 2002; Rabinowitch and Currah, 2002).

Onions grow on a variety of soils ranging from sand to clay loams. However, they prefer loamy soil that is fertile, well drained and high in organic matter, with a preferable pH range of between 6.0 and 8.0 (Olani and Fikre, 2010). Onions could be produced on slightly alkaline soils, but are sensitive to soil salinity (Corgan *et al.*, 2000). According to the FAO (2002), a soil salinity level of 4.3 dS/m or more could decrease the yield of onion by up to 50%.

In Ethiopia, onion grows well all year round at 500 m to 2400 m a.s.l. depending on the season for the year and type of cultivar. It was reported that onion grows in all types of soils on sandy loam to heavy clay. The highest yield of onion is obtained from freely drained friable loam soil with pH of 6.7 to 7 (Lemma and Shimelis, 2003). Bombay red onion variety was released by Melkassa Agricultural Research Centre in 1980 (EARO, 2004). The variety has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color and takes 110-120 days for bulb harvest (EARO, 2004). Bombay red is one of the most commonly and widely used improved variety in Alage.

Onions require frequent irrigation throughout the growing season for several reasons. The root system is shallow; therefore, very little water is extracted from a soil depth deeper than 0.6 m, and most is from the top 0.3 m. Onion roots are mostly non-branching and all roots originate at the stem, or basal plate of the plant. This indicates that upper soil areas must be kept moist to stimulate root growth. Rates of transpiration, photosynthesis and growth are lowered by even mild water stress (Voss and Mayberry, 1997).

The production is rapidly expanding in all administrative regions in the country in different agro-ecological zones either in small pockets or in large commercial farms (MARC, 2004). For optimum yield, onion requires 350–550 mm water but may use more than that in areas where evapotranspiration is appreciably higher (Kalb and Shanmugasundaram, 2001). Best production is obtained when cool temperature prevails over an extended time, permitting considerable foliage and root development before bulb formation starts. After bulb formation begins, high temperature and low relative humidity extending into the harvest and curing period are desirable (Rubatzky and Yamaguchi, 1997; Jilani, 2004). The crop is less sensitive to water deficit during vegetative growth period and late season stage (FAO, 2012).

Onions are harvested when 80% of the bulbs become completely mature, which is evident by the collapse of 20 to 50% of the neck tissue and falling of the tops. That is usually 100 to 140 days after transplanting (Brewster, 1990b). After harvesting, the roots are trimmed and

the tops cut away. After bulbs are properly cured, onions are graded according to the local standards of the country. According to the USDA standard, onions are graded for size and shape, proper maturity and firmness.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted at Alage Agricultural Technical and Vocational Educational Training College from January to June, 2020. The college is located at 7° 65' N latitude and 38° 56' E longitude with an altitude of 1600 meters above sea level in the southern part of the Ethiopian rift valley. It is at 217 km south of Addis Ababa city and 32 km west of Bulbula town in the vicinity of Abijata and Shala lakes (Figure 1). The area is characterized by a bimodal rainfall pattern where short rainy season occurs during the months of March and April and the main rain starts in June and extends to September. High amount of rainfall is

in the month of July and August. While the mean annual rainfall is 800 mm, the annual mean minimum and maximum temperatures are 11°C and 32°C, respectively. The soil textures of the area range from sandy loam to sandy clay loam with some clay loam and clay soils (Eylachew, 2004).

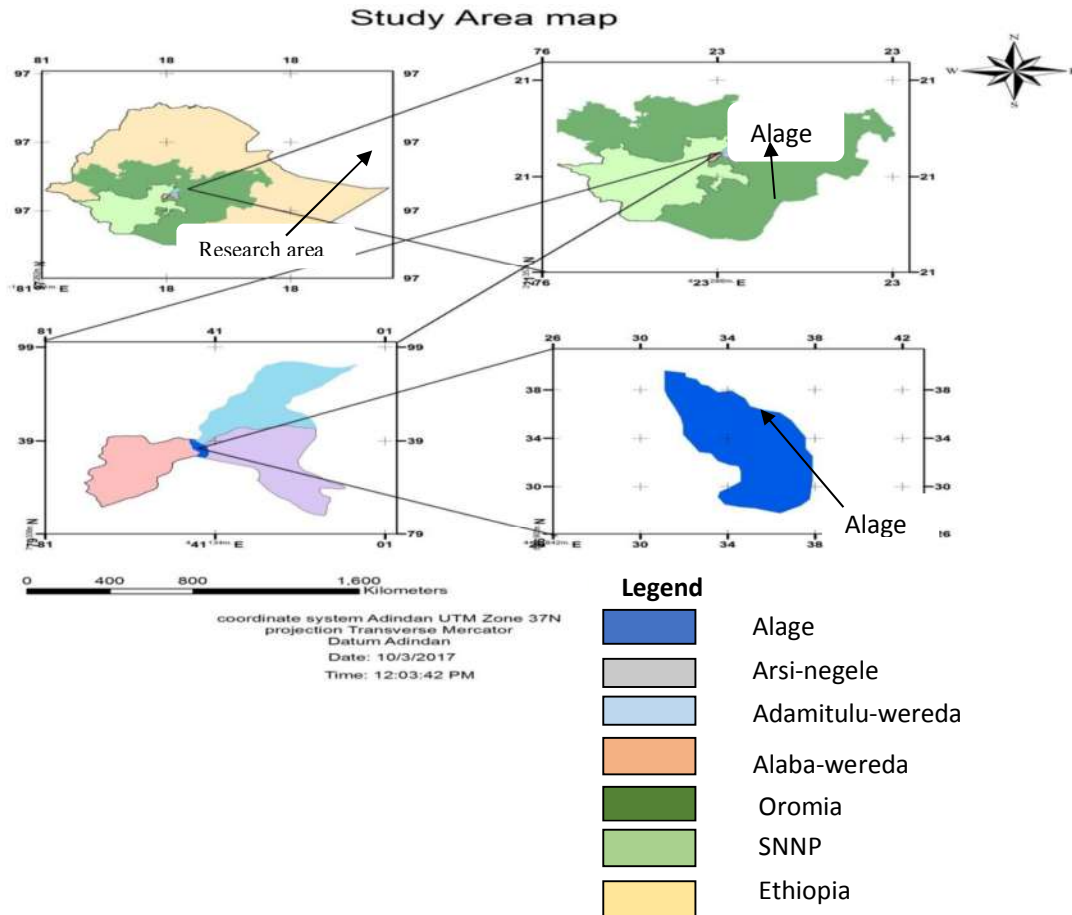


Figure 1: Location map of the study area

3.2. Materials Used

Table 1: Materials used for the experimental work

Materials	Purposes
Parshall flume	to calibrate and measure water flow rate
Soil auger	to take disturbed soil samples
Core sampler	to take undisturbed soil samples
Plastic bag	to collect soil sample
Pressure plate	to determine soil moisture contents at FC
Pressure membrane	to determine soil moisture contents at PWP
Rule	to measure plant and bulb height of onion

Digital caliper	to measure bulb diameter of onion
Pegs and string	for alignment of lay out
Double ring infiltrometer	to measure soil infiltration rate

3.3. Treatments and Experimental Design

The experiment was implemented into two factorial combinations, namely, three irrigation methods, which were alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) as a sub-plot and four irrigation levels of applications, which were 90, 75 and 50% ET_c, and a control irrigation of 100% ET_c as a main plots. AFI means one of the two neighbouring furrows is alternately irrigated during consecutive irrigation. FFI means that irrigation fixed to one of the two neighbouring furrows. CFI or traditional irrigation means irrigating all furrows. With 100% ET_c (full irrigation) implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT program. The 90, 75 and 50% ET_c means 90, 75 and 50% of the full irrigation requirement, respectively.

The experiment was conducted on individual plot size of 2 m x 4 m. Distance between sub-plots, main-plots and blocks were 1, 1.5 and 2 m apart, respectively. The design of experimental plot was split plot with three replications having 12 treatments. Thus total experimental plots were 36 and a gross area of experimental field was 810 m² (20 m x 40.5 m). Each plot accommodated five planting ridges with spacing of 40 cm. The space between on each row and plant was 20 and 10 cm, respectively. The experimental treatment combination, arrangements and randomization are presented in Tables 2, 3 and 4. Lay out of the experimental site is given in Figure 2.

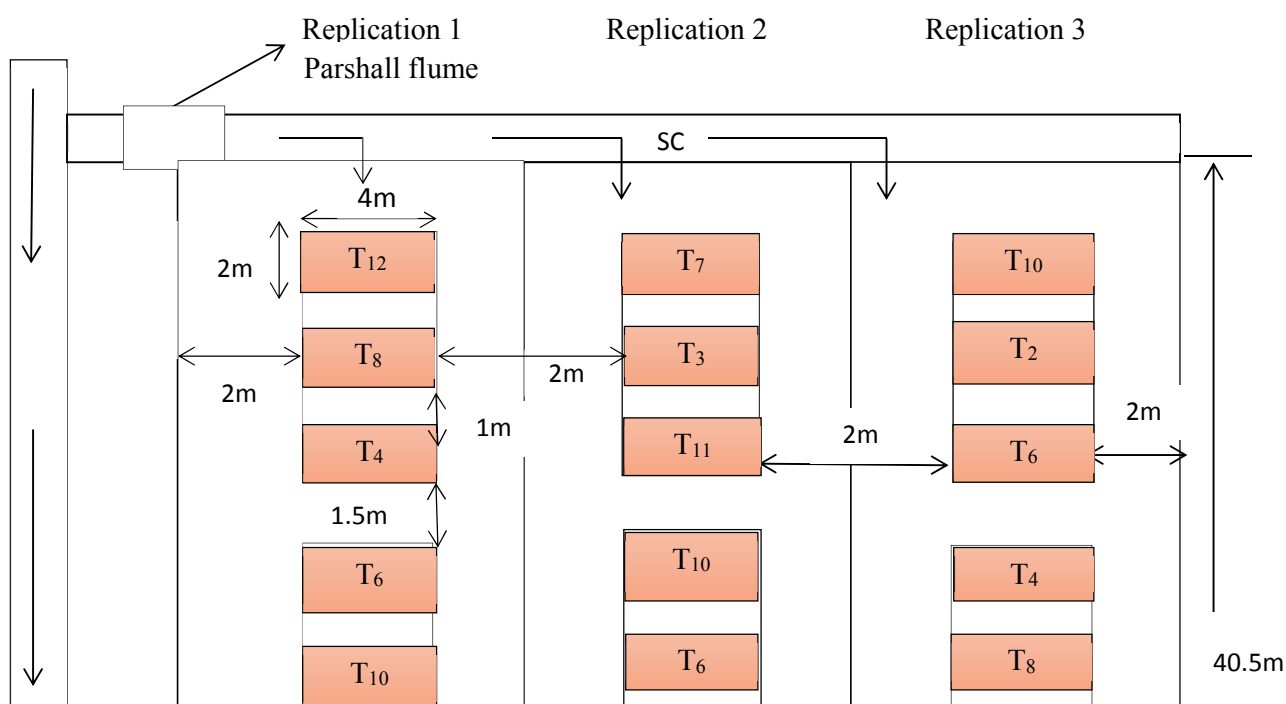




Figure 2: Layout of the experimental field

Table 2: Treatment arrangements of irrigation levels and furrow irrigation methods

Treatments	Descriptions
T ₁	Alternate Furrow Irrigation (AFI) and 100% ETc application
T ₂	Alternate Furrow Irrigation (AFI) and 90% ETc application
T ₃	Alternate Furrow Irrigation (AFI) and 75% ETc application
T ₄	Alternate Furrow Irrigation (AFI) and 50% ETc application
T ₅	Fixed Furrow Irrigation (FFI) and 100% ETc application
T ₆	Fixed Furrow Irrigation (FFI) and 90% ETc application
T ₇	Fixed Furrow Irrigation (FFI) and 75% ETc application

T ₈	Fixed Furrow Irrigation (FFI) and 50% ETc application
T ₉	Conventional Furrow Irrigation (CFI) and 100% ETc application
T ₁₀	Conventional Furrow Irrigation (CFI) and 90% ETc application
T ₁₁	Conventional Furrow Irrigation (CFI) and 75% ETc application
T ₁₂	Conventional Furrow Irrigation (CFI) and 50% ETc application

Table 3: Randomization of treatments at each plot within the replications

Replication	Plot number with its correspondent experimental treatments											
R ₁	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	P ₈	P ₉	P ₁₀	P ₁₁	P ₁₂
	T ₁₂	T ₈	T ₄	T ₆	T ₁₀	T ₂	T ₇	T ₃	T ₁₁	T ₁	T ₅	T ₉
R ₂	P ₁₃	P ₁₄	P ₁₅	P ₁₆	P ₁₇	P ₁₈	P ₁₉	P ₂₀	P ₂₁	P ₂₂	P ₂₃	P ₂₄
	T ₇	T ₃	T ₁₁	T ₁₀	T ₆	T ₂	T ₅	T ₉	T ₁	T ₁₂	T ₄	T ₈
R ₃	P ₂₅	P ₂₆	P ₂₇	P ₂₈	P ₂₉	P ₃₀	P ₃₁	P ₃₂	P ₃₃	P ₃₄	P ₃₅	P ₃₆
	T ₁₀	T ₂	T ₆	T ₄	T ₈	T ₁₂	T ₅	T ₁	T ₉	T ₁₁	T ₇	T ₃

R₁, R₂ and R₃ for replication 1, 2 and 3, P₁, P₂, P₃... P₃₆ for plot 1, 2, 3, ...36 and T₁, T₂, T₃,... T₁₂ for treatment 1, 2, 3, ... 12, respectively

3.4. Soil Sampling and Analysis

Composite soil samples were collected from different plots randomly and diagonally across the experimental field using core sampler before planting at 20 cm soil depth interval up to 60 cm (0 – 20, 20 – 40 and 40 – 60 cm) from the surface for soil physical properties analysis such as bulk density, texture, infiltration rate, field capacity and permanent wilting point and also for chemical properties such as soil pH, organic matter content, percentage of organic carbon and electrical conductivity. The collected samples were thoroughly mixed, labeled, packed and taken to the soil laboratory of Ziway Research Center.

3.4.1. Soil physical properties

Bulk density

Bulk density of soil of the experimental site was determined in the laboratory by taking undisturbed soil samples using core sampler from the given interval and oven dried for 24 hours at a temperature of 105⁰C, and then computed using equation 3.1 as stated by Michael (1978).

$$\rho_b = \frac{W_d}{V_s} \quad (3.1)$$

Where: ρ_b is dry bulk density of the soil in g/cm^3 , W_d is the weight of oven dry soil in g and V_s is the volume of the same soil sample in cm^3 (core volume).

Soil texture

The hydrometric method was used for the particle size analysis of the soils. The textural class of the soil was determined using USDA textural triangle following the procedures indicated by Day (1965).

Field capacity and permanent wilting point

The field capacity (FC) and permanent wilting point (PWP) were determined at Debre Zeit Agricultural Research Centre Laboratory using pressure plate and pressure membrane apparatus, respectively. Soil samples were saturated for one day (24 hours) and a pressure of 1/3 bar and 15 bar were exerted, respectively for FC and PWP, until constant weight at that section was observed.

Soil infiltration rate

Infiltration rate of soil was measured using double ring infiltrometer by taking readings of drop in water level in the inner ring with ruler and stop watch for recording the time that was taken for the water to infiltrate in a given time interval before the experimental work was started. The test was conducted at three locations of the experimental field by ponding water into both inner and outer rings at equal level for extended period of time. Soil infiltration rate was tested for the total of 62 minutes continuously and the depth of water levels infiltrated were measured at increasing time intervals starting from one (1) minutes to ten (10) minutes to get equal infiltration rate. Then readings were taken frequently from inner cylinder until the drop of water level over a given time interval remained constant.

3.4.2. Soil chemical properties

The soil pH was determined by measuring soil solution of 1:2.5 ratios (soil to water) with a pH meter using combination glass electrode as described by Jackson (1958). The percentage of organic carbon (OC) was determined by using the wet digestion method as described by Walkley and Black (1934), and then followed by organic matter determination. Organic matter (OM) content was then determined by multiplying OC by 1.724 (Nelson and Sommers, 1996). Electrical conductivity of the soil was determined using electrical

conductivity meter (EC meter). Irrigation water sample was also taken using containers from irrigation water source of the site for the determination of its pH and electrical conductivity using pH and electrical conductivity meter (EC meter), respectively.

3.5. Experimental Procedures for Crop Management Practices

Onion Bombay red seeds variety was used as seed material. Nursery site establishment was carried out at Alage ATVET College demonstration site on raised beds with size of 2.5 m x 2.5 m. The seed was sown at 10 cm distance between rows lightly covered with soil and mulched with grass until seedlings emerged (2-5 cm from the soil) on January 11, 202. Seedlings were managed in nursery site by watering, weeding, insect and disease controlling, and shading after which they were transplanted to the experimental plots.

Before transplanting seedlings, the experimental field was ploughed and harrowed by using tractor. Large clods were broken down to make the land into a fine tilth, and then 36 plots of 2 m x 4 m were measured, demarcated and laid out. The plots were levelled and furrows and ridges were made at a spacing of 40 cm. Seedlings were transplanted after healthy and vigorous seedlings of 12-15 cm height were carefully uprooted from nursery bed. The nursery bed was irrigated one day before uprooting the seedlings to facilitate the uprooting and subsequent good field establishment of seedling. Then Seedling was transplanted on February 25, 2020 to the experimental plots after five weeks of germination and was harvested after 106 days.

Other recommended agronomic practices like weeding, insect, pest and disease control were kept uniform for all treatments. A common and the same amounts of recommended fertilizer was applied manually in the experimental plots. One-time application of Di-ammonium phosphate (DAP) at transplanting only and split application of Urea at transplanting and 10 days after transplanting were done by hand placement at a rate of 200 kg/ha and 100 kg/ha, respectively (Olani and Fikre, 2010). The chemicals Selecron (3 liter/ha) and Redomil Gold (3 liter/ha) were used, to safeguard the crop against harmful insects and fungus, respectively. Harvesting of onion bulbs was done when 70% plants show neck fall (EARO, 2004). The onion bulbs were cured for four days by windrowing on the ground before topping (Wondimu, 2009).

3.6. Crop Water Requirements

The irrigation water used in the study area was obtained from Gido River. The reference evapotranspiration (ET_o) was estimated using CROPWAT version 8.0 computer software

program employing daily actual climatic data from Alage ATVET College meteorological station. The climatic data such as rainfall, maximum and minimum temperature, humidity, wind speed and sunshine hours were used by the model. The crop water requirements were calculated by multiplying the ETo values with the onion crop coefficients (Kc).

$$ET_c = ETo \times K_c \quad (3.2)$$

Where, ET_c is the daily crop evapotranspiration (mm/day), ETo is daily reference evapotranspiration (mm/day) and K_c is the crop coefficient. K_c for onion was taken as 0.5 at initial stage, 0.5 to 1.0 at development stage, 1.0 at mid-season and 1.0 to 0.8 at late season (Allen *et al.*, 1998).

The net irrigation requirement (IR_n), which is the depth of water needed for the crop from irrigation supply was also calculated using the CROPWAT software based on Allen *et al.*, (1998) as,

$$IR_n = ET_c - P_e \quad (3.3)$$

Where: IR_n = Net irrigation requirement (mm),

ET_c = crop water need (mm) and

P_e = effective rainfall (mm) which is part of the rainfall that is available for the crop.

The method given by Allen *et al.*, (1998) to determine effective rain fall (p_e) as;

$$P_e = 0.6 \times P - \frac{10}{3}, \text{ for } P \leq 70 \text{ mm or}$$

$$P_e = 0.8 \times P - \frac{24}{3}, \text{ for } P > 70 \text{ mm} \quad (3.4)$$

Where: P = Total rain fall (precipitation) in mm during the growing period

Since there was no rain fall occurred during the growing period of the crop at the study site, there was no effective rain that was available for the crop. For this case the amount of water that was required by the crop at study site was supplied only by irrigation.

3.7. Irrigation Scheduling and Management

The total available water (TAW) was computed from the moisture content at FC and PWP using equation 3.5 (Allen *et al.*, 1998).

$$TAW = (\theta_{FC} - \theta_{PWP}) \times \rho_b / \rho_w \times DZ \quad (3.5)$$

Where: TAW is the total available water in the root zone (mm), θ_{FC} and θ_{PWP} are moisture content at field capacity and permanent wilting point in % (weight basis), respectively, ρ_b is the bulk density of the soil in g/cm^3 , ρ_w is density of water in g/cm^3 , and D_z is the maximum effective root zone depth of onion (mm).

Readily available water (RAW) is the amount of water that crops can extract from the root zone without suffering any water stress. For maximum crop production, the irrigation schedules were fixed based on RAW. Since onion is sensitive to water deficit, for high yield, soil water depletion should not exceed 25% of the TAW ($p=25\%$) (Doorenbos and Kassam, 1979). Thus RAW was computed from the expression:

$$RAW = p \times TAW \quad (3.6)$$

Where: RAW is in mm, p is allowable permissible soil moisture depletion and taken 0.25 for onion, based on FAO's recommendation for onion (FAO, 1996) and TAW is total available water in mm.

The permissible soil moisture depletion (RAW) was taken as 100% ET_c; accordingly, the irrigation application with 0% deficit represents 100% ET_c application. The 10, 25, and 50% ET_c deficit irrigation water applications indicate 90, 75 and 50% of ET_c application, respectively.

3.8. Gross Irrigation Water Requirement and Discharge Measurement

Field irrigation application efficiency (E_a) is the ratio of water directly available to the crop to water received at the field inlet. It is affected by the rate of supply, infiltration rate of the soil, the storage capacity of the root zone and land levelling. Water is mostly lost through deep percolation at the head end and through runoff at the tail end in furrow irrigation and deep percolation and evaporation in the basin.

The gross irrigation requirement was computed by adopting a field application efficiency of 60% (FAO, 1989). According to Brouwer and Prins (1989), furrow irrigation application efficiencies normally for short and end diked furrow as 60%. In this experimental setup, water was applied with precise measurement; furrows were short and end-diked. Therefore, for this particular experiment, furrow irrigation efficiency was taken as 60% and the gross irrigation water requirement was calculated based on equation 3.7:

$$IR_g = \frac{IR_n}{E_a} \quad (3.7)$$

Where: IR_g is the gross irrigation requirement in mm, IR_n is net irrigation requirement (mm), and E_a is the furrow application efficiency (%).

The total amount of water requirement estimated was diverted to the furrow with calibrated Parshall flume having appropriate opening diameter of three inch (3") with a length of 2 m and its appropriate head ranges from 3-33cm (Teklu, 2016).

The amount of water diverted to each furrow treatments was measured by using a 3 inch Parshall flume device. The Parshall flume is a critical depth measuring device, which is installed in a canal to measure the rate of flow. The discharge was calculated as suggested by Michael, (1997):

$$Q=0.177h^{1.55} \quad (3.8)$$

Where: Q = discharge from Parshall flume, (l/s)

h = effective head of parshall flume causing flow, (cm)

The time required to deliver the desired depth of water into each plot was calculated using the equation 3.8 (Kandiah, 1981).

$$t = \frac{IR_g \times w \times l}{q \times 60} \quad (3.9)$$

Where: IR_g = gross depth of water applied (mm), t = application time (min), l = plot furrow Length (m), w = plot width (m), q = flow rate (l/s) at specific parshall flume head and 60 is unit adjusting figure.

3.9. Data Collection

Agronomic data

Relevant agronomic data were recorded during the time of the experiment. Five random plants from the central three rows per plot excluding the border rows and border plants were taken as a sample.

Plant height (cm): Five plants were selected from the interior rows to avoid border effect. Plant heights of five randomly selected plants were measured from the central rows of each plot at the end of each stage of the crop. The average value of the five plant height was recorded as plant height of each plot.

Number of leaf Pre plant (No): Five numbers of leaves were selected from the interior rows randomly at the end of each stages and the average was computed to obtain number of

leaves per plant. The sum of total counted number of leaves of sampled plants was divided by the number of plants to get mean leaf number per plant.

Bulb length (cm): Refers to the lengths of randomly selected five plant bulbs, which measured using digital caliper in centimeter. Then, average bulb height was calculated.

Bulb diameter (cm): Refers to the diameters of five plant bulbs, which selected randomly from interior rows and measured at the widest point in the middle portion of the mature bulb using a digital caliper.

Weight of single bulb (g): To calculate the average weight of the bulb in each plot, five plants were randomly selected and weighed on electronic balance after cutting the leaves from 2-2.5 cm above the neck. Finally, the average weight of the bulb in each plot was calculated in grams.

The dry weight of bulb (g): The fresh bulbs from five randomly selected plants were weighed and dried in an oven at 65°C temperature till constant weight. Finally, the average weight of the dry bulb in each plot was calculated in grams.

Marketable bulb yield (kg/ ha): Refers to yield of onions, which are not under sized free from physiological disordered and pest damaged bulbs. It was determined from weight of bulbs harvested from the net plot using digital balance.

Unmarketable bulb yield (kg/ ha): Refers to sized, color, physiological disordered and pest damaged bulbs which was determined from weight of bulbs harvested from the net plot using digital balance (Moray *et al.*, 2012).

Total bulb yield (kg/ ha): It was recorded from net plot by weighing all bulbs taken from central rows of the plot.

3.10. Water Productivity

Water productivity is a measure of the ability of agricultural systems to convert water into food. Water productivity was expressed in terms of crop water use efficiency and irrigation water use efficiency.

3.10.1. Crop water use efficiency

Crop water use efficiency (CWUE) is mostly used to describe crop water use effectiveness in terms of crop yield (crop productivity). CWUE was determined by dividing the bulb yield

produced from each treatment to the total depth of water received by the crop according to Lovelli *et al.*, (2007).

$$CWUE = \frac{Y}{ET_c} \quad (3.10)$$

Where: CWUE = crop water use efficiency (Kg m⁻³); Y = Total yield (kg/ha) and ET_c = crop evapotranspiration (mm or m³)

3.10.2 Irrigation water use efficiency

Irrigation water use efficiency (IWUE) was determined by dividing total bulb yield to total irrigation water depth applied according to Lovelli *et al.*, (2007).

$$IWUE = \frac{Y}{I_g} \quad (3.11)$$

Where: IWUE = Irrigation water use efficiency (Kg m⁻³); Y = Total yield (kg/ha) and I_g = gross irrigation (mm or m³)

3.11. Statistical Data Analysis

The collected data's were analyzed by analysis of variance (ANOVA) using statistical software (gen stat 15th Editions) which was improved statistical analysis system (SAS). Mean separation was done by using least significant difference (LSD) test to assess any significant difference among treatments means, whenever the treatment effects were found significant.

4. RESULTS AND DISCUSSIONS

4.1. Physical, Chemical and Infiltration Characteristics of the Soil

Analysis of soil samples for the major soil physical and chemical properties was carried out at soil laboratories and field in order to characterize soils of the study area.

4.1.1. Soil physical properties

The soil physical properties of the study area are presented in Table 5. The result of the soil analysis of the experimental site showed that the average composition of sand, silt and clay percentages were 29.4, 33.7 and 36.9%, respectively. Thus, according to the USDA soil textural classification, the soil textural class was clay loam for experimental area.

Table 4: Physical properties of the soil at the experimental site

Soil Property	Soil depth in (cm)

		(0-20)	(20-40)	(40-60)	Average
Particle size distribution	Sand (%)	30.2	29.4	28.5	29.4
	Silt (%)	33.1	33.7	34.2	33.7
	Clay (%)	36.7	36.9	37.3	36.9
Textural class		Clay loam	Clay loam	Clay loam	Clay loam
Bulk density(g/m ³)		1.05	1.08	1.15	1.1
FC (%)		31.6	30.3	28.9	30.3
PWP (%)		15.4	14.1	13.7	14.4
TAW (mm/m)		170.1	174.96	174.8	174.9

The soil had a bulk density of 1.05 gm/cm³ at the surface, 1.15 gm/cm³ at 60 cm soil depth and an average soil bulk density of 1.1 g/cm³. This could be because of slight decrease of organic matter with depth and compaction due to the weight of the overlying soil layer (Brady and Weil, 2002). Bulk density reflects the ability of the soils to function for structural support, water and solute movement, and soil aeration. The soil moisture contents at field capacity and permanent wilting point of the experimental site showed variation with depth. The average soil moisture contents at field capacity and permanent wilting point of the experimental site were 30.3 and 14.4%, respectively through 60 cm soil depth. According to Israelson and Hanson (1962), the average field capacity range should be 23-31% and permanent wilting point range should be 11-15%, in which the value of the moisture in the present study was within the recommended moisture range.

4.1.2. Soil chemical properties

The soil chemical properties of the study area are presented in Table 6. The mean soil pH value was found to be 7.66, which is within the optimum range for onion production (6 – 8) (Olani and Fikre, 2010). It was slightly alkaline and hence suitable for onion crop production according to Lemma and Shimeles (2003). The value of ECe of a soil was 1.21 dSm⁻¹, which is also suitable for onion. Soils having the ECe less than 4 dSm⁻¹ are considered as non-saline and suitable for vegetable production (Hazelton and Murphy, 2007). The organic carbon content at the experimental site was 1.9%. Organic Matter content (OM) is considered to

improve water-holding capacity, nutrient release and soil structure. The OM of the soils of study area was 3.1%. According to Landon (1991), organic matter (OM) is categorized as low (1-2%), moderate (2-4%), and high (4-6%). Based on this category OM of the study area was moderate.

Table 5: Chemical properties of the soil at the experimental site

Depth (cm)	pH	EC (dSm ⁻¹)	OC (%)	OM (%)
0-20	7.67	1.24	2.1	3.16
20-40	7.78	1.17	1.8	3.11
40-60	7.53	1.22	1.73	2.98
Average	7.66	1.21	1.9	3.1

Increasing salt content in irrigation water may be directly toxic to plants, which in turn, lowers mineral uptake and distribution activities of growth hormones (Hussein, *et al.*, 2005 and Kaya *et al.*, 2009). The analysis of the irrigation water of the site showed pH value of 7.75 and EC_w value of 0.65 dSm⁻¹. According to Bryan *et al.* (2007), the irrigation water is classified in terms of pH as low (< 7), slight to moderate (7-8) and severe (> 8). Based on this classification, the characteristics of the irrigation water in the study area were found to be slight to moderate. According to FAO (1999), water salinity is classified as low (0.1-0.25 dSm⁻¹), medium (0.25-0.75 dSm⁻¹), high (0.75-2.25 dSm⁻¹) and very high (> 2.25 dSm⁻¹) salinity levels. Based on this category water quality of the study area was fails at medium salinity levels class.

4.1.3. Infiltration characteristics of the soil

The average infiltration rate and cumulative infiltration curves of the soils at the field were generated from collected data (Figure 3 and appendix Table 1). The basic infiltration rate was about 5.1 mm/hr, which is within the acceptable range for clay loam soil (2.5 to 15 mm/hr) (Israelson and Hanson, 1962; FAO, 1979). This means that a water layer of 5.1 mm on the soil surface will take one hour to reach to the basin.

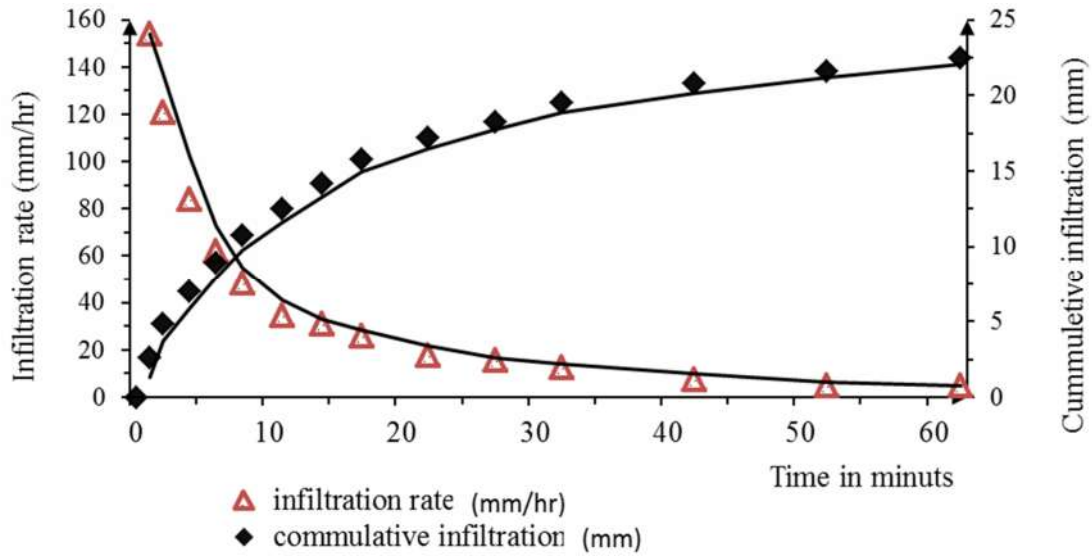


Figure 3: Soil infiltration rate and cumulative infiltration curves of experimental site

4.2 Crop Water Requirement and Irrigation Water Management

The result showed that the minimum 3.46 mm/day and maximum 4.48 mm/day ETo value occurred in the months of July and March, respectively with an average value of 4.07 mm/day for the whole growth period (Appendix Table 2). Monthly ETo during the study period was also determined (Appendix Table 3). Generally the evaporative power of the atmosphere was under moderate range (3-5 mm/day) (Allen *et al.*, 1998). Total seasonal crop water requirement of onion was calculated to the full irrigated treatment (100% ETc) depth of the experimental site which was 432.9 mm (Table 6).

The remaining treatment plots received the crop water requirement of onion according to the intended irrigation methods and levels of irrigation (Appendix Table 4). Accordingly, the 90, 75 and 50% ETc of irrigation level with CFI method were applied 394.9, 337.5 and 241.9 mm, respectively and 100, 90, 75 and 50% ETc irrigation level with AFI and FFI methods were applied the same amount of 241.9, 217.7, 181.4 and 120.9 mm, respectively. The crop water requirement values were low at the beginning of the growing season, increased gradually to attain a maximum during development and mid stage and subsequently decreased based on crop growth stages.

Table 6: Crop water requirement (mm/period) of onion at experimental site for full irrigation level (100% ETc)

Date	Day	ETo	Kc	CWR/ETc	Rain	Net. Irr.	Gr. Irr.
25-Feb	1	34.20	0.50	17.1	0	17.1	28.5
28-Feb	4	33.80	0.50	16.9	0	16.9	28.2
3-Mar	7	33.00	0.50	16.5	0	16.5	27.5
9-Mar	13	34.00	0.50	17.0	0	17.0	28.3
15-Mar	19	33.96	0.53	18.0	0	18.0	30.0
21-Mar	25	27.00	0.70	18.9	0	18.9	31.5
27-Mar	31	32.14	0.70	22.5	0	22.5	37.5
2-Apr	37	27.57	0.87	24.0	0	24.0	40.0
8-Apr	43	31.15	0.87	27.1	0	27.1	45.2
14-Apr	49	28.37	0.98	27.8	0	27.8	46.3
20-Apr	55	26.73	0.98	26.2	0	26.2	43.7
26-Apr	61	26.46	0.99	26.2	0	26.2	43.7
2-May	67	26.46	0.99	26.2	0	26.2	43.7
8-May	73	26.36	0.99	26.1	0	26.1	43.5
14-May	79	26.36	0.99	26.1	0	26.1	43.5
20-May	85	26.26	0.99	26.0	0	26.0	43.3
26-May	91	25.73	0.96	24.7	0	24.7	41.2
1-Jun	97	28.47	0.85	24.2	0	24.2	40.3
7-Jun	103	25.18	0.85	21.4	0	21.4	35.7
10-Jun	End				0		
Total				432.9		432.9	721.6

CWR= Crop water requirement; ETc=Crop evapotranspiration; Net Irr = Net irrigation and Gr. Irr. Gross Irrigation

4.3. Response of Onion Growth, Yield and Yield Parameters to Deficit Irrigation and Furrow Irrigation Methods

Deficit irrigation application under furrow irrigation methods significantly affected onion growth and yield components like plant height, leaf number per plant , bulb height, bulb diameter, bulb weight, bulb dry matter, marketable, none-marketable and total bulb yield.

4.3.1 Onion growth parameters

The results of onion growth parameters including a plant height and number of leaves per plant were recorded at the end of each growth stage as affected by the application of different treatment. The study has revealed a significant ($P < 0.05$) difference between treatments due to deficit irrigation levels and furrow irrigation methods on onion growth parameters.

Plant height at the end of each growth stage

The different levels of irrigation and furrow irrigation methods at each growth stages showed significant effect on plant height of onion (Table 7). Analysis of variance for plant height at the end initial and late-season stages of onion had no significantly difference affected by the interaction of irrigation levels and furrow irrigation methods; whereas it had significantly difference affected plant height of onion at developmental and mid-season stages of onion (Appendix Table 5). Plant height of onion at the end of initial stage had significantly ($P < 0.05$) difference among each other by irrigation levels. The maximum plant height of 28.69 cm was obtained from 100% ETc (control irrigation) depth of water applied while 90 and 75% ETc irrigation depth that resulted in plant height of 26.36, and 25.31 cm, respectively. The minimum plant height of 21.76 cm was obtained from treatments that received 50% ETc of irrigation depth. The full irrigation level got 6.93 cm which was greater than plant height irrigated with level of 50% ETc. However, there was no significance difference ($p < 0.05$) between treatments that received 100 and 90, and also 90 and 75% ETc.

Furrow irrigation methods were found to show highly significant different ($P < 0.01$) on plant height of onion at the end of initial stage. The maximum plant height of 26.73 cm was obtained for CFI method followed by AFI and FFI that attained plant height of 25.87 and 24.00 cm, respectively. The treatment irrigated with CFI method got 2.73cm greater plant height than treatment irrigated with FFI method. There was no significantly different ($p < 0.05$) observed among treatments irrigated with CFI and AFI method on plant height.

Plant height of onion at the end of developmental stage had significantly ($p < 0.05$) difference among each other by irrigation levels. The maximum plant height of 44.91 cm was obtained for 100% while 90 and 75% ETc irrigation depth that resulted in plant height of 42.82 and 40.44 cm, respectively. The minimum plant height of 35.42 cm was attained from 50% ETc applied depth of water. There was no significance difference ($p < 0.05$) between treatments that received 100, 90, and 75% ETc.

Furrow irrigation methods were showed highly significant difference ($P < 0.01$) on plant height of onion at the end of development stage. The maximum of 43.13 cm plant height at this stage was obtained for CFI method followed by AFI and FFI that attained of 42.17 and 37.40 cm, respectively. There was no significantly different ($p < 0.05$) plant height observed among treatments irrigated with CFI and AFI method.

Analysis of variance revealed that plant height of onion at the end of development stage was significantly ($p < 0.05$) affected by the interaction of furrow irrigation methods and irrigation levels. The maximum and minimum plants height of 46.87 and 33.80 cm were obtained from treatments received 100% with CFI and 50% ETc with FFI, respectively. The plant height measured at the end of this stage was statistically the same for treatments received 90% with CFI (45.80 cm) and 100% ETc with AFI (45.60 cm) that showed a difference of only 0.2 cm height between them.

The plant height of onion at the end of mid-season stage was highly significant ($P < 0.01$) affected by irrigation levels. At this stage maximum plant height of 50.53 cm was obtained by the treatments received 100% ETc irrigation depth followed by 90 and 75% ETc depth that obtained of 48.43 and 46.73 cm, respectively. The minimum plant height of 43.02 cm was obtained by irrigation level of 50% ETc depth. There was no significance difference ($p < 0.05$) between treatments that received 100 and 90, and also 90 and 75% ETc depths.

Furrow irrigation methods were highly significant ($p < 0.01$) affected plant height of onion at the end of mid-season stage. The maximum and minimum plant height of 48.70 and 45.01 cm were obtained with irrigation methods of CFI and FFI, respectively.

Analysis of variance revealed that plant height of onion at the end of mid-season stage was significant ($p < 0.05$) affected by the interaction of furrow irrigation method and deficit irrigation levels. Significantly maximum plant height of 52.93 cm was obtained for CFI with 100% followed by AFI with 100% and CFI with 90% ETc depth that resulted comparable heights of 51.93 and 49.73 cm, respectively. The minimum plant height of 41.40 cm was obtained from the treatment irrigated with 50% ETc depth with FFI method.

The plant height of onion at the end of late-season stage was highly significant ($P < 0.01$) affected by irrigation levels. The maximum plant height of 53.47 cm was obtained from treatment irrigated with 100% ETc depth followed by 90, and 75% ETc was got plant heights of 52.42, and 50.09 cm, respectively. The minimum plant height of 46.00 cm was attained

by irrigation level of 50% ETc depth. The maximum height difference 7.47cm was seen between 100 and 50% ETc irrigation depth.

Furrow irrigation methods were highly significant ($p < 0.01$) affected plant height of onion at the end of late-season stage. The maximum and minimum plant height of 52.95 and 46.47 cm were obtained with irrigation methods of CFI and FFI, respectively and there was no significant difference ($p < 0.05$) on plant height under CFI (52.95) and AFI (52.07 cm) method that had only 0.88 cm height variation.

From the study it was understood that interaction of furrow irrigation method and deficit irrigation level had no significant ($p < 0.05$) effect on plant height of onion at initial and late-season stages. Whereas it had significant ($p < 0.05$) effect on plant height of onion at developmental and mid-season stages of onion. Plant height increased with increasing irrigation level at all stage of the crop due to better availability of soil moisture that may enhance the vegetative growth of plants by increasing cell division and elongation.

The result was agreed with the findings of El-Oksh *et al*, (1993), who reported that plant height increased with increasing soil moisture level. Also, Curah and Proctor, (1990) reported that, when plants respond to water stress by closing their stomata to slow down water loss by transpiration, gas exchange within the leaf is limited, consequently, photosynthesis and growth will slow down, Aujla and Samadan (1992) reported that irrigation level had significant effect on plant height. The result also agrees with the findings of Mebrahtu *et al*. (2018) who reported that water deficit significantly reduced plant height, Akele (2019), who found that water stress, reduces plant height, which in turn affects yield.

Table 7: Effect of irrigation level and furrow irrigation method on plant height of onion at each stage

Irrigation level (%)	Crop growth stage			
	Initial	Development	Mid-season	Late-season
100	28.69 ^c	44.91 ^b	50.53 ^a	53.47 ^c
90	26.38 ^{bc}	42.82 ^b	48.43 ^{ab}	52.42 ^{cd}
75	25.31 ^b	40.44 ^b	46.73 ^b	50.09 ^d
50	21.76 ^a	35.42 ^a	43.02 ^c	46.00 ^e

LSD _{0.05}	3.241	4.664	2.521	3.378
Furrow irrigation method				
CFI	26.73 ^b	43.13 ^b	48.70 ^a	52.95 ^b
AFI	25.87 ^b	42.17 ^b	47.83 ^b	52.07 ^b
FFI	24.00 ^a	37.40 ^a	45.01 ^c	46.47 ^a
LSD _{0.05}	1.249	1.298	0.850	1.154
CV1 (%)	6.4	5.7	2.7	3.3
CV2 (%)	5.7	3.7	2.1	2.6

Means followed by the same letter(s) within the column are not significantly different at $P < 0.05$; LSD= least significant difference; CV = Coefficient of variation.

Number of leaf per plant at the end of each growth stage

Analysis of variance for number of leaves per plant at the end of each growth stages of onion was significantly affected by the irrigation levels and furrow irrigation methods (Table 8) ;whereas there was no significant effect by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 6). Analysis of variance for number of leaves per plant at the end of initial stage of onion was significantly ($P < 0.05$) affected by the irrigation levels. There were non-significant difference among 100, 90, and 75% ETc depth of water applied; whereas there were significant difference between 100 and 50, 90 and 50 and 75 and 50% ETc depth of water applied. The maximum number of leaves of 4.80 per plant was obtained at 100% ETc depth of water applied. While the minimum number of leaves of 3.67 per plant was obtained at 50% ETc depth of water applied.

Analysis of variance for number of leaves per plant at the end of initial stages of onion was highly significant ($p < 0.01$), due to the furrow irrigation methods. The maximum number of leaves of 4.77 per plant was recorded for CFI method followed by AFI and FFI that obtained 4.50 and 3.68 number of leaves per plant, respectively. There were significant differences among CFI, AFI, and FFI method.

Analysis of variance for number of leaves per plant at the end of development stage of onion was highly significant ($p < 0.01$) affected by the irrigation levels. There were non-significant difference between 100 and 90 and 90 and 75% ETc; whereas there were significant differences among (100, 75, and 50) and (90, 75 and 50) % ETc depth of water applied. The maximum number of leaves of 8.20 per plant was attained at 100% ETc followed by 90 and 75% ETc depth of water applied that obtained of 7.82 and 7.36 number of leaves per plant,

respectively. The minimum number of leaves of 6.11 per plant was obtained at 50% ETc depth of water applied.

Analysis of variance for number of leaves per plant at the end of development stages of onion was highly significant ($p < 0.01$), due to the furrow irrigation methods. The maximum number of leaves of 7.83 per plant was obtained from CFI method followed by AFI and FFI that attained of 7.52 and 6.77 numbers of leaves per plant, respectively. There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for number of leaves per plant at the end of mid-season stage of onion was highly significant ($p < 0.01$) influenced by the irrigation levels. There was non-significant difference between 100 and 90% ETc; whereas there were significant differences among (100, 75, and 50) and (90, 75 and 50) % ETc depth of water applied. The maximum number of leaves of 9.62 per plant was obtained at 100% ETc depth of water applied followed by 90 and 75% ETc that obtained of 9.07 and 8.16 number of leaves per plant, respectively. The minimum number of leaves of 7.24 per plant was recorded at 50% ETc depth.

Analysis of variance for number of leaves per plant at the end of mid-season stages of onion was highly significant ($p < 0.01$), due to the furrow irrigation methods. The maximum number of leaves of 9.55 per plant was obtained for CFI method followed by AFI and FFI that recorded of 8.67 and 7.35 numbers of leaves per plant, respectively. There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for number of leaves per plant at the end of late-season stage of onion was highly significant ($p < 0.01$) affected by the irrigation levels. There were non-significant difference between 100 and 90% ETc; whereas there were significant differences among (100, 75, and 50) and (90, 75 and 50) % ETc depth of water applied. The maximum number of leaves of 10.67 per plant was obtained at 100% ETc depth of water applied followed by 90 and 75% ETc that attained 10.27 and 9.40 numbers of leaves per plant, respectively. The minimum number of leaves of 8.38 per plant was obtained at 50% ETc depth.

Analysis of variance for number of leaves per plant at the end of late-season stages of onion was highly significant ($p < 0.01$), due to the furrow irrigation methods. The maximum number of leaves of 10.650 per plant was obtained for CFI method followed by AFI and FFI that obtained 10.017 and 8.367, respectively. There were significant differences among CFI, AFI, and FFI method.

At this study it was observed that leaf number per plant at the end of each growth stage showed significant variation ($p < 0.05$) among different treatments for different irrigation levels applied and different furrow irrigation methods used; whereas no significant ($p < 0.05$) difference of leaf number per plant among treatments was observed by the interaction of irrigation levels and furrow irrigation methods.

The result revealed that leaf number per plant increase with increasing irrigation levels. As a result, plots which receive full irrigation level showed more leaf number per plant than other treatments at each stage. The result was in line with the findings of Abbey and Joyce (2004), who reported that the higher leaf number per plant resulted from application of 100% ETc depth is due to the irrigation effect that facilitates nutrient availability and photosynthesis for uninterrupted growth of the plant, and the reduced number of leaves per plant at 50% ETc depth may be attributed to effects of water stress on cell expansion.

The result was also agreed with the findings of Thabet *et al.* (1994), who indicated that the number of leaves and bulb dry matter and bulb ratio were increased by increasing irrigation, El-Haris and Abdel Razek (1997), growth characteristics, yield and yield components of onion generally improved with the increased in total water applied during growing period, Biswas *et al.* (2003), Onion bulbs of irrigated treatments gave highest leaves number per plant than the non-irrigated one. The result also agrees with the findings of Mebrahtu *et al.* (2018), who reported that number of leaves per plant was increased by increasing irrigation levels.

Table 8: Effect of irrigation level and furrow irrigation method on number of leaves per plant at each growth stage

Irrigation level (%)	Crop growth stage			
	Initial	Development	Mid-season	Late-season
100	4.800 ^a	8.200 ^a	9.622 ^a	10.667 ^c
90	4.511 ^a	7.822 ^{ab}	9.067 ^a	10.267 ^c
75	4.289 ^a	7.356 ^b	8.156 ^b	9.400 ^d

50	3.667 ^b	6.111 ^c	7.244 ^c	8.378 ^c
LSD _{0.05}	0.6184	0.8333	0.8949	0.8424
CV (%)	7.2	5.7	5.3	4.4
Furrow irrigation method				
CFI	4.767 ^a	7.833 ^a	9.550 ^a	10.650 ^a
AFI	4.500 ^b	7.517 ^b	8.667 ^b	10.017 ^b
FFI	3.683 ^c	6.767 ^c	7.350 ^c	8.367 ^c
LSD(P=0.05)	0.1136	0.1499	0.2870	0.3114
CV (%)	3.0	2.3	3.9	3.7

Means followed by the same letter(s) within the column are not significantly different at $P < 0.05$; LSD= least significant difference; CV = Coefficient of variation.

4.3.2 Yield and yield component parameters of onion

The results of onion yield and yield component parameters including a bulb diameter, bulb length, bulb weight, dry weight of bulb, marketable, unmarketable and total bulb yield obtained were affected by the application of the different treatments. The data revealed a significant difference ($P < 0.05$) between treatments due to furrow irrigation methods and irrigation levels on onion yield parameters.

Bulb Diameter

Analysis of variance for bulb diameter of onion was significantly affected by the irrigation levels and furrow irrigation methods, but there was no significant effect by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 7). Analysis of variance for bulb diameter of onion was highly significant ($P < 0.01$) affected by the irrigation levels (Table 9). There were non-significant difference between 100, and 90, and 90, and 75% ETc depth of water applied; whereas there were significant differences among 100, 75, and 50% ETc depth of water applied. The maximum bulb diameter of 6.20 cm was obtained at 100% ETc (control irrigation) followed by 90 and 75% ETc depth of water applied that obtained 5.85 and 5.40 cm bulb diameter, respectively. The minimum bulb diameter of 4.68 cm was recorded at 50% ETc depth.

Analysis of variance for bulb diameter of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum bulb diameter of 6.02 cm was obtained for CFI method followed by AFI and FFI that obtained of 5.73 and 4.82 cm bulb diameter, respectively. There were significant differences among CFI, AFI, and FFI methods.

From the result, the increased in bulb diameter with increasing water content may be due to the fact that high moisture content favors gas exchange and facilitate photosynthesis which intern increase nutrient uptake of the plant and contributes for the formation of large bulb size of onion.

The result of the study was in line with the findings of Thabet *et al.*, (1994), who reported that the number of leaves, and bulb dry matter and bulb diameter were increased by increasing irrigation, Martin de Santa Olalla *et al.*, (2004) plots which received the greatest volumes of water during the development and ripening stages yield harvests with higher percentages of large-size bulbs whereas the water shortages induced during the growth and bulb formation stages led to higher percentages of small-size bulbs which indicated that size of bulb vary proportionally with the level of water. The result also agrees with the findings of Mebrahtu *et al.* (2018), who reported bulb diameter of onions was increased by increasing irrigation water, Akele (2019) indicated that the bulb diameter of onions was increased at a higher amount of irrigation water.

Bulb length

Analysis of variance for bulb length of onion was significantly affected by the irrigation levels and furrow irrigation methods, but there was no significant effect by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 7). Analysis of variance for bulb length of onion was significantly ($P < 0.05$) affected by the irrigation levels (Table 9). There were non-significant difference between 100 and 90 and 90 and 75% ETc depth of water applied; whereas there were significant difference among 100, 75 and 50% ETc depth of water applied. The maximum bulb length of 5.99 cm was obtained at 100% ETc followed by 90 and 75% ETc depth of water applied that obtained of 5.70 and 5.27 cm bulb height, respectively. The minimum bulb length of 4.52 cm was obtained at 50% ETc depth.

Analysis of variance for bulb length of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum bulb length of 5.85 and 4.68 cm were obtained from CFI and FFI methods, respectively and AFI method was resulted a bulb length of 5.58 cm. There were significant differences among CFI, AFI, and FFI methods.

Table 9: Effect of furrow irrigation methods and irrigation levels on bulb diameter and bulb length of onion

Irrigation level (%)	BD (cm)	BL (cm)
100	6.158 ^a	5.989 ^c
90	5.849 ^{ab}	5.696 ^{cb}
75	5.402 ^b	5.267 ^b
50	4.680 ^c	4.522 ^a
LSD _{0.05}	0.7126	0.7141
CV (%)	6.5	6.7
Furrow irrigation method		
CFI	6.015 ^a	5.853 ^c
AFI	5.732 ^b	5.575 ^b
FFI	4.820 ^c	4.677 ^a
LSD(P=0.05)	0.2242	0.2345
CV (%)	4.7	5.0

Means followed by the same letter(s) within the column are not significantly different at $P < 0.05$; LSD= least significant difference; CV = Coefficient of variation; BD = bulb diameter and BL= bulb length.

The result revealed that the amount of water applied to each treatment had a direct relation with bulb length in which depth of water applied and furrow methods showed significantly affected on bulb height. This result of study agrees with findings of Martin de Santa Olalla *et al.* (2004) who observed smaller sized bulbs in mild water-stressed onion plants. Bulb height is directly related to the amount of water applied because higher water levels promote better water comfort to the plants (David *et al.*, 2016).

Bulb weight

Analysis of variance for average bulb weight of onion was significantly affected by the irrigation levels and furrow irrigation methods and also by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 8). Analysis of variance for average bulb

weight of onion was highly significant ($P < 0.01$) affected by the irrigation levels. There were non-significant difference between 100, and 90, and 90, and 75% ETc depth of water applied; whereas there were significant differences among 100, 75, and 50% ETc depth of water applied. The maximum average bulb weight of 67.39 gm was obtained at 100% ETc followed by 90 and 75% ETc depth of water applied that obtained of 64.28 and 58.95 gm, respectively. The minimum average bulb weight of 52.44 gm was obtained at 50% ETc depth.

Analysis of variance for average bulb weight of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum average bulb weight of 65.71 and 53.39 gm were obtained from CFI and FFI methods, respectively and AFI method was resulted an average bulb weight of 63.20 gm. There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for average bulb weight of onion was highly significant ($P < 0.01$) affected by the interaction of irrigation levels and furrow irrigation methods (Table 10). The maximum average bulb weight of 73.98 gm was obtained for CFI with 100% ETc (full irrigation) followed by AFI with 100 and CFI with 90% ETc that resulted of 70.45 and 70.35 gm, respectively. The minimum average bulb weight of 49.52 gm was obtained from the treatment irrigated with 50% ETc depth with FFI method.

The result revealed that average bulb weight increased with increasing irrigation levels. As a result, plots which receive full irrigation level with CFI method showed more average bulb weight than other treatments followed by the treatments which received 100%ETc with AFI method. This result of study agrees with findings of Neeraja *et al.* (1999) and Sharda *et al.* (2006) reported that bulb weight increased with increasing irrigation level. Similarly average bulb weight of onion increased when level of irrigation water applied increased (Akele, 2019).

Table 10: Effects of interaction of irrigation levels and furrow irrigation methods on bulb weight of onion

Treatments	Bulb weight of onion(gm)		
	Furrow irrigation method		
Irrigation level (%)	CFI	AFI	FFI
100	73.99 ^a	70.45 ^a	57.74 ^{bc}
90	70.35 ^a	67.88 ^{ab}	54.60 ^c

75	63.84 ^b	61.32 ^b	51.71 ^c
50	54.66 ^c	53.16 ^c	49.52 ^c
LSD _{0.05}	6.38		
CV1 (%)	5.2		
CV2 (%)	2.4		

Means followed by the same letter(s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV1 = Coefficient of variation for irrigation level; CV2= Coefficient of variation for furrow irrigation method

Dry weight of bulb

Analysis of variance for dry weight of bulb of onion was significantly affected by the irrigation levels and furrow irrigation methods and also by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 8). Analysis of variance for dry weight of bulb of onion was highly significant ($P < 0.01$) affected by the irrigation levels. The maximum dry weight of bulb of 51.44 gm was obtained from irrigating 100% ETc depth and had no significant difference from treatments received 90% ETc depth that resulted of 48.10 gm. While the minimum dry weight of bulb of 26.54 gm was obtained in the case of 50% ETc irrigation depth.

Analysis of variance for dry weight of bulb of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum dry weight of bulb of 46.29 and 34.10 gm were obtained from CFI and FFI methods respectively, and AFI method was resulted a dry weight of bulb of 43.56 gm. There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for dry weight of bulb of onion was highly significant ($P < 0.01$) affected by the interaction of irrigation levels and furrow irrigation methods (Table 11). Significantly maximum dry weight of bulb of 56.53 gm was obtained for CFI with 100% ETc followed by AFI with 100 and CFI with 90% ETc that resulted of 55.22 and 54.96 gm, respectively. The minimum dry weight bulb of 24.52 gm was obtained from the treatment irrigated with 50%ETc depth with FFI method.

More frequent irrigation resulted in the higher dry weight of bulb accumulation in the plant. The result was agreed with the findings of Thabet *et al.* (1994), who indicated that the number of leaves and bulb dry matter and bulb ratio were increased by increasing irrigation. These findings was also similar with those of Neeraja *et al.* (1999), Martin de Santa Olalla

et al. (2004) and Sharda *et al.* (2006) reported that bulb weight increased with increasing irrigation level.

Table 11: Effects of interaction of irrigation levels and furrow irrigation methods on dry weight of bulb of onion

Treatments	Dry weight of bulb of onion (gm)		
	Furrow irrigation method		
Irrigation level (%)	CFI	AFI	FFI
100	56.53 ^a	55.22 ^a	42.56 ^c
90	54.96 ^a	51.50 ^{ab}	37.82 ^{cd}
75	44.30 ^{bc}	41.78 ^c	31.51 ^{de}
50	28.69 ^e	26.41 ^e	24.52 ^e
LSD _{0.05}	8.775		
CV1 (%)	10.5		
CV2 (%)	5.0		

Means followed by the same letter(s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV1 = Coefficient of variation for irrigation level; CV2= Coefficient of variation for furrow irrigation method

Marketable bulb yield

Analysis of variance for marketable bulb yield of onion was significantly affected by the irrigation levels and furrow irrigation methods and also by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 9). Analysis of variance for marketable bulb yield of onion was highly significant ($P < 0.01$) affected by the irrigation levels (Table 13). There were non-significant difference between 100, and 90, and 90, and 75% ETc depth of water applied; whereas there were significant differences between 100 and 75, 100 and 50, 90 and 50 and 75 and 50% ETc depth of water applied. The maximum marketable bulb yield of 32695 kg ha⁻¹ was obtained at 100% ETc followed by 90 and 75% ETc depth of water

applied that obtained of 30636 and 28283 kg ha^{-1} , respectively. The minimum marketable bulb yield of 25144 kg ha^{-1} was attained at 50% ET c depth.

Analysis of variance for marketable bulb yield of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum marketable bulb yield of 30594 and 27266 kg ha^{-1} were obtained from CFI and FFI methods, respectively and AFI method was resulted a marketable bulb yield of 29708 kg ha^{-1} . There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for marketable bulb yield of onion was highly significant ($P < 0.01$) affected by the interaction of irrigation levels and furrow irrigation methods (Table 12). Significantly maximum marketable bulb yield of 34538 kg ha^{-1} was obtained from CFI with 100% ET c depth followed by AFI with 100% and CFI with 90% ET c that resulted of 33396 and 32292 kg ha^{-1} , respectively. The minimum marketable bulb yield of 23741 kg ha^{-1} was obtained from the treatment irrigated with 50% ET c depth with FFI method.

This result indicates that any level of water stress can reduce considerable onion yield. From the study it could be showed that maximum marketable bulb yield was observed from fully irrigated treatment with CFI method followed by AFI method with 100% ET c depth treatment. Whereas treatments receiving 50% ET c depth with FFI method was resulted the minimum marketable bulb yields.

The current result was in agreement with Sepaskhah and Ghasemi (2008) reported that small amount of applied water reduced yield in every other furrow irrigation (AFI and FFI) as compared to CFI due to water stress. The increment in marketable bulb yield due to application of irrigation water could be attributed to the increment in vegetative growth and increased production, which is associated with increment in leaf area index, bulb diameter and average bulb weight (Neeraja *et al.*, 1999). The result also agrees with the findings of Mebrahtu *et al.* (2018) and Akele (2019) reported that marketable bulb yield of onions was increased by increasing irrigation water.

Table 12: Effects of interaction of irrigation levels and furrow irrigation methods on marketable bulb yield of onion

Marketable bulb yield of onion (Kg ha^{-1})	
Treatments	Furrow irrigation method

Irrigation level (%)	CFI	AFI	FFI
100	34538 ^a	33396 ^{ab}	30149 ^b
90	32292 ^{ab}	31305 ^b	28312 ^{bc}
75	29386 ^{bc}	28600 ^{bc}	26863 ^c
50	26159 ^{cd}	25531 ^{cd}	23741 ^d
LSD _{0.05}	3093.6		
CV1 (%)	5.3		
CV2 (%)	1.4		

Means followed by the same letter(s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV1 = Coefficient of variation for irrigation level; CV2= Coefficient of variation for furrow irrigation method

Unmarketable bulb yield

Analysis of variance for unmarketable bulb yield of onion was significantly affected by the irrigation levels and furrow irrigation methods; whereas there was no significant effect by the interaction of irrigation levels and furrow irrigation methods (Appendix Table 9). Analysis of variance for unmarketable bulb yield of onion was highly significant ($P < 0.01$) affected by the irrigation levels (Table 13). There were significant differences among 100, 90, 75 and 50% ETc depth of water applied. The maximum unmarketable bulb yield of 2132 kg ha⁻¹ was obtained at 50% ETc depth followed by 75 and 90% ETc depth of water applied that obtained of 1185 and 681 kg ha⁻¹, respectively. The minimum unmarketable bulb yield of 403 kg ha⁻¹ was obtained at 100% ETc depth.

Analysis of variance for unmarketable bulb yield of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum unmarketable bulb yield of 1212 and 976 kg ha⁻¹ were obtained from FFI and CFI methods, respectively and AFI method was resulted an unmarketable bulb yield of 1112 kg ha⁻¹. There were significant differences among CFI, AFI, and FFI methods.

Table 13: Effect of irrigation levels and furrow irrigation methods on yield component parameters of onion

Treatments	Yield parameters of onion
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Irrigation level (%)	MBY (kg ha^{-1})	UMBY (kg ha^{-1})	TBY(kg ha^{-1})
100	32695 ^a	403 ^a	33098 ^c
90	30636 ^{ab}	681 ^b	31317 ^{cb}
75	28283 ^b	1185 ^c	29468 ^{ba}
50	25144 ^c	2132 ^d	27275 ^a
LSD _{0.05}	3087.30	268.47	3143.10
Furrow Irrigation method			
CFI	30594 ^a	976 ^a	31570 ^c
AFI	29708 ^b	1112 ^b	30820 ^b
FFI	27266 ^c	1212 ^c	28478 ^a
LSD _{0.05}	355.10	47.46	326.80
CV1 (%)	5.3	12.2	5.2
CV2 (%)	1.4	5.0	1.2

Means followed by the same letter(s) are not significantly different at ($P < 0.05$); LSD= Least significant difference; CV = Coefficient of variation; MBY= Marketable bulb yield; UMBY= Unmarketable bulb yield; TBY= Total bulb yield

The result showed that; yield of very small bulbs increased with increasing deficit irrigation. This may be for the cases that under moisture stress condition, stomata closer and low rate of transpiration takes place which brought about reduced photosynthesis and results poor bulb growth and development.

The current result was agreed with the findings of Martin de Santa Olalla *et al.* (2004), who reported that the increase in water deficit favored an increase in the percentage of small size bulbs with diameters between 30 and 40 mm, Kaman *et al.* (2006), fixed furrow irrigation lowers quality of potato tubers as a result of limitation of water, Kebede (2003), who reported that stressed onion plants may bulb too early, produce small-sized bulbs and bulb splits and thus, produce high amount of unmarketable yield. Similarly, Mebrahtu *et al.* (2018), who reported that yield of very small bulbs size increased with deficit irrigation increased.

Total bulb yield

Analysis of variance for total bulb yield of onion was significantly influenced by the irrigation levels and furrow irrigation methods and also by the interaction of deficit irrigation levels and furrow irrigation methods (Appendix Table 9). Analysis of variance for marketable bulb yield of onion was significant ($P < 0.05$) affected by the irrigation levels (Table 13). The maximum total bulb yield of onion was 33098 kg ha^{-1} obtained from the treatment received 100% ETc depth which had no significant difference ($p < 0.05$) from treatment irrigated with 90% ETc depth that resulted of 31317 kg ha^{-1} . The minimum total bulb yield of 27275 kg ha^{-1} was obtained at 50% ETc depth.

Analysis of variance for total bulb yield of onion was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum total bulb yield of 31570 and 28478 kg ha^{-1} were obtained from CFI and FFI methods, respectively and AFI method was resulted a total bulb yield of 30820 kg ha^{-1} . There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for total bulb yield of onion was highly significant ($P < 0.01$) affected by the interaction of irrigation levels and furrow irrigation methods (Table 14). During the study the analysis of variance revealed that the maximum total bulb yield of onion was obtained 34812 kg ha^{-1} from treatment irrigated CFI method with 100 depth followed by treatment irrigated AFI method with 100% ETc depth that got comparable total bulb yield of 33784 kg ha^{-1} . The minimum total bulb yield of 25922 kg ha^{-1} was attained from the treatment irrigated with 50% ETc depth with FFI method.

The result agrees with the findings of Sammis *et al.* (2000), who reported onions under water deficiency decrease in its evapotranspiration and consequently yield, Pelter *et al.* (2004) also showed that total yield was reduced by soil-water stress imposed at any growth stage. Bekele and Tilahun (2007) reported that yield of onion significantly different from optimal irrigation if the water deficit of 25, 50, and 75% ETc is in the second, third or during all stages but deficit at first and fourth growth stages had insignificantly effect on yield as compared to optimum application. Similarly, Mebrahtu (2019), who reported that the increased total bulb yield by applying full (no deficit) irrigation could have better performance on vegetative growth like plant height, number of leaves and leaf length which increase photosynthetic capacity of the plant, which in turn can improve bulb weight and contribute to increment in total bulb yield. The result also agrees with the findings of Akele (2019), who reported that total bulb yield of onions was increased by increasing irrigation water.

Table 14: Effects of interaction of irrigation levels and furrow irrigation methods on total bulb yield of onion

Treatments	Total bulb yield of onion (Kgha ⁻¹)		
	Furrow irrigation method		
Irrigation level (%)	CFI	AFI	FFI
100	34812 ^a	33784 ^{ab}	30698 ^b
90	32797 ^{ab}	32036 ^{ab}	29117 ^b
75	30437 ^b	29790 ^b	28177 ^{bc}
50	28234 ^{bc}	27670 ^{bc}	25922 ^c
LSD _{0.05}	3147.1		
CV1 (%)	5.2		
CV2 (%)	1.2		

Means followed by the same letter(s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV1 = Coefficient of variation for irrigation level; CV2= Coefficient of variation for furrow irrigation method

4.4 Water Productivity

4.4.1 Crop Water Use Efficiency

Analysis of variance for CWUE was significantly affected by the irrigation levels and furrow irrigation methods and also by the interaction of irrigation levels and furrow irrigation methods at the study area (Appendix Table 10). Analysis of variance for CWUE was highly significant ($P < 0.01$) affected by the irrigation levels. The maximum CWUE obtained during the study period was 20.85 kgm⁻³ from the treatment received 50% ETc depth followed by treatment irrigated with 75% ETc depth that resulted of 15.03 kgm⁻³ while, 90, and 100% ETc depth treatments obtained CWUE of 13.27 and 12.61 kgm⁻³, respectively. There were significant differences among (50, 75, and 90) and (50, 75, and 100) % ETc irrigation levels but which had not significant differences between 90 and 100% ETc irrigation levels.

Analysis of variance for CWUE was highly significant ($p < 0.01$) affected by the furrow irrigation methods. The maximum and minimum CWUE of 18.99 and 9.72 kgm⁻³ were

obtained from method of AFI and CFI, respectively and FFI method was resulted a CWUE of 17.61 kgm⁻³. There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for CWUE was highly significant ($P < 0.01$) influenced by the interaction of irrigation levels and furrow irrigation methods (Table 15). During the study the analysis of variance revealed that the maximum CWUE was measured 25.56 kgm⁻³ from treatment irrigated AFI method with 50% ET_c depth followed by treatment irrigated FFI method with 50% ET_c depth that obtained comparable CWUE of 23.95 kgm⁻³. The minimum CWUE of 8.04 kgm⁻³ was obtained from the treatment irrigated with 100% ET_c depth with CFI method followed by treatment irrigated with 90% ET_c depth with CFI method that resulted CWUE of 8.42 kgm⁻³.

From this study it could be observed that the increased irrigation application levels for each furrow irrigation method, resulted a decreased CWUE which shows that as depth of application increase water lose by deep percolation, surface runoff and evaporation increase rather than water utilized by crop. The result agrees with the findings of Gençoglan and Yazar (1999), who reported that CWUE values decreased with increasing water use. The result also confirms findings of El-Halim (2013), who states that crop water use efficiency for alternate furrow irrigation substantially increased as compared with conventional furrow irrigation for corn. Similarly, Mebrahtu (2019), who reported that deficit irrigations increased the water use efficiency of onion decreased.

Table 15: Effects of interaction of irrigation levels and furrow irrigation methods on crop water use efficiency of onion

Treatments	Crop water use efficiency (kgm ⁻³)		
	Furrow irrigation method		
Irrigation level (%)	CFI	AFI	FFI
100	8.04 ^h	15.61 ^{de}	14.18 ^{ef}
90	8.42 ^{gh}	16.44 ^d	14.95 ^e
75	9.37 ^g	18.35 ^c	17.36 ^{cd}

50	13.04 ^f	25.56 ^a	23.95 ^b
LSD _{0.05}	1.31		
CV1 (%)	4.2		
CV2 (%)	1.7		

Means followed by the same letter(s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV1 = Coefficient of variation for irrigation level; CV2= Coefficient of variation for furrow irrigation method

4.4.2. Irrigation Water Use Efficiency

Analysis of variance for IWUE was significantly affected by the irrigation levels and furrow irrigation methods and also by the interaction of irrigation levels and furrow irrigation methods at the study area (Appendix Table 10). Analysis of variance for IWUE was highly significant ($P < 0.01$) affected by the irrigation levels. The maximum IWUE obtained during the study period was 12.51 kgm^{-3} from the treatment received 50% ET_c depth followed by treatment irrigated with 75% ET_c depth that resulted of 9.02 kgm^{-3} while, 90 and 100% ET_c depth of water treatments obtained IWUE of 7.96 and 7.57 kgm^{-3} , respectively. There were significant differences among (50, 75, and 90) and (50, 75, and 100) % irrigation levels but which had not significant differences between 90 and 100% ET_c irrigation levels.

Analysis of variance for IWUE was highly significant ($p < 0.01$) affected by the furrow irrigation methods. Significantly maximum and minimum IWUE of 11.39 and 5.83 kgm^{-3} were obtained from methods of AFI and CFI, respectively and FFI method was resulted an IWUE of 10.56 kgm^{-3} . There were significant differences among CFI, AFI, and FFI methods.

Analysis of variance for IWUE was highly significant ($P < 0.01$) affected by the interaction of irrigation levels and furrow irrigation methods (Table 16). During the study the analysis of variance revealed that the maximum IWUE was measured 15.34 kgm^{-3} from treatment irrigated AFI method with 50% ET_c depth followed by treatment irrigated FFI method with 50% ET_c depth that obtained comparable IWUE of 14.37 kgm^{-3} . The minimum IWUE of 4.82 kgm^{-3} was obtained from the treatment irrigated with 100% ET_c depth with CFI method followed by treatment irrigated with 90% ET_c depth with CFI method that resulted IWUE of 5.05 kgm^{-3} .

Table 16: Effects of interaction of irrigation levels and furrow irrigation methods on irrigation water use efficiency of onion

Irrigation water use efficiency (kgm ⁻³)			
Treatments	Furrow irrigation method		
Irrigation level (%)	CFI	AFI	FFI
100	4.82 ^h	9.36 ^{de}	8.51 ^{ef}
90	5.05 ^{gh}	9.87 ^d	8.97 ^e
75	5.62 ^g	11.01 ^c	10.41 ^{cd}
50	7.83 ^f	15.34 ^a	14.37 ^b
LSD _{0.05}	0.78		
CV1 (%)	4.2		
CV2 (%)	1.7		

Means followed by the same letter(s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV1 = Coefficient of variation for irrigation level; CV2= Coefficient of variation for furrow irrigation method

On this study the values obtained indicate that the increasing irrigation water application a decreased in IWUE was resulted and the lowest IWUE was obtaining from treatments which were irrigated with full irrigation depth of water.

The result of study agrees with the findings of Sepaskhah and Hosseini (2008), as the reported the high water productivity values obtained from AFI method due to the small amount of water applied for AFI method as compared with the CFI method. Similarly, Fabeiro *et al.* (2003) and Kebede (2003) reported that irrigation water use efficiency was higher at lower levels of available soil moisture. In addition, Geerts *et al.* (2009), reported that increased irrigation water use efficiency can be attributed to avoid negative agronomic conditions during crop growth, such as pests, diseases, anaerobic conditions in the root zone due to water logging, etc. Alternative furrow irrigation technique with 100% ET_c irrigation was 28% superior to convectional furrow irrigation with 100% ET_c (Mebrahtu, 2019).

4.5. Yield and Applied Water Relationship

The relation between applied water and total onion bulb yield was evaluated for each interaction of irrigation method and deficit irrigation level (Figure 4 (A)). The relation between IWUE and total onion bulb yield was also evaluated for each interaction of

irrigation method and deficit irrigation level (Figure 4 (B)). It was observed that total bulb yield of onion increased when irrigation water application increased while total bulb yield of onion was increased when IWUE decreased.

The result of the study was in line with that of Mebrahtu (2019) the amount of water applied increased over conventional irrigation method the yield also increased, but high productivity of water were gained in fixed and alternative furrow irrigation methods. Clearly, water productivity depends on total applied water.

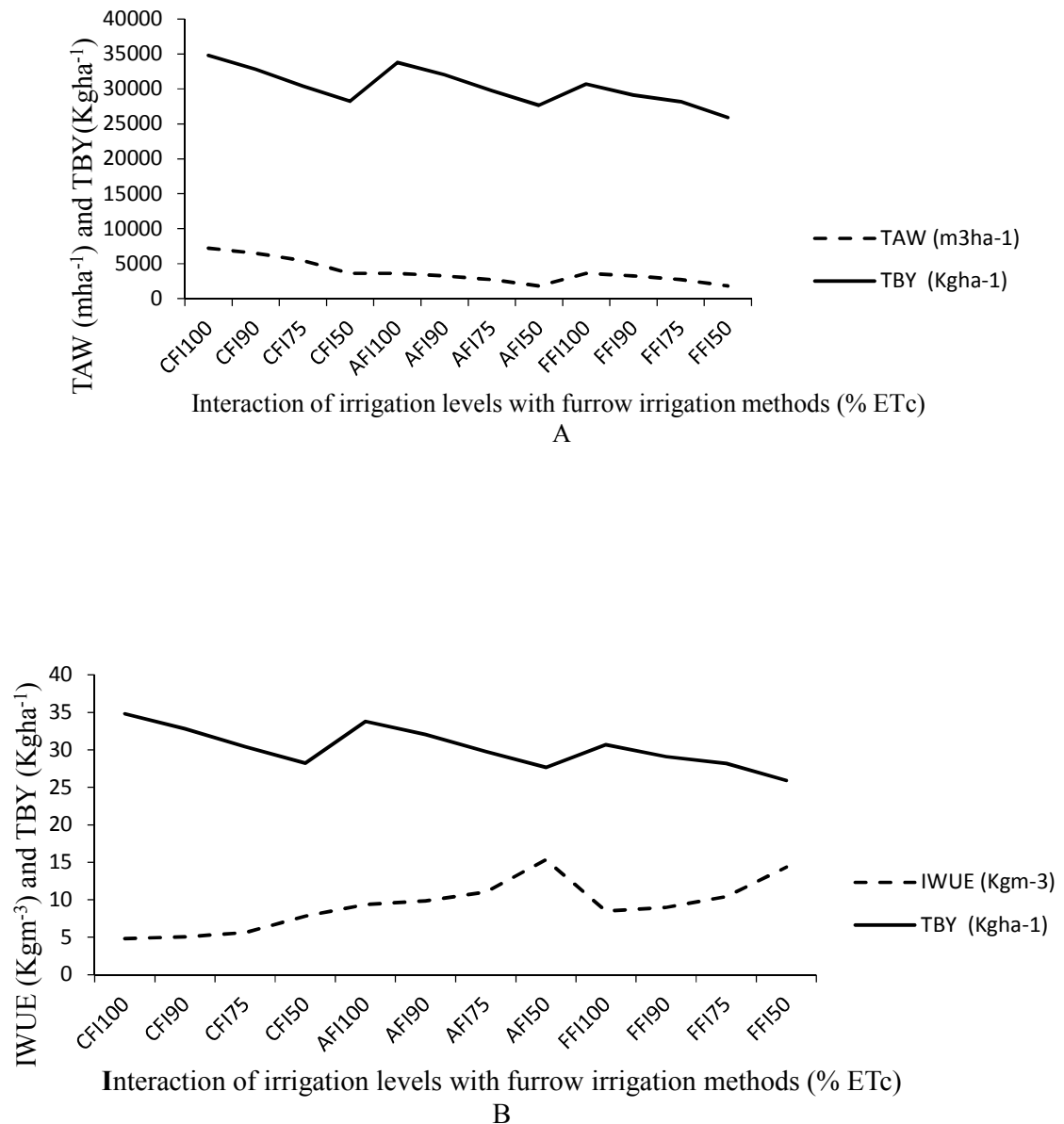


Figure 4: The relationships between (A) total applied water and total bulb yield of onion and (B) irrigation water use efficiency and total bulb yield of onion

4.6. Relative Water Saved and Yield Reduction as Influenced by Deficit Irrigation

The amount of water saved from deficit irrigated treatments relative to the full irrigated treatment and yield reduction (Table 17). Diverting the saved water to increase the irrigated area may compensate for decreases in crop yields. The study also showed that amount of water applied with AFI and FFI methods reduced by half and increased water use efficiency that produce water saved of 5412 m³ha⁻¹ for 50% ET_c deficit treatment. On the other hand, applying irrigation water by AFI method with 100% ET_c irrigation level was resulted 50% water saved and only 2.95% yield redaction occurred when compared to treatments receiving full depth of water with CFI method.

The study result was in line with that of Hassene and Seid (2017), who stated that relative water use efficiency was higher for AFI followed by FFI and lowered for CFI that received the same irrigation depth of 75% ET_c, Nelson and Al-Kaisi (2011), suggested that the economic and environmental benefits of using the AFI method are higher than all other irrigation methods because less water is applied and the economic return is higher.

Table 17: Irrigation water saved and corresponding yield reduction as influenced by deficit irrigation

Trt.	TWA (m ³ ha ⁻¹)	TBYPH (Kgha ⁻¹)	IWUE (Kgm ⁻³)	Water saved (m ³ ha ⁻¹)	Water saved (%)	Yield redaction (Kgha ⁻¹)	Yield redaction (%)
T ₁	3608.0	33784	9.36	3608.0	50.0	1028	2.95
T ₂	3247.2	32036	9.87	3968.8	55.0	2776	7.97
T ₃	2706.0	29790	11.01	4510.0	62.5	5022	14.43
T ₄	1804.0	27670	15.34	5412.0	75.0	7142	20.52
T ₅	3608.0	30698	8.51	3608.0	50.0	4114	11.82

T ₆	3247.2	29117	8.97	3968.8	55.0	5695	16.36
T ₇	2706.0	28177	10.41	4510.0	62.5	6695	19.23
T ₈	1804.0	25922	11.37	5412.0	75.0	8890	25.54
T ₉	7216.0	34812	4.82	0.0	0.0	0	0.00
T ₁₀	6494.4	32797	5.05	721.6	10.0	2015	5.79
T ₁₁	5412.0	30437	5.62	1804.0	25.0	4375	12.57
T ₁₂	3608.0	28234	7.83	3608.0	50.0	6578	18.90

Trt. = Treatment; TWA= Total water applied; TBYPH= Total bulb yield per hectare; IWUE= Irrigation water use efficiency and T₁, T₂, T₃..., T₁₅ for Treatment 1, 2, 3 ..., 15

4.7. Present Simple Correlation Coefficient of Growth and Yield Parameters

Correlation coefficient (r) analysis is used to find out the degree and direction of the relationship between two or more variables. Table 18 is presented results of simple linear correlation (r) analysis carried out the relationship between different plant growth parameters, yield, and yield components of onion. The findings showed that the total bulb yield was positively strong and highly significant ($p < 0.01$) correlated with plant height at mid-season stage ($r = 0.87^{**}$), plant height at late-season stage ($r = 0.89^{**}$), leaf number per plant at mid-season stage ($r = 0.81^{**}$), leaf number per plant at late-season stage ($r = 0.83^{**}$), bulb diameter ($r = 0.89^{**}$), bulb height ($r = 0.90^{**}$), and bulb weight ($r = 0.92^{**}$).

The results indicate that application of irrigation with moisture stress treatments on onion positively affecting the important growth parameters and yield components of the crop. The positive and significant correlation observed among the yield parameters indicating that the final yield is directly dependent on the values of these parameters.

On the other hand, irrigation water use efficiency was correlated negatively with all the studied parameters except crop water use efficiency and unmarketable bulb yield. This revealed that increased in irrigation water productivity was reducing the yield and yield components due to the reduction of irrigation water amount.

This results in line with the study of G/Medhin (2015). A similar study conducted by Metwally (2011) indicated that plant height and bulb diameter had positive and significant correlation with bulb yield. Abd El-Hady *et al.* (2015) also found that there is a significant and positive correlation between bulb diameter and bulb yield.

Table 18: Pearson's correlation coefficient (r) of growth and yield parameters of onions

	PHIS	PHDS	PHMSS	PHLSS	NLIS	NLDS	NLMSS	NLLSS	BD	BH	BW	TBY	IWUE
PHIS	1												
PHDS	0.473***	1											
PHMSS	0.505**	0.495**	1										
PHLSS	0.370 ^{ns}	0.425**	0.861*	1									
NLIS	0.415***	0.408***	0.837***	0.919***	1								
NLDS	0.578***	0.509***	0.894***	0.88***	0.576***	1							
NLMSS	0.664***	0.568***	0.878***	0.850***	0.635***	0.626***	1						
NLLSS	0.552***	0.501***	0.853***	0.847***	0.537***	0.494***	0.941***	1					
BD	0.473**	0.442**	0.819*	0.870**	0.483**	0.455***	0.806**	0.822**	1				
BH	0.474*	0.352 ^{ns}	0.820*	0.867**	0.485***	0.468**	0.808**	0.823**	0.999**	1			
BW	0.419*	0.401*	0.864*	0.883**	0.435**	0.427**	0.819**	0.789**	0.859**	0.858**	1		
TBY	0.511*	0.508**	0.868**	0.892*	0.505**	0.489**	0.812*	0.833**	0.890**	0.903**	0.920**	1	
IWUE	-0.548**	-0.627*	-0.644*	-0.596**	-0.593*	-0.707*	-0.747*	-0.709*	-0.644**	-0.647**	-0.651**	-0.540**	1

PHIS = Plant height at initial Stage; PHDS = Plant height at development Stage; PHMSS = Plant height at mid-season stage; PHLSS= Plant height at late-season stage; NLPIS = Leaf number per plant at initial stage; NLPDS = Leaf number per plant at development Stage; NLPMS = Leaf number per plant at mid-season stage; NLPLSS= Leaf number per plant at late-season stage; BD = Bulb diameter; BH = Bulb height; BW = Bulb weight; TBY = Total bulb yield; *= significant at P <0.05; **= significant at P <0.01; ***= significant at P <0.001 and ns= non-significant

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

A factorial experiment was carried out in split plot design using four irrigation levels as a main plot (90, 75, 50% ET_c, and a control irrigation of 100% ET_c) and three furrow irrigation methods as a sub-plot (alternate furrow irrigation, fixed furrow irrigation and conventional furrow irrigation) in three replications having 12 treatments. The objective of the study was to identify the levels of deficit irrigation and different furrow irrigation methods that provide optimum onion yield and to enhance water productivity under limited water condition.

The results of onion growth parameters (plant height and number of leaves per plant at the end of each growth stages), yield and yield component parameters of onion (bulb diameter, bulb length, bulb weight, dry weight of bulb, marketable yield, unmarketable yield and total bulb yield) and water productivity (CWUE and IWUE) were significantly affected ($p < 0.05$) by the irrigation level and furrow irrigation method. The plant height at developmental and mid-season stages, bulb weight, dry weight of bulb, marketable bulb yield, total bulb yield, CWUE and IWUE were significantly influenced ($p < 0.05$) by the interaction of irrigation levels and furrow irrigation methods.

Hence, this study revealed that AFI and FFI methods save 50% water than CFI method. The maximum and minimum marketable bulb yield of 30594 and 27266 kg ha⁻¹ were achieved from CFI and FFI methods, respectively and AFI method gave a marketable bulb yield of 29708 kg ha⁻¹. The maximum and minimum total bulb yield of 31570 and 28478 kg ha⁻¹ were obtained from CFI and FFI methods, respectively and the AFI method resulted in a total bulb yield of 30820 kg ha⁻¹. Unmarketable bulb yield was reduced as the amount of irrigation level increased. The highest unmarketable bulb yield was obtained from FFI method with the value of 1212 kg ha⁻¹ and the lowest, 976 kg ha⁻¹, correspond to the CFI method. The unmarketable bulb yield of 1112 kg ha⁻¹ was obtained for the AFI method.

The maximum marketable bulb yield of 32695 kg ha⁻¹ was attained at 100% ET_c, followed by 90 and 75% ET_c depth of water applied, which resulted in yield of 30636 and 28283 kg ha⁻¹, respectively. The maximum total bulb yield of onion was 33098 kg ha⁻¹ was obtained from the treatment which received 100% ET_c depth and it had no significant difference ($p < 0.05$) from treatment irrigated with 90% ET_c depth, which resulted in a yield of 31317 kg ha⁻¹. Thus, level of deficit irrigation that allows achieving optimum onion yield was 90% ET_c.

The maximum marketable and total bulb yield of Bombay Red onion variety were 34538 and 34812kg ha^{-1} , respectively, from treatment irrigated with CFI method of 100% ET c depth. It was followed by treatment irrigated with AFI method of 100% ET c depth, giving comparable marketable and total bulb yield of 33396 and 33784kg ha^{-1} , respectively. The result of AFI method with 100% ET c irrigation level showed only 2.95% yield reduction and 50% efficiency in terms of IWUE when compared to the CFI method with 100% ET c irrigation level. The highest IWUE was 15.34 kg m^{-3} obtained from AFI method with 50% ET c . The least IWUE was 4.82 kg m^{-3} obtained from full irrigation level with CFI method.

Generally, it can be concluded that, the yield of onion was increased when the application of irrigation water increased. In contrast, CWUE and IWUE were increased as applied irrigation water decreased. Under conditions that water are scarce, including the study area, AFI method with 100% ET c was best. Adoption AFI method was found to be the best in terms of water use efficiency and yield produced in addition to reducing the labour, time and energy required at the field. However, at areas where water are not scarce, it can be possible applying CFI method with 100% ET c

5.2. Recommendations

From the findings of the experiment at study area for the crop season, the following recommendations are suggested.

- ❖ Accordingly, it is recommended that farmers and commercial growers can produce Bombay Red onion by applying combination of 90% ET c irrigation level with alternate furrow irrigation method.
- ❖ As the experiment was carried out Bombay Red onion variety for one season and in one place, repeating the experiment in space and time is important to improve the validity of the finding.

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APPENDICES

Appendix Table 1: Infiltration rate measurement of the experimental soil data using double ring infiltrometer

Time		Blok-1				Blok-2				Blok-3				Average	
Time elapsed (min)	Cumulative time (min)	Infiltration (mm)	Cumulative Infiltration (mm)	Infiltration rate (mm/min)	Infiltration rate (mm/hr)	Infiltration (mm)	Cumulative Infiltration (mm)	Infiltration rate (mm/min)	Infiltration rate (mm/hr)	Infiltration (mm)	Cumulative Infiltration (mm)	Infiltration rate (mm/min)	Infiltration rate (mm/hr)	Infiltration rate (mm/hr)	Cumulative infiltration (mm)
0	0	0	0			0	0			0	0				0
1	1	2.8	2.8	2.80	168.0	2.60	2.60	2.60	156.0	2.3	2.3	2.30	138.0	154.0	2.57
1	2	2.5	5.3	2.50	150.0	2.40	5.03	2.43	145.8	1.9	4.2	1.90	114.0	120.6	4.84
2	4	2.3	7.6	1.15	69.0	2.20	7.23	1.10	66.0	1.8	6.0	0.90	54.0	84.0	6.94
2	6	2.1	9.7	1.05	63.0	1.90	9.13	0.95	57.0	1.8	7.8	0.90	54.0	62.0	8.88
2	8	2.1	11.8	1.05	63.0	1.80	10.93	0.90	54.0	1.7	9.5	0.85	51.0	48.0	10.74
3	11	1.9	13.7	0.63	38.0	1.70	12.63	0.57	34.0	1.6	11.1	0.53	32.0	34.7	12.48
3	14	1.8	15.5	0.60	36.0	1.68	14.31	0.56	33.6	1.5	12.6	0.50	30.0	29.0	14.14
3	17	1.7	17.2	0.57	34.0	1.60	15.91	0.53	32.0	1.5	14.1	0.50	30.0	24.0	15.74
5	22	1.6	18.8	0.32	19.2	1.30	17.21	0.26	15.6	1.5	15.6	0.30	18.0	17.6	17.20
5	27	1.5	20.3	0.30	18.0	0.20	17.41	0.04	2.4	1.4	17.0	0.28	16.8	15.4	18.24
5	32	1.3	21.6	0.26	15.6	1.25	18.66	0.25	15.0	1.3	18.3	0.26	15.6	12.4	19.52
10	42	1.2	22.8	0.12	7.2	1.23	19.89	0.12	7.4	1.3	19.6	0.13	7.8	7.5	20.76
10	52	0.9	23.7	0.09	5.4	0.85	20.74	0.08	5.1	0.8	20.4	0.08	4.8	5.1	21.61
10	62	0.9	24.6	0.09	5.4	0.85	21.59	0.08	5.1	0.8	21.2	0.08	4.8	5.1	22.46

Appendix Table 2: Climatic condition and reference evapotranspiration rate of the study area for long term (2008-2019)

Months	Min. Temp °C	Max. Temp °C	Humidity %	Wind km/day	Sun Hours	Rad MJ/m ² /day	ETo mm/day	Rain Mm
January	7.9	29.1	37	72	7.1	18.4	3.71	7.5
February	11.0	30.6	37	67	7.9	20.6	4.13	34.7
March	11.9	31.9	53	68	7.9	21.6	4.48	79.2
April	14.8	29.0	51	69	7.8	21.5	4.44	86.4
May	11.9	28.6	74	78	8.9	22.5	4.38	90.6
June	12.3	28.0	75	95	8.1	20.9	4.11	107.5
July	12.8	25.5	78	52	6.3	18.4	3.46	139.0
August	12.6	26.0	77	35	6.7	19.5	3.60	123.7
September	12.5	27.0	77	69	7.1	20.2	3.84	103.5
October	10.5	31.1	71	69	9.2	22.7	4.47	20.8
November	9.2	29.1	58	86	10.2	23.0	4.39	8.4
December	8.9	28.1	37	80	8.1	19.3	3.85	2.6
Average	11.4	28.7	60	70	7.9	20.7	4.07	
Total								803.9

Appendix Table 3: Climatic condition and reference evapotranspiration rate of the study area during study period

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (Hours)	Rad (MJ/m ² /day)	ETo (mm/day)
February	11.0	30.6	37	67	8.0	20.8	4.16
March	11.9	31.1	53	68	7.9	21.6	4.43
April	14.8	29.0	51	69	7.8	21.5	4.42
May	12.0	28.9	75	79	8.7	22.2	4.36
June	12.2	28.0	75	94	8.2	21.0	4.15
Average	12.38	29.52	58.2	75.4	8.12	21.42	4.30

Appendix Table 4: Net and gross irrigation water requirement of onion at experimental site for all irrigation levels

Net irrigation (mm/period)					Gross irrigation (mm/period)			
Date	100% ETc	90% ETc	75% ETc	50% ETc	100% ETc	90% ETc	75% ETc	50% ETc
25-Feb	17.1	17.1 ^{FI}	17.1 ^{FI}	17.1 ^{FI}	28.5	28.5 ^{FI}	28.5 ^{FI}	28.5 ^{FI}
28-Feb	16.9	16.9 ^{FI}	16.9 ^{FI}	16.9 ^{FI}	28.2	28.2 ^{FI}	28.2 ^{FI}	28.2 ^{FI}
3-Mar	16.5	16.5 ^{FI}	16.5 ^{FI}	16.5 ^{FI}	27.5	27.5 ^{FI}	27.5 ^{FI}	27.5 ^{FI}
9-Mar	17.0	15.3	12.6	8.5	28.3	25.5	21.3	14.2
15-Mar	18.0	16.2	13.5	9.0	30.0	27.0	22.5	15.0
21-Mar	18.9	17.0	14.2	9.5	31.5	28.4	23.6	15.8
27-Mar	22.5	20.3	16.9	11.3	37.5	33.8	28.1	18.8
2-Apr	24.0	21.6	18.0	12.0	40.0	36.0	30.0	20.0
8-Apr	27.1	24.4	20.3	13.6	45.2	40.7	33.9	22.6
14-Apr	27.8	25.0	20.9	13.9	46.3	41.7	34.8	23.2
20-Apr	26.2	23.6	19.7	13.1	43.7	39.3	32.8	21.8
26-Apr	26.2	23.6	19.7	13.1	43.7	39.3	32.8	21.8
2-May	26.2	23.6	19.7	13.1	43.7	39.3	32.8	21.8
8-May	26.1	23.5	19.6	13.05	43.5	39.2	32.6	21.75
14-May	26.1	23.5	19.6	13.05	43.5	39.2	32.6	21.75
20-May	26.0	23.4	19.5	13.0	43.3	39.0	32.5	21.7
26-May	24.7	22.2	18.5	12.4	41.2	37.1	30.9	20.6
1-Jun	24.2	21.9	18.2	12.1	40.3	36.3	30.3	20.2
7-Jun	21.4	19.3	16.1	10.7	35.7	32.1	26.8	17.8
10-Jun	End							
Total	432.9	394.9	337.5	241.9	721.6	658.1	562.5	403

CWR= Crop water requirement; ETc=Crop evapotranspiration; Net Irr = Net irrigation; Gr. Irr. Gross Irrigation and FI= Full irrigation

Appendix Table 5: Mean squares analysis of variance (ANOVA) for plant height at initial, development, mid-season and late-season stages of onion

Source of variation	DF	Mean square			
		PHIS	PHDS	PHMSS	PHLSS
Replication	2	5.083	17.773	1.094	5.191
Deficit irrigation level(DIL)	3	74.975*	149.993*	90.907**	98.745**
Error	6	7.894	16.348	4.778	8.575
Furrow irrigation method(FIM)	2	23.413***	113.053***	44.720***	148.348***
Interaction (DIL x FIM)	6	0.193 ^{ns}	6.308*	2.691*	2.776 ^{ns}
Error	16	2.083	2.249	0.964	1.779
Total	35				

DF= degree of freedom; PHIS = Plant height at initial Stage; PHDS = Plant height at development Stage; PHMSS = Plant height at mid-season stage; PHLSS= Plant height at late-season stage; *= significant at P <0.05; **= significant at P <0.01; ***= significant at P <0.001 and ns= non-significant

Appendix Table 6: Mean squares analysis of variance (ANOVA) for leaf number per plant at initial, development, mid-season and late-season stages of onion

Source of variation	DF	Mean square			
		NLPIS	NLPDS	NLPMSS	NLPLSS
Replication	2	0.253	0.101	0.301	0.271
Deficit irrigation level(DIL)	3	2.084*	7.435**	9.821**	9.276**
Error	6	0.287	0.522	0.602	0.533
Furrow irrigation method(FIM)	2	3.823***	3.601***	14.708***	16.674***
Interaction (DIL x FIM)	6	0.044 ^{ns}	0.022 ^{ns}	0.049 ^{ns}	0.3056 ^{ns}
Error	16	0.017	0.030	0.110	0.129
Total	35				

DF= degree of freedom; NLPIS = Leaf number per plant at initial stage; NLPDS = Leaf number per plant at development Stage; NLPMSS = Leaf number per plant at mid-season stage; NLPLSS= Leaf number per plant at late-season stage; *= significant at P <0.05; **= significant at P <0.01; ***= significant at P <0.001 and ns= non-significant

Appendix Table 7: Mean squares analysis of variance (ANOVA) for bulb diameter and bulb height of onion

Source of variation	DF	Mean square	
		BD	BH
Replication	2	0.6411	0.5457
Deficit irrigation level(DIL)	3	3.7031**	3.6552*
Error	6	0.3817	0.3833
Furrow irrigation method(FIM)	2	4.6789***	4.5380***
Interaction (DIL x FIM)	6	0.0209 ^{ns}	0.0206 ^{ns}
Error	16	0.0671	0.0734
Total	35		

DF= degree of freedom; BD = Bulb diameter; BH = Bulb height; *= significant at $P < 0.05$; **= significant at $P \leq 0.01$; ***= significant at $P < 0.001$ and ns= non-significant

Appendix Table 8: Mean squares analysis of variance (ANOVA) for bulb weight and dry weight of bulb of onion

Source of variation	DF	Mean square	
		BW	DWB
Replication	2	21.854	17.065
Deficit irrigation level(DIL)	3	386.229***	1113.386**
Error	6	29.854	56.290
Furrow irrigation method(FIM)	2	508.464***	485.738***
Interaction (DIL x FIM)	6	23.245***	30.072***
Error	16	2.161	4.296
Total	35		

DF= degree of freedom; BW = Bulb weight; DWB = Dry weight of bulb; **= significant at $P < 0.01$ and ***= significant at $P < 0.001$

Appendix Table 9: Mean squares analysis of variance (ANOVA) for marketable bulb yield, unmarketable bulb yield and total bulb yield of onion

Source of variation	DF	Mean square		
		MBY	UMBY	TBY
Replication	2	16354002	97652	18179888
Deficit irrigation level(DIL)	3	94708952**	5197705***	56111367*
Error	6	7163630	54171	7425093
Furrow irrigation method(FIM)	2	35634616***	168253***	31205339***
Interaction (DIL x FIM)	6	842432**	7582 ^{ns}	764064**
Error	16	168329	3008	142567
Total	35			

DF= degree of freedom; MBY = Marketable bulb yield; UMBY = Unmarketable bulb yield; TBY = Total bulb yield; *= significant at P <0.05; **= significant at P <0.01; ***= significant at P <0.001 and ns= non-significant

Appendix Table 10: Mean squares analysis of variance (ANOVA) for crop water use efficiency and irrigation water use efficiency

Source of variation	DF	Mean square	
		CWUE	IWUE
Replication	2	3.188	1.148
Deficit irrigation level(DIL)	3	126.561***	45.562***
Error	6	1.262	0.454
Furrow irrigation method(FIM)	2	300.241***	108.087***
Interaction (DIL x FIM)	6	54.892***	1.761***
Error	16	0.073	0.026
Total	35		

DF= degree of freedom; CWUE = Crop water use efficiency; IWUE = Irrigation water use efficiency and ***= significant at P < 0.001



Appendix Figure 1: Infiltration rate measurement of the experimental site soil



Appendix Figure 2: During land preparation and layout of the experimental site



Appendix Figure 3: During field management of the experimental site



Appendix Figure 4: During data collection and recording of growth and yield parameters

