



**EFFECT OF DEFICIT IRRIGATION AND IRRIGATION INTERVAL ON
YIELD AND ABOVE GROUND BIOMASS OF HARICOT BEAN
(*Phaseolus vulgaris L.*) IN ADAMI TULLU, OROMIA, ETHIOPIA.**

MSc.THESIS

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MARCH,2019

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(*Phaseolus vulgaris L.*) IN ADAMI TULLU, OROMIA, ETHIOPIA.**

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**A THESIS SUBMITTED TO THE
DEPARTMENT OF WATER RESOURCES AND IRRIGATION
ENGINEERING, FACULTY OF BIOSYSTEMS AND WATER
RESOURCES ENGINEERING, SCHOOL OF GRADUATE STUDIES,
INSTITUTE OF TECHNOLOGY, HAWASSA UNIVERSITY, HAWASSA,
ETHIOPIA**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER'S OF SCIENCE IN IRRIGATION AND
DRAINAGE ENGINEERING.**

MARCH, 2019

ADVISORS' APPROVAL SHEET
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DEDICATION

I dedicate this thesis manuscript to my father Belachew Woldeyes, my mother Bargiche Hamid, my dear husband Adem Gare and my beloved sister Achameyelesh Belachew for treating me with affection, love and dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare that this thesis entitled “**Effect of deficit irrigation and irrigation interval on yield and above ground biomass of haricot bean (*Phaseolus vulgaris* L.) in Adami Tullu, Oromia, Ethiopia**” is my own work and all sources of materials used for this thesis have been properly acknowledged. I have followed all ethical and scientific principles of scholarship in the preparation, data collection, and analysis and assemblage of this thesis. I seriously declare that this thesis is not previously submitted for the award of a degree at this or any other University.

This thesis is submitted in partial fulfillment of the requirements for a MSc. degree in Irrigation and Drainage Engineering at the Hawassa University and deposited in the University’s Library to be available for readers and borrowers under the rule of the Library.

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ACKNOWLEDGEMENT

Thanks to the almighty Allaha who gave me peace and health throughout my life and to study my MSc.

I would like to make bigger gratitude to Dilla University for giving me the chance to pursue my MSc. study.

My deepest gratitude to my major advisor Dr. Tewedros Assefa and my co-advisor Mrs. Selamawit Assegid for their guidance, technical advice, material support, supervision, suggestion and constructive ideas from the beginning of proposal preparation to the final of the document.

I would like to say thanks to Adami Tullu Agricultural Research Center for giving me experimental site to work my experiment and to all staff members for their support in fieldwork and providing laboratory equipments.

Heartfelt thanks to my family and my dear husband Adem Gare who had been on my side during my study and still strong craves for my success.

My deepest gratitude to my friends, Atalel Awoke ,Aregash Deboch and Munira Hussein for giving me moral support and suggestion about my thesis.

LIST OF ABBREVIATIONS

AGDB	Above Ground Dry Biomass
ATARC	Adami Tullu Agricultural Research Center
CROPWAT	Crop Water Requirement Estimation Model
CSA	Central Statistics Agency
CV	Coefficient of Variation
CWR	Crop Water Requirement
CWUE	Crop Water Use Efficiency
DAFF	Department of Agriculture, Forestry and Fisheries
EC	Electrical Conductivity
ETc	Crop Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
FWUE	Field Water Use Efficiency
HI	Harvest Index
II	Irrigation Interval
IL	Irrigation Level
K	Potassium
Kc	Crop Coefficient
LSD	List Significant Difference

MoWR	Ministry of Water Resources
pH	Power of Hydrogen
PWP	Permanent Wilting Point
RCBD	Randomized Complete Block Design
Rep	Replication
SAS	Statistical Analysis Software
SNNPR	Southern Nations Nationalities and People Region
TAW	Total Available Water
OC	Organic Carbon
WUE	Water Use Efficiency

TABLE OF CONTENTS

DEDICATION	i
STATEMENT OF THE AUTHOR	ii
ACKNOWLEDGEMENT	iii
LIST OF ABBREVIATIONS.....	iv
TABLE OF CONTENTS.....	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDIX TABLES	xi
LIST OF APPENDIX FIGURES.....	xii
ABSTRACT.....	xiii
1. INTRODUCTION	1
1.1. Background	1
1.2. Statement of the Problem.....	3
1.3. Objectives.....	5
1.3.1. General Objective	5
1.3.2. Specific Objectives	5
1.4. Research Questions	5
1.5. Significance of the Study	6
1.6. Scope of the Study.....	6
2. LITERATURE REVIEW	7
2.1. Water Resources in Ethiopia.....	7
2.2. Irrigation Scheduling.....	7
2.3. Deficit Irrigation.....	8
2.4. Plants Response to Water Stress	9

2.5. Crop Water Requirements	10
2.6. Water Use Efficiency (WUE)	11
2.7. Yield Response Factor of Crops to Deficit Irrigation	11
2.8. Haricot Bean varieties and production importance	12
3. MATERIALS AND METHODS.....	14
3.1. Description of the Study Area	14
3.2. Soil Sampling and Analysis	15
3.3. Experimental Design and Treatments	17
3.4. Discharge Measurement and Field Layout.....	18
3.5. Crop Water Requirement and Irrigation Schedule	21
3.6. Agronomic Practices	22
3.7. Yield and yield component data collected	23
3.8. Water Use Efficiency	24
3.9. Yield Response Factor	24
3.10. Statistical analysis	25
4. RESULTS AND DISCUSSION.....	26
4.1. Physical and Chemical Properties of the Soil in the Experimental Site.....	26
4.1.1. Physical Properties of the Soil.....	26
4.1.2. Chemical Properties of the Soil	27
4.2. Reference Evapotranspiration	28
4.3. Crop Water Requirement	29
4.4. Effect of Deficit Irrigation and Irrigation Intervals on Yield and Yield Components.....	34
4.4.1. Days to 50% Flowering and Maturity	34
4.4.2. Plant Height	37
4.4.3. Thousand Seed Weight	38

4.4.4. Number of Pods per Plant.....	39
4.4.5. Yield and Yield Response Factor	42
4.4.6. Number of Seeds per Pod	44
4.4.7. Above Ground Dry Biomass (AGDB)	44
4.4.8. Pod Width and Length.....	45
4.4.9. Leaf Area Index	46
4.4.10. Harvest Index.....	47
4.4.11. Number of Leaves per Plant	48
4.4.12. Water Use Efficiency.....	49
5. SUMMARY, CONCLUSION AND RECOMMENDATIONS.....	50
5.1. Summary	50
5. 2. Conclusion.....	51
5.3. Recommendation.....	52
6. REFERENCES	53
7. APPENDICES	65

LIST OF TABLES

Table 1. Days to different growth stages of haricot bean	13
Table 2. Experimental treatments	17
Table 3. Physical properties of the soil	26
Table 4. Chemical properties of the soil	28
Table 5. The reference evapotranspiration of the study area	29
Table 6. Crop and irrigation water requirement values for 3 days irrigation interval during the period of growing season.	30
Table 7. Crop and irrigation water requirement values for 5 days irrigation interval during the period of growing season.	32
Table 8. Crop and irrigation water requirement values for 7 days irrigation interval during the period of growing season.	33
Table 9. Summary of irrigation interval and irrigation level effects on days to 50% flowering, maturity, plant height, number of pods per plant, number of seeds per pod, crop water use efficiency and field water use efficiency.	35
Table 10. Interaction effect of irrigation level and interval results on days to 50% flowering, maturity, plant height, number of pods per plant, number of seeds per pod, CWUE and FWUE.	36
Table 11. Results of irrigation interval and irrigation level effect on haricot bean yield and above ground biomass.	40
Table 12. Interaction effect of irrigation interval and irrigation level results on haricot bean	41
Table 13. Results of yield response factor	43

LIST OF FIGURES

Figure 1. Location map of study area	14
Figure 2. Experimental field layout	20
Figure 3. Infiltration characteristics of the soil	27

LIST OF APPENDIX TABLES

Appendix Table 1. Long term maximum temperature of the study area in degree celsius	65
Appendix Table 2. Long term minimum temperature of the study area in degree celsius	66
Appendix Table 3. Long term relative humidity of the study area in percent	68
Appendix Table 4. Long term annual sunshine hour in hr/day data of the study area	69
Appendix Table 5. Long term annual wind speed data of the study area in meter per second	70
Appendix Table 6. Long term annual rain fall data of the study area in millimeter	72
Appendix Table 7. Infiltration test data using double ring infiltrometer	74
Appendix Table 8. Free flow discharge values for different size parshall flumes	75
Appendix Table 9. Factorial ANOVA Table for days to 50% flowering	76
Appendix Table 10. Factorial ANOVA Table for maturity day	76
Appendix Table 11. Factorial ANOVA Table for plant height	77
Appendix Table 12. Factorial ANOVA Table for number of pod per plant	77
Appendix Table 13. Factorial ANOVA Table for number of seed per pod	78
Appendix Table 14. Factorial ANOVA Table for pod width	78
Appendix Table 15. Factorial ANOVA Table for pod length	79
Appendix Table 16. Factorial ANOVA Table for number of leaves per plant	79
Appendix Table 17. Factorial ANOVA Table for thousand seed weight	80
Appendix Table 18. Factorial ANOVA Table for yield	80
Appendix Table 19. Factorial ANOVA Table for AGDB	81
Appendix Table 20. Factorial ANOVA Table for leaf area index	81
Appendix Table 21. Factorial ANOVA Table for harvest index	82
Appendix Table 22. Factorial ANOVA Table for CWUE	82
Appendix Table 23. Factorial ANOVA Table for FWUE	83

LIST OF APPENDIX FIGURES

Appendix Figure 1. Double Ring Infiltrometer	79
Appendix Figure 2. Land preparation	79
Appendix Figure 3. Initial stage.....	80
Appendix Figure 4. Development stage.....	80
Appendix Figure 5. Mid stage	81
Appendix Figure 6. Late stage	81
Appendix Figure 7. During harvesting	82
Appendix Figure 8. During threshing	82
Appendix Figure 9. Yield of Haricot bean.....	83
Appendix Figure 10. During yield measurement.....	83

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ABSTRACT

*Availability of water in the required quality and quantity is vital for crop production. Water scarcity does not only occur in arid and semi-arid areas but also it occurs in areas that receive high rainfall and have abundant fresh water resources. Especially in regions with water shortage, deficit irrigation strategies have become important tools to attain higher water use efficiency and optimum yield. Proper irrigation interval is also used to utilize scarce water resources efficiently and effectively by applying the required amount of water when it is needed. These, however, need testing the application of the system under specific condition for a given crop. The objective of this study was to investigate the response of yield and above ground biomass of haricot bean (*Phaseolus vulgaris* L.) under deficit irrigation and various irrigation intervals in Adami Tullu, Oromia, Ethiopia. The treatments were comprised of factorial combinations of two factors. The treatments were four levels of water application (100% , 85% , 70% , and 50% ETc) with three irrigation intervals (3, 5 and 7 days).The experimental design used in this study was randomized complete block design (RCBD) with three replications. Irrigation depth was monitored using a parshall flume with an opening having 3 inch throat width. The analysis of variance for the result of the study indicated significant ($P < 0.05$) differences for yield, above ground biomass and WUE. The highest yield (2202.2 kg/ha) was obtained under treatments which received 100% ETc with 3 day irrigation interval, while the lowest yield (1220.2 kg/ha) was obtained under treatment which received 50% ETc with 7 day irrigation interval. In terms of crop yield and water use efficiency, 50% ETc deficit irrigation application with 3 day irrigation interval gave the highest CWUE of 0.54 kg/m³ and FWUE of 0.38 kg/m³, while the lowest value of CWUE was 0.32 kg/m³ and FWUE was 0.26 kg/m³ were obtained under 100% ETc with 7 day irrigation interval. Therefore, based on yield, above ground biomass and WUE, irrigation level of 85% ETc with 5 day irrigation interval could be recommended to achieve higher yield, above ground biomass and water use efficiency in water scarcity area.*

Key words: Deficit irrigation, Irrigation interval, Haricot bean, water use efficiency.

1. INTRODUCTION

1.1. Background

Water is the most vital factor affecting life in many regions of the world. Water demand increases in the sectors of agriculture, power generation, and industry (Andarzian *et al.*, 2011). Water is scarce both in quantity and quality and water scarcity does not only occur in arid and semi-arid areas but also it occurs in areas that receive high rainfall and have abundant fresh water resources. Water Management affected by domestic, agricultural, industrial and environmental demand of water (Kassam *et al.*, 2007).

Water scarcity as a result of drought and quality deterioration influence many aspects of agricultural productivity and production around the world. In this regard, irrigation contributes to achieving food security and guarantying well established agricultural growth. In arid and semi-arid areas, irrigation sector uses more than 80 percent of the water withdrawn from rivers in developing countries (Ludlow and Muchow, 1990).

Water is a principal factor in agricultural production. Proper development of every plant needs an optimum water supply that meets its physiological needs (Mannocchi and Mecarelli, 1994). Crops are different in term of the amounts of water they need for survival and optimum production. During dry growing periods there is not enough rainfall to compensate for soil moisture losses through evapotranspiration (Jury and Vaux, 2005).

The backbone of Ethiopian economy is rain fed agriculture. However, rainfall is decreasing in many parts of Ethiopia as a result of climate change. Climate change related reasons for the decrease in rain fed agricultural production include extended drought periods, decline in ground water levels and erratic nature of precipitation. Ethiopia is the most populated country in Africa subsequently to Nigeria. Therefore, the rain fed agriculture is not enough to safe food self-reliance (Awulachew *et al.*, 2007).

The Central Rift Valley of Ethiopia is one of the areas where large investments in irrigation development are taking place for the production of cash crops. Rapid population growth results in destruction of environmentally sensitive area contributing to declining soil fertility erosion, low crop yields, feed shortages, progressive land degradation, and reduction of areas under uncultivated (Kamara *et al.*, 2002).

In the context of improving water productivity, deficit irrigation (DI) is a water management method in which water is saved with accepting little yield reduction without any severe damage to the plant either during a particular developmental stage or throughout the whole growing season. Especially in water-shortage regions, deficit irrigation strategies have become important tools to attain higher water use efficiency and reduce cost of water. Reduced yield as the effect of deficit irrigation, mainly under water scarcity condition, may be compensated by increasing production by irrigating other areas (Kirda, 2002). Proper irrigation interval also used to utilize scarce water resources efficiently and effectively by applying the required amount of water when it is needed (Mofoke *et al.*,2002).

The agricultural potential of Adami Tullu is low and mainly determined by the semi-arid and arid climate. The amount of rainfall is low in relation to the high evaporative demand. Erratic, late start or early withdrawal of the rainy season cause frequent crop failures. However, the availability of accessible water resources, relatively good infrastructure, suitable soils, proximity to the market and high radiation provide opportunities for irrigated agriculture. In the year 2000 the irrigated area by different sectors such as small-scale farmers, State farm, Red Cross Prison farm, Churches and others was 1848 ha (OESPO, 2003).

Pulse crop is important source of income for farmers due to the increasing demand in the domestic and export markets (Ferris and Kaganzi, 2008).Haricot bean is a type of pulses and one of the most important cash crops and source of protein for farmers in Ethiopia (Ali *et al.*, 2003).The production of Haricot bean is usually under rain fed condition and as a result

inadequate or changeable rainfall may limit the production. Therefore, irrigation practice is required to increase its production (Acosta and Domingo, 2009).

Haricot bean has a relatively shallow rooting depth, requires frequent irrigation and is more sensitive to water stress (Labidi *et al.*, 2009). According to the Central Statistical Agency of Ethiopia, the national average production of Haricot bean is 1.6 tons/ha (CSA, 2016).

Hence, studying the effect of applying regulated deficit irrigation and irrigation interval of haricot bean is a paramount importance to achieve higher water use efficiency. Understanding the yield response factor of haricot bean with deficit irrigation and irrigation interval through the growth season is important for proper scheduling of the limited water supply and for better crop management practice related to soil moisture. To gain high yield of haricot bean and achieve sustainable crop yield, it is necessary to gain knowledge of the haricot bean response to different irrigation levels and interval.

1.2. Statement of the Problem

Shortage of water represents one of the most limiting factors in crop production worldwide (Mohamed, 2000). Rainfall variability, drought, over-exploitation and severe wastage of water resources have long been a serious problem in Ethiopia (World Bank, 2006). Limited water resources and increasing water require for industrial and urban settlements have caused reduces in the quantity and quality of farming water utilize (Osman *et al.*, 2001). Ethiopia is facing a tremendous challenge in meeting the food needs of rapid growing population (FAO, 1995). Farmers in dry area of Ethiopia depend on inconsistent, unrealistic and small rainfall to produce staple food crops for their livelihoods.

According to World Bank (2006) report most parts of Ethiopia receive about 70% of rain during the month of June, July and August. Production of sustainable and reliable food supply is almost impossible due to political constraints, rising production costs, groundwater scarcities, temporal and spatial imbalance in distribution of rainfall resulting in less water being available for agriculture. Frequently, crop failure occurs for the reason that unavailability of water at some critical growth stages of the crop.

Bean producing areas are the middle, eastern and southern parts of Ethiopia (Abebe, 2009 and Katungi *et al.*, 2009). In the central part of Ethiopia, farmers produce early maturing white bean for export as their cash crop, while in the southern parts, due to an extensive growing period, it is planted with maize and other crops (Amare and Haile, 1989 and Katungi *et al.*, 2009).

One of the crop types which is grown in the low land of Oromia particularly in the Rift Valley belt is haricot bean. Haricot bean's contribution to households' nutrition, income and food security is very high. Regardless of its contribution, however, the emphasis given to this crop is relatively low compared to other food crops. The production of haricot beans is usually under rain fed conditions and as a result inadequate or changeable rainfall may limit the production (Acosta and Domingo, 2009). The emphasis given to this crop is relatively low compared to other food crops together with water scarcity factors, affects the adoption of improved haricot bean production technologies and consequently production and productivity of the crop. Irrigation in Oromia Region is one of the major ways of improving income to the rural communities but the practice has operational problems. For instance, farmers are not able to produce optimum production because they either under irrigate or over irrigate, which leads to a loss of economy. In Adami Tullu water scarcity results competition and exploitation of water among domestic, private investors, farmers and industries and this results conflict between users. Mofoke *et al.* (2002) reported that irrigation scheduling is done based on farmers' judgment, not based on scientific principles. Therefore, optimum deficit irrigation and irrigation interval is needed to reduce this problem.

1.3. Objectives

1.3.1. General Objective

The general objective of this study was to investigate the response of yield and above ground biomass of haricot bean crop under deficit irrigation and irrigation interval in Adami Tullu, Oromia, Ethiopia.

1.3.2. Specific Objectives

- To determine optimum irrigation level and irrigation interval by considering different levels of water application and irrigation interval.
- To determine the crop yield and above ground biomass production at different water application depth and interval.
- To evaluate water use efficiency of haricot bean under deficit irrigation.

1.4. Research Questions

This field experiment would answer the following questions:

1. Would there be a significant decrease the crop yield and above ground biomass production at different water application depth and interval?
2. What would be the recommend amount of irrigation water and interval to obtain optimum crop yield and above ground biomass production of haricot bean in the study area?
3. What would be the water use efficiency of haricot bean under deficit irrigation?

1.5. Significance of the Study

Deficit irrigation reduces water application depth, nutrient loss, fertilizer needs, costs of irrigation water, the opportunity costs of water, increases ground water quality, and irrigation efficiency. This is particularly important to the area where water is scarce and is becoming so expensive. Irrigation water productivity can be increased by simply applying less amount of water. This is done by simply irrigating at a lower point on the crop water requirement Vs yield curve something less than the yield-maximizing level. In doing so, one could attain higher irrigation efficiency (English, 2002).

When deficit irrigation is properly practiced, it increases quality of crop yield, protein content, and sugar content; reduces crop cycle length, grain size and etc. crop yield reduction is slight when compared with the income increase through diverting the saved water to irrigate crops of other area (Kirda, 2002). The optimum length of irrigation interval throughout the crop growth stage might carry about a reduction in the number of irrigations and results a profitable crop yield. This strategy can result in the increase of water productivity and also when number of irrigation and amount of water application for crop decreases then conflict between users reduce. Therefore, the finding of this study is expected to improve agricultural practice of farmers to use water efficiently which in turn increase productivity and farm return.

1.6. Scope of the Study

This MSc.thesis research was carried out at the experimental site of Adami Tullu Agricultural Research Centre (ATARC) during the dry season in 2018 G.C. The focus of this study was mainly to investigate the response of yield and above ground biomass of haricot bean crop under deficit irrigation and irrigation interval.

2. LITERATURE REVIEW

2.1. Water Resources in Ethiopia

Water is one of the most important resources of the world, and cannot be replaced by any alternatives and also affects all natural, social and economic systems. Furthermore currently, the utilization of freshwater for economic purposes has been challenging (Arsano, 2007). In developing country the situation is exacerbated by rapid population growth and urbanization. The challenge in developing country is water and food safety. The increasing food demand and decreasing water distribution suggest that competition for water used for agriculture, domestic and industry (World Bank, 2006).

Agriculture is the backbone of Ethiopian economy. Due to lack of fresh water and growing competition for pure water, and there is no enough water for most farmers to produce more than one crop per year, because serious water shortages are developing in the arid and semi-arid region due to dry spells and droughts which have resulted in chronic food shortage currently facing in Ethiopia. Water is a critical agricultural input in arid and sem-arid regions that has high effect on crop yield and crop production (Jafar *et al.*, 2007).

According to the recent information, Ethiopia has concerning 124.4 billion cubic meter river water resources, 70 billion cubic meter lake water resources, and 30 billion cubic meter ground water resources. It has a probable to develop 3.8 million ha of irrigation and 45,000 MW hydropower productions (Belete *et al.*, 2014). Irrigation development is increasingly enhanced in Ethiopia. Even though Ethiopia is well known for its vast water resource potential, the erratic distribution in time and space coupled with limited capacity to store water is the most challenging problem that limited the contribution of the resource to the development of the country. Irrigation potential of Ethiopia is 3500000 ha (Awulachew *et al.*, 2007). The total area of irrigated in Ethiopia was 625,819 ha during the year of 2005-2006 (MoWR, 2006).

2.2. Irrigation Scheduling

Irrigation scheduling refers to the decision as to when to irrigate and how much water to apply and irrigating for a short time then waiting for another short time until the end of irrigation water

applied. Proper irrigation scheduling is used to reduce water use only by reducing runoff from either irrigation or rainfall, by decreasing percolation of water beneath the root zone in excess of any required leaching for salinity management, by reducing soil water evaporation after an irrigation, or by controlling soil water depletion in a manner that reduces evapotranspiration during known non-sensitive crop growth stages (Mofoke *et al.*,2002). Salma (2016) reported that yield and water use efficiency increased with increasing irrigation frequency or reduced interval. Bashari (2004) reported that treatments that have long day irrigation interval advanced for maturity of sesame cultivars (*sesamumindicum l.*). FAO (1989) explained that when surface irrigation methods are used, it is not very practical to vary the irrigation depth and frequency too much. In surface irrigation, variations in irrigation depth are merely possible within restrictions. It is also very confusing for the farmers to vary the program all the time. For that reason, it is frequently important to approximation the irrigation schedule and to fix the most suitable depth and interval to keep the irrigation depth and the interval stable over the growing period. Numbers of researcher have analyzed the effect of irrigation interval on different crop type. Therefore, from the above review irrigation interval throughout the crop growth stage might bring about a reduction in the number of irrigations and results in an economic crop yield.

2.3. Deficit Irrigation

Deficit irrigation is the deliberate and systematic under-irrigation of a crop, thus the crop is allowed to sustain some degree of water deficit and yield reduction (English, 1990). Deficit irrigation is reducing some amount of water from crop water requirement at various growth stages and throughout growth stage by increasing economic gain (Zhang *et al.*, 2004).60% of haricot bean yield losses that causes decreasing income from the crop were observed due to water stress in Ethiopia (Molina *et al.*,2001).In mung bean, leaves under different irrigation intervals study had shown that water stress had lead to significant increase in the content of abscisic acid(Webber *et al.*,2006).

Different literatures reported that water stress leads to significant decrease in number of days to flowering and maturity stages. Days to 50% of flowering and maturing of faba bean under stress condition were found to be shorter as the crop try to escape from unfavorable condition by ending their life few days earlier than those under normal or high soil moisture conditions

(Ahmed *et al.*, 2008). Plants under water stress were commonly shorter in height than those with a higher amount of water supplied (Alsuhaibani, 2009 and; Simsek *et al.*, 2011). Gebregwergis (2014) reported that days to maturity of onion shortened as it tried to escape from unfavorable stress conditions by ending its life a few days earlier than those under normal or high soil moisture conditions. Zelalem (2015) reported that there is no significant difference between furrow system and deficit irrigation on number of leaves per plant of maize. There is no significant difference on the combined effect of irrigation furrow system and deficit irrigation on number of leaves per plant of onion (Yemane, 2017). Crops under water deficit were similar on plant height, number of pods per plant and number of seeds per pod with those supplied with optimum amount of irrigation water during the whole growth stages for haricot bean (Kalima, 2013). Kalima (2013) also reported that hundred seed weight of haricot bean at 75% ETC irrigation with KE4 genotype had similar results with 100% ETC irrigation.

Sunusi (2014) reported that the highest yield was obtained when water level was reduced on some percent and statistically, similar yields were obtained at 3 day and 5 day irrigation intervals. During flowering stages and beginning of pod development, reduced grain yields of haricot bean due to water deficit reduce different growth stages (Molina *et al.*, 2001). The factors that affect growth and survival of bean are low pH, nutrient availability, temperature and low moisture. Under such conditions, water stress reduces yield of the crop. Irregular availability of water during production exposes plants to water deficit during every growth stage (Smesrud *et al.*, 1997). Khepar and Chaturvedi (1982) reported that 50, 75 and 100% ETC of water application required for maximum production for irrigation. It was found that for full irrigation, the profits increased by 21 to 25% and when optimum, rather than maximum was used, the profits increased by 44 to 49%. From the above review number of researchers have analyzed the economics of deficit irrigation in specific situations and have concluded that this technique can improve agricultural practice and increase net farm income.

2.4. Plants Response to Water Stress

Water stress is a major environmental factor limiting growth like morphological features and physiological processes associated with plant growth and development and then ultimately reduce grain yield (Toker and Cagiran, 1998).

Haricot bean in Adami Tullu is grown by small scale farmers as a rain-fed crop, and most of them cannot afford to irrigate the crop. The growth, development and performance of haricot bean are adversely affected by water stress as the country experiences both intermittent and terminal droughts. There is critical need for cultivars that are tolerant to water deficit in order to reduce yield losses as well as reduce the amount of water needed for irrigation. Buildup of solutes in the guard cell cytoplasm reduces guard cell water potential (Christmann and Grill, 2009). The responses of plants to stresses depended on many factors, such as the phenological stage, the duration and degree of stress (Torres *et al.*, 2006).

Emam *et al.* (2010) reported that plant height, number of leaves per plant, leaf area, and number of pods per plant and above ground dry biomass of haricot bean decreased significantly due to water stress. Akinçi (2009) and Losel (2010) reported that water deficit caused major reductions in plant height, leaf number per plant, leaf area index, fresh and dry weight of cotton plant. Water stress has also been reduces many characteristics of faba beans (*Vicia faba* L.). In haricot beans, accelerated maturity of crop along with reducing grain yield and mean weight of hundred seeds following water stress, have been reported (Singh, 1995).

2.5. Crop Water Requirements

The first step in the proper design of an irrigation scheme is to know the crop water requirement. Crop water requirement means the rate of evaporation of a disease free crop growing in a field of not less than one hectare under optimal soil conditions. Crop water requirement is computed as ET_c and is expressed in millimeter per day (FAO, 1998). Direct measurement procedures are laborers and time consuming. Consequently, CROPWAT is used to compute crop evapotranspiration (Allen *et al.*, 1998). The software calculates crop water and irrigation requirements by utilizing inputs of climatic, crop and soil data. Based on this program, reference evapotranspiration can be calculated from actual temperature, humidity, sunshine hours and wind speed data, according to FAO Penman Monteith method. Crop water requirement is also a function of crop type and its growing period (FAO, 1998). Crop capability differs in extract of water from soil. For most plants, the available water is about 50% of the total water supply before reaching the permanent wilting point. Generally, the amount of water lost from a crop and soil under actual conditions is known as crop evapotranspiration (ET_c) (Plaut and Meiri, 1994).

Crop water requirements and irrigation water requirements can be carried out from the selected crop and includes, average planting and harvesting date (FAO, 1996). Crop coefficient, rooting depth, depletion level and yield response factors and length of growth stages also very important to compute ETC and irrigation water requirements because these parameter different from one crop to another. The water requirements are different from one plant to another. Even though growing crops are always using water, the rate of water use depends on the type of crop, the degree of maturity and atmospheric situation, such as radiation, temperature, wind, and humidity. The rate of growth at different soil water contents varies with different soils and crops. During early stages of growth the water needs are generally low, but they increase rapidly during the maximum growing period to the fruiting stage. During maturity stage, water use reduces as the crops mature (Plaut and Meiri, 1994).

2.6. Water Use Efficiency (WUE)

The effectiveness of water in agricultural production is normally low because of water scarcity. Only 40 to 60% of the water is efficiently used by the crop, the rest of the water is misplaced in the system or in the farm either through evaporation, linkage of pipe, runoff, or by percolation into the groundwater. Water use efficiency can be achieved by improving the method of water delivery, irrigation interval, efficiency of water use of crop, and by using of drought tolerant crops. Water use efficiency can be increased by improving irrigation interval practices (Mofoke *et al.*,2002). The term “water use” may either be field water use or actual crop evapotranspiration, hence differentiating FWUE from CWUE. Water use efficiency is mainly relying on the economic yield of the crop rather than water use (Michael, 1978). Farmers give attention to increasing irrigation water use efficiency because water use efficiency is affected by pipe and canal linkage, interception of crop, soil texture, cultural practices and plant species (Howell, 1994).

2.7. Yield Response Factor of Crops to Deficit Irrigation

The yield response factor (K_y), as defined by Stewart's formula, is an expression of the sensitivity of a given crop to water deficits (Dejuan *et al.*, 1996). Yield response factor (K_y) plays a very important role in predicting yields under water shortage conditions when used in a

crop production function. Doorenbos and Pruitt (1977) recommended standard values of yield response factors for generalized use. But none is available for local condition. So, experiments were conducted to determine the yield response factors for the study location.

The response of yield to water supply is quantified through the yield response factor (K_y) which relates relative yield decrease ($1 - Y_a/Y_m$) to relative evapotranspiration deficit. Water deficit of a given magnitude, expressed in the ratio of actual evapotranspiration (ET_a) and maximum evapotranspiration (ET_m), may either occur continuously over the total growing period of the crop or it may occur during anyone of the individual growth periods such as establishment, vegetative, flowering, yield formation, or ripening (Doorenbos and Kassam, 1979). The magnitude of water deficit in the former refers to the deficit in relation to crop water requirements over the total growing period of the crop and in the latter; the deficit refers to the crop water requirements of the individual growth period. The K_y values for most crops are derived from the assumption that the relationship between relative yield (actual yield (Y_a) / maximum yields (Y_m)) and relative evapotranspiration (ET_a / ET_m) is linear and is valid for water deficits of up to 50% ET_c (Doorenbos and Kassam, 1979). Therefore, from the above review yield response factor computed for deficit level of this study because the maximum water deficit of the treatment was 50% ET_c .

2.8. Haricot Bean varieties and production importance

Twelve pulse species are grown in Ethiopia. These are faba bean (*Vicia faba L.*), field pea (*Pisum sativum L.*), chickpea (*Cicer arietinum L.*), lentil (*Lens culinaris Medik.*), grass pea (*Lathyrus sativus L.*), fenugreek (*Trigonella foenum-graecum L.*), lupine (*Lupinus albus L.*), haricot bean (*Phaseolus vulgaris L.*), soya bean (*Glycine max L.*), cowpea (*Vigna unguiculata L.*), pigeon pea (*Cajanus cajan L.*) and mung beans (*ibid*). Among the individual pulses, faba beans accounts for the greatest portion of grain production at 31%, followed by haricot beans (20%) and chickpeas (17%). Other pulses account for the remaining 32% in Ethiopia. Chickpea is categorized as highland pulse crop and grown in the cooler agro ecology. Conversely, haricot bean is predominantly grown in the warmer and low land parts of the country (CSA, 2016).

Haricot bean is now planted around the world and in different cultivars, locally known as ‘Boleqe’ also known as dry bean, common beans, kidney beans, french bean, runner bean, black beans. The family of the dry beans is fabaceae, sub-family papilionoideae and genus *Phaseolus*. *Phaseolus vulgaris* (dry or common beans) is a species of the genus *Phaseolus*. It is grown mainly as a source of protein (Beebe, 2012).

In Ethiopia, smallholder farmers traditionally dominate the production of dry beans in mostly intercropping cropping systems in rotation with maize, sorghum or other crops particularly as an important food crop and source of cash (Girma, 2009).

Dry beans grow in subtropical and dry tropical zones, so it does well in warm climates with average temperatures ranging 18 to 24°C. Temperatures exceeding 30°C during flowering might cause flower abortion (Teshale *et al.*, 2005).

The Haricot bean production areas are Oromia, Amhara and Southern of Ethiopia. Their share to the national haricot bean production is 51% for Oromia, 24 % for Amhara and 21% for SNNPR (Walelign, 2002).

The crop grows well at altitude of about 1250 m above sea level with rainfall ranging from 400 to 650 mm. Moreover, it performs best on deep, friable and well aerated soil types. The crop takes between 85 to 115 days to mature depending on cultivar and season, while the national average yield of haricot beans is low ranging from 0.5 to 0.8 tone /ha, which is far below the corresponding yield recorded at research sites in South Africa is ranges of 1.5 to 2.5 tone/ha (DAFF, 2011). Days to different growth stage of haricot bean is presented in Table 1.

Table 1. Days to different growth stages of haricot bean

Growth stage	Day of growth stage(day)
Initial	20
Development	27
Mid	35
Late	20

Source: Allen *et al.*, 1998

3. MATERIALS AND METHODS

3.1. Description of the Study Area

This experimental study was conducted at the experimental site of Adami Tullu Agricultural Research Centre (ATARC) during the dry season in 2018 G.C. ATARC is located in the mid-rift valley region in Adami Tullu - Jido Kombolcha Wereda, at a distance of about 167 km south of Addis Ababa along the high way to Hawassa. It has latitude of $7^{\circ} 37' - 8^{\circ} 7'$ N and longitude of $38^{\circ} 23' - 38^{\circ} 57'$ E geographical coordinates. The site has an average altitude of 1650 m above sea level, the average annual rainfall of 760.9 mm, the annual mean minimum and maximum temperature of 12.6°C and 27°C , respectively. The area is characterized by unreliable rainfall, water shortage, and overgrazing. Farmers use water from Bulbula River for irrigation.

Farmers around the experimental site usually produce potato, onion, tomato, head cabbage, haricot bean, and maize during off-season by using irrigation, and teff, maize, barley, and wheat during the rainy season. Adami Tullu – Jido Kombolcha has a total population of 141,745 of which 50.4% are male. Its total land area is 1403.3 km^2 (CSA, 2007). Location map of the study area is presented in Figure 1.

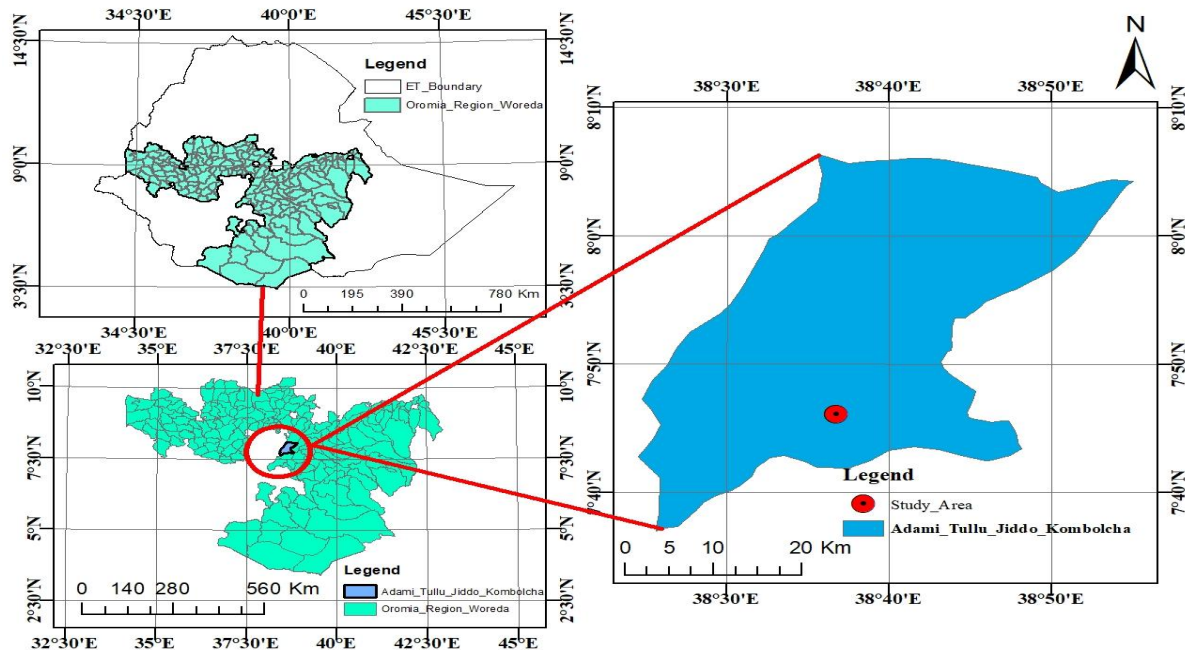


Figure 1. Location map of study area

3.2. Soil Sampling and Analysis

Physiochemical properties of the soil were analyzed at Addis Abeba Water Works Design and Enterprise, Oromia Agricultural Research Institute Batu Soil Research Center and Adami Tullu Agricultural Research Center. The physio-chemical properties of the soil at the experimental site were analyzed for bulk density, field capacity, permanent wilting point, soil texture, infiltration, pH, organic carbon, electrical conductivity, total nitrogen, potassium, organic matter and available Phosphorus to determine the level of availability of nutrients. To determine the above soil properties the soil sample were taken up to 60 cm from three spots chosen diagonally on the experimental field before land preparation and planting (Zelalem, 2015). The soil samples were taken at these depths because of the root depth of haricot bean that goes up to 60cm (Doorenbos and Pruit, 1977; Doorenbos and Kassam, 1979).

Bulk density was determined by using core sampler volume of 98.125 cm³. The samples were dried at 105°C for 24hr in oven and then the bulk density was calculated as the ratio of dry weight of soil to volume of core sampler. The formula is presented in equation 1 (Hillel, 2004).

$$\text{Bulk density} = \frac{\text{dry weight of soil in g}}{\text{volume of core sampler in cm}^3} \dots\dots\dots 1$$

Soil moisture content at field capacity and permanent wilting point measurements were calculated by using pressure plate apparatus by applying a suction of 0.33 and 15 bars, respectively to a saturated soil sample. When there was no more water droplets from the soil samples as a result of the action of gravity, the soil moisture at this level was taken as field capacity by applying a suction of 0.33 bar and permanent wilting point by applying a suction of 15 bar (Stakman *et al.*, 1969). The moisture content at field capacity and permanent wilting point on volume basis were calculated by multiplying the gravimetric water content on weight basis by the bulk density of the soil sample. Total available water was computed from the moisture content of field capacity and permanent wilting point using the following equation as indicated by Allen *et al.*, 1998.

$$\text{TAW} = 1000 (\Theta_{\text{FC}} - \Theta_{\text{PWP}}) * D_Z \dots\dots\dots 2$$

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 on volume basis (m^3/m^3), respectively and DZ is the maximum effective root zone depth of haricot bean at times of each irrigation water application in m.

Soil particle size was analyzed by using hydrometer method. Then textural class was determined based on the ratio of the proportion of particles of clay, silt and sand by using soil textural triangle (Hillel, 2004).

The infiltration rate at particular time intervals are collected and analyzed from three selected sites of ATARC on diagonal basis by using double ring infiltrometer (Appendix Figure 9). The inner and outer cylinders were inserted 30 cm into the ground using the driving plate and steel hammer and 10cm depth was left above ground, and tamped the soil into the space between the soil and cylinders. The measuring bridge serves as guide for the float and the float with the scale across the center of inner cylinder. Using bucket, both cylinders were filled with water simultaneously. The water inside the outer cylinder avoids lateral movement of water from the inner cylinder. The initial water level inside the inner cylinder was recorded and the change in the water level was recorded with a stop watch. The depths of water levels infiltrated were measured at increasing time intervals starting from 3 minute to 30 minute. Periodically both cylinders were refilled to maintain approximately constant head. The recording was stopped when the soil reached at saturation (Amreeta, 2014).

Soil chemical properties of organic carbon content was determined by titration method which is oxidation under standardized condition with potassium dichromate in sulpheric acid digestion according to Walkley and Black (1934) method. OM content was calculated by multiplying OC by 1.724 (Nelson and Sommers, 1996). The pH was measured in water suspension with soil to water ratio 1:2.5 by pH meter. EC was measured in water suspension with soil to water ratio 1:2.5 by electro conductivity meter. Total nitrogen content of the soil was determined by wet oxidation procedure of modified Kjeldahl method (Okalebo *et al.*, 2002). Available Phosphorus content of the soils was determined according to the procedure of olsen method (Olsen and Sommers, 1982). Available potassium measured by Ammonium Acetate (1 M NH_4OAC).

3.3. Experimental Design and Treatments

The treatments in this study were comprised of factorial combinations of two factors and the design was randomized complete block design. The treatments were four levels of water application (100% ET_c, 85% ET_c, 70% ET_c, and 50% ET_c) with three irrigation intervals (3 day, 5 day and 7 day) and were replicated three times. Therefore, in total, there were thirty six (36) plots of 2 m × 4 m the size of each plot. The total experimental area was 525 m² (35 m x 15 m). A distance of 1 m and 1.5 m was left between plots and blocks, respectively. There is no standard value for irrigation level and irrigation interval but different researcher use different values. The design of the irrigation levels were in line with Zelalem (2015) who reported the same level of deficit irrigation and also the irrigation intervals were in line with Sunusi (2014) who reported the same irrigation intervals. The Experimental treatments are presented in Table 2.

Table 2. Experimental treatments

Irrigation levels	Irrigation intervals		
	3 day	5 day	7 day
100% ET _c	T9	T1	T5
85% ET _c	T10	T2	T6
70% ET _c	T11	T3	T7
50% ET _c	T12	T4	T8

Where:

T1: five day irrigation interval with 100% ET_c

T2: five day irrigation interval with 85% ET_c

T3: five day irrigation interval with 70% ET_c

T4: five day irrigation interval with 50% ET_c

T5: seven day irrigation interval with 100% ET_c

T6: seven day irrigation interval with 85% ET_c

T7: seven day irrigation interval with 70% ETc

T8: seven day irrigation interval with 50% ETc

T9: three day irrigation interval with 100% ETc

T10: three day irrigation interval with 85% ETc

T11: three day irrigation interval with 70% ETc

T12: three day irrigation interval with 50% ETc

3.4. Discharge Measurement and Field Layout

The irrigation water source for the experiment was from Bulbula River. The water was brought to a reservoir by using a pump and to the field under gravity using closed pipes. The distance between the river and the reservoir was 50 m and also the distance between the reservoir and the parshall flume was 13 m. The volume of the reservoir was 36 m³ (4 m height, 3 m width and 3 m length). Water was then directed to smaller supply channels that feed the furrows. The parshall flume was installed at a distance of 10 m away from field and gross irrigation requirement amount was diverted to the furrows with calibrated parshall flume having appropriate opening throat width of three inches (3") (Appendix Figure 6). Water flow to each plot was controlled by using a 3 inch throat width Parshall flume installed at the upper side of the experimental field. The time required to deliver the desired depth of water into each plot was calculated using the following equation recommended by Kandiah (1981) and experimental field layout is presented in Figure 2.

$$t = \frac{l * w * d}{60 * q} \dots\dots\dots 3$$

Where:

d= gross depth of water applied (mm)

t= application time (min)

l= plot furrow length (m)

w = plot width (m)

q = flow rate (discharge) (l/s) and sixty is unit adjusting figure.

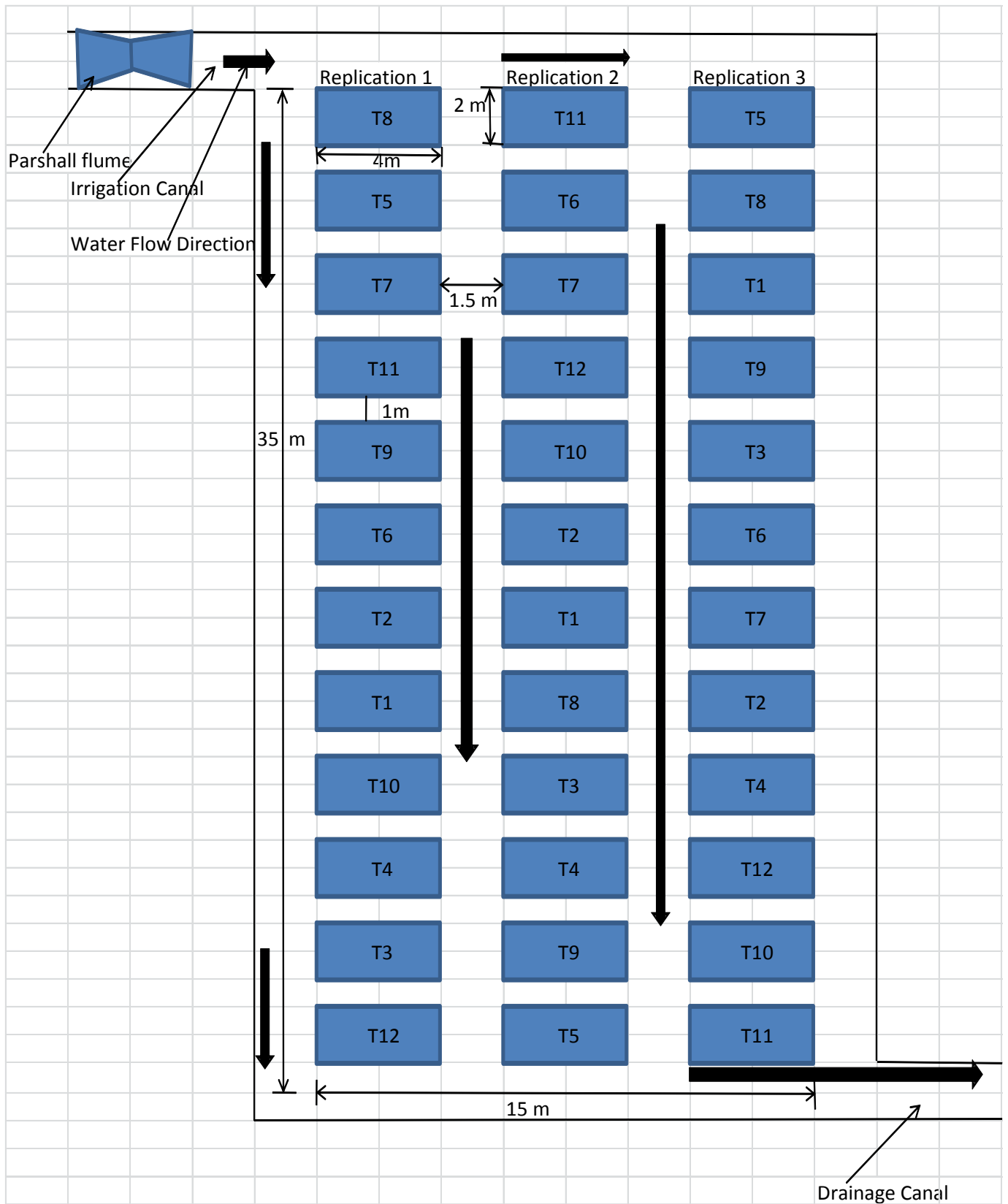


Figure 2. Experimental field layout

3.5. Crop Water Requirement and Irrigation Schedule

Monthly climatic data of 1981-2017 years were collected from Adami Tullu Agricultural Research Center Meteorological Station (Appendix Table 1-6) to compute monthly ETo by using CROPWAT model version_8.0. The model determines ETo based on Penman Montieth equation 4 (Allen *et al.*, 1998):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \left(\frac{900}{T + 273} \right) U_2 (e_s - e_a)}{\Delta + \gamma [1 + 0.34U_2]} \dots\dots\dots 4$$

Where: ETo = reference evapotranspiration (mm/day),

Rn = net radiation at the crop surface (MJm²/day),

G = soil heat flux density (MJm²/day),

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

U₂ = wind speed at 2 m height (m/s),

e_s = saturation vapour pressure (kPa),

e_a = actual vapour pressure (kPa),

e_s-e_a = saturation vapour pressure deficit (kPa),

Δ = saturation slope of vapour pressure curves (kPa °C⁻¹) and

γ = psychrometric constant (kPa °C⁻¹).

Crop water requirement was computed from the multiplication of reference crop evapotranspiration (ETo) with crop coefficient (Kc). The value of Kc for haricot bean was 0.4 at initial stage, 0.4 < developmental stage < 1.15, 1.15 at mid stage and 1.15 > late stage > 0.35 and also the maximum crop height was 0.4m. The formula of crop water requirement is presented in equation 5 (Allen *et al.*, 1998).

$$ET_c = ETo * Kc \dots\dots\dots 5$$

Where, ETC - Crop Water Requirement (mm/day)

Kc - Crop Coefficient (dimensionless)

ETo- Reference Evapotranspiration(mm/ day)

According to Doorenbos and Pruitt (1977), furrow irrigation application efficiencies normally vary from 50-70%. In this experimental setup, water was applied with precise measurement; furrows were short and end-diked. As a result, there was no run-off and no deep percolation. Therefore, a higher value of application efficiency (70%) was adopted. Then gross irrigation computed by the ratio of net irrigation required with the value of application efficiency.

3.6. Agronomic Practices

Haricot bean of Awash 1 variety was used in this experiment. The crop is locally available and widely grows in Adami Tullu. Planting was done on 12 February 2018 G.C and two seeds were sown per hole at the recommend planting depth of 6cm with spacing of 40 cm between rows and 10 cm between plants. The crop attained 100% germination after 12 days from planting. Then thinning of one seedling per hole was carried out after 15 days from sowing (Meseret and Amin, 2014). Recommended doses of fertilizers of 100 kg/ha urea and 100 kg/ha DAP were added to increase yield (Samson *et al.*, 2006). Full irrigation treatments were based on the estimated crop water requirement (ETc) calculated over the whole growing season and deficit treatments imposed less water as planned comprised of 50%, 70% and 85% of the full irrigation treatment (100% ETc). All needed management aspects were conducted according to the agronomic recommendation of the crop. The plant population was about 250,000 plants/ha. The phenological differentiation of the crop was categorized in to four growth stages. Accordingly, stage 1: initial stage 20 days (February 12-March 3); stage 2: developmental stage 27 days (March 4-March 30); stage 3: mid stage 35 days (May 31-May 4); stage 4: late stage 20 days (May 5-May 24) (Allen *et al.*, 1998). The crop was harvested after 102 days from planting date. After harvesting, the crop was left on the field for three days for further drying before threshing and after threshing the seed was dried in the open sun for 2 days, then the yield is weighted by using sensitive balance. Land preparation was presented in Appendix Figure1.

3.7. Yield and yield component data collected

Days to 50% flowering and maturity, plant height, leaf area, number of pods per plant, number of seeds per pod, above ground dry biomass, pod width, pod length and number of leaves per plant data were taken from ten plants from each plot excluding the border rows. Days to 50% flowering were measured by counting days from planting up to 50% flowering. Days to maturity were measured by counting days from planting up to when the pod color changed to yellow. The plant height was measured from the base of the plant to the apical bud of plant and expressed in centimeters. Total leaf area was recorded by measuring maximum length and width of trifoliolate leaves and multiplying these inputs by a correction factor of 0.6 derived from the actual leaf area determined by using a leaf area meter. Then, leaf area index (LAI) values for each plot were then calculated by multiplying the leaf area values by the plant density (250000plants/ha) based on equation 6 (Zelalem, 2015).

$$\text{Leaf area index} = \text{leaf area (m}^2\text{/plant)} * \text{plant density (plant/ha)} \dots\dots\dots 6$$

Pod number per plant were counted from ten plants from each plot, then mean values were recorded as number of pods per plant. Number of seeds per pod counted from ten randomly selected plants were converted to mean values and recorded as number of seeds per pod. Above ground dry biomass were computed from ten randomly taken plants by cutting above ground biomass then drying at 70°C for 24 hrs then harvest index was computed by the ratio grain yield to above ground dry biomass based on equation 7 (Zelalem,2015).

$$\text{HI} = \frac{\text{grain yield(kg/ha)}}{\text{AGDB(kg/ha)}} * 100 \dots\dots\dots 7$$

Pod width were measured from ten plants from each plot by using ruler and expressed as in centimeter, then mean values were recorded as pod width of haricot bean. Pod length were measured from ten plants from each plot by using ruler and expressed as in centimeter, then mean values were recorded as pod length of haricot bean. Numbers of leaves per plant were counted from ten plants from each plot, then mean values were recorded as number of leaves per plant. One thousand seed weight and yield were measured from central rows excluding border rows. One thousand numbers of seed were counted from each plot and weighted. The yield obtained from each plot was then expressed as kilogram per hectare (kg/ha). Monthly climatic

data of 1981-2017 years were collected from Adami Tullu Agricultural Research Center Meteorological Station (Appendix Table 1-6) to compute monthly ETo by using CROPWAT model version_8.0.

3.8. Water Use Efficiency

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water used in m³. Crop water use efficiency (CWUE, kg/m³) was calculated as marketable yield (kg/ha) obtained per unit volume of seasonal ETc (m³/ha) as presented in Equation 8 and also field water use efficiency (FWUE, kg m⁻³) for each experimental treatment was estimated as marketable yield (kg ha⁻¹) obtain per unit amount of seasonal irrigation water apply (SIWA, m³/ha) as presented in Equation 9 (Heydari , 2014).

$$CWUE = \frac{Y}{ETc} \dots\dots\dots 8$$

$$IWUE = \frac{Y}{I} \dots\dots\dots 9$$

Where Y is the economical yield (kg ha⁻¹)

ETc is the seasonal crop evapotranspiration (mm), and

I is the gross amount of irrigation water applied (mm).

3.9. Yield Response Factor

The standard formulation by Stewart *et al.* (1977) relates four parameters (Ya, Ym, ETa and ETm) to a fifth the yield response factor (Ky), which relates relative yield decrease to relative evapotranspiration of irrigation deficit level. It varies depending on crop species, variety, irrigation method and management, and growth stage when deficit evapotranspiration occurs and yield response factor is determined as presented in Equation 10.

$$1 - \frac{Y_a}{Y_m} = Ky \left(1 - \frac{ET_a}{ET_m} \right) \dots\dots\dots 10$$

Where:

Ya=actual yield (kg/ha),

Y_m = maximum yield (kg/ha),

ET_a = actual evapotranspiration (mm),

ET_m = maximum evapotranspiration (mm), and

K_y = yield response factor.

3.10. Statistical analysis

All the relevant data were collected from the experimental plots and were subjected to analysis of variances (ANOVA) using the SAS computer software program version 9.2 (SAS Institute, 1996) and significant treatment means were compared using least significant difference (LSD) test at $P < 0.05$ level of significance.

4. RESULTS AND DISCUSSION

4.1. Physical and Chemical Properties of the Soil in the Experimental Site

4.1.1. Physical Properties of the Soil

The results of the physical properties of soil analyses are presented in Table 3. The soil textural class was found to be loam sand in all depths throughout the profile investigated based on the USDA soil textural classification triangle.

Table 3. Physical properties of the soil

Depth (cm)	δ_b (g/cm ³)	FC (%) on weight basis	FC (%) on volume basis	PWP (%) on weight basis	PWP (%) on volume basis	TAW (mm/m)	% sand	% silt	% clay	Class
0-30	1.35	11.2	15.12	3.4	4.59	105.3	72	17	11	Loam sand
30-60	1.36	12.2	16.59	3.45	4.66	119.3	73	16	11	Loam sand

Where: δ_b =Bulk density

The bulk density values were 1.35 g/cm³ and 1.36 g/cm³ for 0 - 30 cm and 30 - 60 cm depths respectively. The critical value of bulk density for restricting root growth varies with soil type (Hunt and Gilkes, 1992) but in general bulk densities greater than 1.6 g/cm³ tend to restrict root growth (Mckenzie *et al.*, 2004). Results obtained under the present investigation were within desirable range for optimum movement of air and water in the soil for crop root growth. Moisture content at field capacity of the soil was 11.2% and 12.2% on weight basis for 0-30 cm and 30-60 cm, respectively. Soil moisture content at permanent wilting point was 3.4% and 3.45% on weight basis for 0-30 cm and 30-60 cm, respectively. Total available water of the soil was 105.3 and 119.3 mm/m for 0-30 cm and 30-60 cm, respectively. Results obtained under the

present investigation are in line with those obtained by Allen *et al.* (1998) reported that total available water, field capacity, permanent wilting point were in the range of 60 – 120mm/m, 11-19% on volume basis and 3-10% on volume basis, respectively for loam sand texture.

To characterize the experimental site, the soil infiltration rate was determined using the double ring infiltrometer. The infiltration measurement was done at three locations on diagonal basis. The mean basic infiltration rate was found to be 12 mm/hr. The result of infiltration rate obtained was slow because Hunt and Gilkes (1992) reported that moderately slow infiltration rate was in the range of 5 – 20mm/hr. The infiltration characteristics of the soil at site is summarized in Appendix Table 23 and presented in Figure 3.

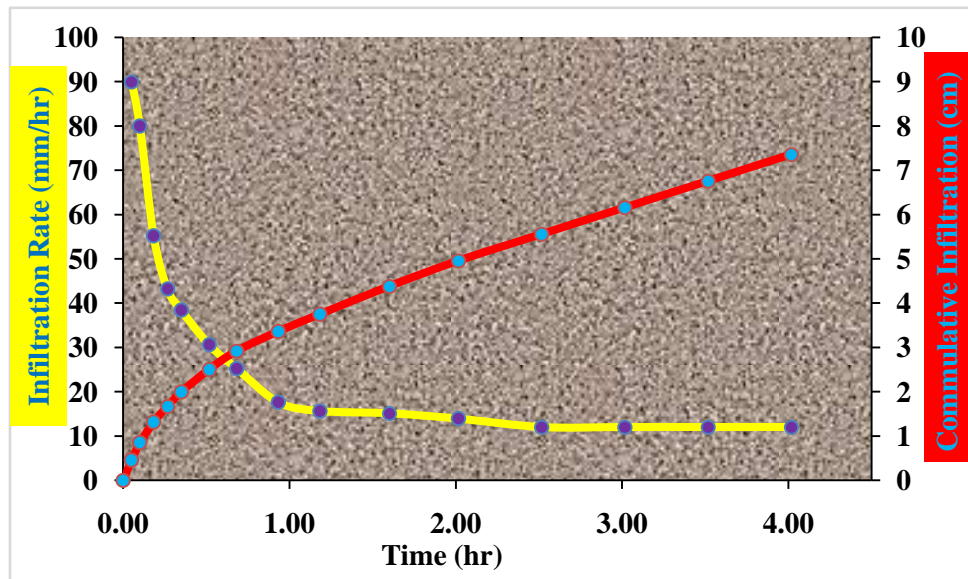


Figure 3. Infiltration characteristics of the soil

4.1.2. Chemical Properties of the Soil

The pH range of 6.0-7.5 is optimum for the adequate availability of nutrients in the soil for crop production (Bangladesh Agricultural Research Council, 2005). The result showed that the pH of the experimental site was suitable for crop production. Tekalign (1991) and Berhanu (1980) reported that moderate percentage of total nitrogen was in the range of 0.12 – 0.25 %. So, the total nitrogen of the experimental site was moderate. Results of Phosphorus available in the soil was very low because phosphorus value was low in the range of 1 – 5ppm (Jones and

Benton,2003).According to Tekalegn (1991) organic content of the soil was medium for the reason that the organic carbon was medium between 1.5 – 3%.Conventionally, soils are seen as saline at an electric conductivity of the saturation extract exceeding 4Mmhos/cm. Therefore, this soil was not saline soil. Critical and toxicity levels of some plant nutrient elements of potassium was 121 mg/Kg (Leenaars *et al.*, 2015).Results indicated that potassium availability of the soil was above critical value. Chemical properties of the soil are presented in Table 4.

Table 4.Chemical properties of the soil

Depth of soil (cm)	EC dS/m at 25°C	pH	% N	P (ppm)	K (mg/Kg)	%OC	%OM
0-30	0.104	7.5	0.154	3.28	536.98	2.53	4.36
30-60	0.214	7.4	0.12	4.68	460.07	2.41	4.15

4.2. Reference Evapotranspiration

Monthly long term climatic data from 1981-2017 years were collected (Appendix Table 1-6) from Adami Tullu Agricultural Research Center Meteorological Station. Then monthly ETo was computed by using CROPWAT model version_ 8.0 based on monthly maximum temperature, minimum temperature, relative humidity, sunshine hour, radiation and wind speed. The reference evapotranspiration of the study area was computed and the result is presented in Table 5.

Table 5. The reference evapotranspiration of the study area

Month	T min (°C)	T max (°C)	Humidity (%)	Wind Speed (km/day)	Sunshine (hr)	Rad-iation (MJ/m/day)	ETo (mm/day)
January	10.9	28.3	52	431	9	21.1	6.17
February	12	29.4	50	428	9	22.3	6.68
March	13	30.3	51	394	9	23.3	6.82
April	14.1	29.7	58	375	8	21.8	6.13
May	14.8	29.2	61	411	8	21.2	5.94
June	14.8	28	63	566	8	20.7	6.03
July	14.7	25	70	545	6	17.9	4.72
August	14.5	25.1	71	440	6	18.4	4.52
September	13.3	26.4	69	296	7	20.1	4.64
October	11.2	28.1	56	340	8	21	5.66
November	10.2	28	51	433	9	21.3	6.26
December	9.8	27.4	52	456	9	20.7	6.06
Mean	12.8	27.9	59	426	8	20.8	5.8

Where: T min (°C) is minimum temperature in degree celsius and T max (°C) is maximum tempreture in degree Celsius.

The maximum ETo occur in March was found to be 6.82mm/day and the minimum ETo occur in August was found to be 4.52mm/day.

4.3. Crop Water Requirement

Crop water requirement for haricot bean was calculated by multiplying reference evapotranspiration by crop coefficient of haricot bean. For 3days, 5days and 7 days irrigation interval during the period of growing season are presented in Table 6, Table 7 and Table 8, respectively.

Table 6. Crop and irrigation water requirement values for 3 days irrigation interval during the period of growing season.

Date	ET _o (mm/ day)	Crop K _c	ET _c (mm/ day)	100% ET _c (mm/period)	85% ET _c (mm/period)	70% ET _c (mm/period)	50% ET _c (mm/period)
14-Feb	6.68	0.4	2.67	8.02	6.82	5.61	4.01
17-Feb	6.68	0.4	2.67	8.02	6.82	5.61	4.01
20-Feb	6.68	0.4	2.67	8.02	6.82	5.61	4.01
23-Feb	6.68	0.4	2.67	8.02	6.82	5.61	4.01
26-Feb	6.68	0.4	2.67	8.02	6.82	5.61	4.01
1-Mar	6.73	0.4	2.69	8.08	6.87	5.66	4.04
4-Mar	6.82	0.41	2.79	8.37	7.11	5.86	4.19
7-Mar	6.82	0.48	3.3	9.89	8.41	6.92	4.95
10-Mar	6.82	0.57	3.86	11.59	9.85	8.11	5.80
13-Mar	6.82	0.65	4.43	13.3	11.31	9.31	6.65
16-Mar	6.82	0.73	5	15	12.75	10.50	7.50
19-Mar	6.82	0.82	5.57	16.71	14.20	11.70	8.36
22-Mar	6.82	0.9	6.14	18.41	15.65	12.89	9.21
25-Mar	6.82	0.98	6.71	20.12	17.10	14.08	10.06
28-Mar	6.82	1.07	7.27	21.82	18.55	15.27	10.91
31-Mar	6.82	1.14	7.77	23.32	19.82	16.32	11.66
3-Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
6-Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
9-Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
12-Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58

15- Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
18- Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
21- Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
24- Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
27- Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
30- Apr	6.13	1.15	7.05	21.15	17.98	14.81	10.58
3- May	5.94	1.15	6.83	20.49	17.42	14.34	10.25
6- May	5.94	1.11	6.59	19.78	16.81	13.85	9.89
9- May	5.94	0.99	5.88	17.64	14.99	12.35	8.82
12- May	5.94	0.87	5.17	15.5	13.18	10.85	7.75
15- May	5.94	0.75	4.46	13.37	11.36	9.36	6.69
18- May	5.94	0.63	3.74	11.23	9.55	7.86	5.62
21- May	5.94	0.51	3.03	9.09	7.73	6.36	4.55
24- May	5.94	0.39	2.32	6.95	5.91	4.87	3.48

Table 7. Crop and irrigation water requirement values for 5 days irrigation interval during the period of growing season.

Date	ET _o (m m/day)	Crop K _c	ET _c (mm /day)	100% ET _c (mm/period)	85% ET _c (mm/period)	70% ET _c (mm/period)	50% ET _c (mm/period)
16-Feb	6.68	0.4	2.67	13.36	11.36	9.352	6.68
21-Feb	6.68	0.4	2.67	13.36	11.36	9.352	6.68
26-Feb	6.68	0.4	2.67	13.36	11.36	9.352	6.68
3-Mar	6.76	0.4	2.7	13.52	11.49	9.464	6.76
8-Mar	6.82	0.48	3.3	16.48	14.01	11.536	8.24
13-Mar	6.82	0.62	4.24	21.22	18.04	14.854	10.61
18-Mar	6.82	0.76	5.19	25.95	22.06	18.165	12.98
23-Mar	6.82	0.9	6.14	30.69	26.09	21.483	15.35
28-Mar	6.82	1.04	7.09	35.43	30.12	24.801	17.72
2-Apr	6.54	1.14	7.48	37.42	31.81	26.194	18.71
7-Apr	6.13	1.15	7.05	35.25	29.96	24.675	17.63
12-Apr	6.13	1.15	7.05	35.25	29.96	24.675	17.63
17-Apr	6.13	1.15	7.05	35.25	29.96	24.675	17.63
22-Apr	6.13	1.15	7.05	35.25	29.96	24.675	17.63
27-Apr	6.13	1.15	7.05	35.25	29.96	24.675	17.63
2-May	6.05	1.15	6.96	34.79	29.57	24.353	17.40
7-May	5.94	1.84	10.91	54.55	46.37	38.185	27.28
12-May	5.94	0.91	5.41	27.03	22.98	18.921	13.52
17-May	5.94	0.71	4.22	21.09	17.93	14.763	10.55
22-May	5.94	0.51	3.03	15.15	12.88	10.605	7.58
24-May	5.94	0.37	2.2	4.4	3.74	3.08	2.20

Table 8. Crop and irrigation water requirement values for 7 days irrigation interval during the period of growing season.

Date	ET _o (mm/day)	Crop K _c	ET _c (mm/day)	100% ET _c (mm/period)	85% ET _c (mm/period)	70% ET _c (mm/period)	50% ET _c (mm/period)
18- Feb	6.68	0.4	2.67	18.7	15.90	13.09	9.35
25- Feb	6.68	0.4	2.67	18.7	15.90	13.09	9.35
4- Mar	6.76	0.4	2.73	19.12	16.25	13.38	9.56
11- Mar	6.82	0.54	3.68	25.73	21.87	18.01	12.87
18- Mar	6.82	0.73	5	35.01	29.76	24.51	17.51
25- Mar	6.82	0.93	6.33	44.29	37.65	31.00	22.15
1- Apr	6.13	1.11	6.81	47.64	40.49	33.35	23.82
8- Apr	6.13	1.15	7.05	49.35	41.95	34.55	24.68
15- Apr	6.13	1.15	7.05	49.35	41.95	34.55	24.68
22- Apr	6.13	1.15	7.05	49.35	41.95	34.55	24.68
29- Apr	6.13	1.15	7.05	49.35	41.95	34.55	24.68
6- May	5.97	1.13	6.76	47.34	40.24	33.14	23.67
13- May	5.94	0.91	5.41	37.84	32.16	26.49	18.92
20- May	5.94	0.63	3.74	26.2	22.27	18.34	13.10
24- May	5.94	0.41	2.44	9.74	8.3	6.82	4.87

4.4. Effect of Deficit Irrigation and Irrigation Intervals on Yield and Yield Components

4.4.1. Days to 50% Flowering and Maturity

Effect of Irrigation Level

The irrigation levels were very high significantly different in terms of days to 50% flowering (Appendix Table 8) and days to maturity (Appendix Table 9) ($P < 0.001$). Significantly higher 63 days to flowering and 95.56 days to maturity were recorded under 100% ETc, while the lowest 51.67 days to flowering and 91.67 days to maturity were recorded under 50% ETc. Haricot bean grown under 50% ETc deficit irrigation application throughout the growth season took short number of days to reach 50% flowering and maturity whereas the optimal irrigation application (100% ETc) took the longer days to reach 50% flowering and maturity (Table 9). Results obtained under the present investigation are in line with those obtained by Ahmed *et al.* (2008), regarding number of days to 50% flowering and maturity, for faba bean where it was noticed that plants try to escape from unfavorable stress conditions by ending their life few days earlier than those under normal or high soil moisture conditions. Kalima (2013) reported that 100% ETc water stress regime showed the longest days to fifty percent flowering, while the 50 % ETc water stress regime had the shortest days to fifty percent flowering for haricot bean. Alsuhaibani (2009) indicated that soil water stress leads to significant decrease in number of days to flowering and maturity. Singh (1995) also reported that water stress during flowering and grain filling accelerated maturity of dry bean. The mid and late growth stage of haricot bean are presented in Appendix Figures 4 and 5, respectively.

Effects of Irrigation Interval

The irrigation interval were very high significantly different in terms of days to 50% flowering (Appendix Table 8) and days to maturity (Appendix Table 9) ($P < 0.001$). Significantly higher 58 days to flowering and 94.83 days to maturity were recorded under 3 day irrigation interval, while the lowest 55.3 days to flowering and 92.17 days to maturity were recorded under 7 day irrigation interval. The results showed that, 3 days irrigation interval resulted in relatively took long days for haricot bean to reach 50% flowering and maturity as compared to the 5 and 7 days

irrigation intervals (Table 9) .Long day irrigation interval reduce time to maturity (Bashari,2004).

Interaction Effects of Irrigation Levels and Irrigation Intervals

The interaction effect of irrigation levels and irrigation intervals on days to 50% flowering (Appendix Table 8) and maturity (Appendix Table 9) were insignificant ($P < 0.05$). The higher 64.33 days to flowering were recorded under 3 day irrigation interval with 100% ETc and statistically, similar 63.67 days to flowering were recorded under 5 days irrigation interval with 100% ETc and also 97 days to maturity were recorded in 3 day irrigation interval with 100% ETc ,while the lower 51 days to flowering and 90.67 days to maturity were recorded in 7 day irrigation interval with 50% ETc (Table 10).

Table 9. Summary of irrigation interval and irrigation level effects on days to 50% flowering, maturity, plant height, number of pods per plant, number of seeds per pod, crop water use efficiency and field water use efficiency.

Treatments	DF	DM	PH (cm)	NP/P	NS/P	CWUE (kg/m ³)	FWUE (kg/m ³)
100% ETc	63a	95.56a	41.66a	25.76a	6.68a	0.36a	0.25a
85% ETc	58.67b	93.89b	40.06b	22.96b	6.32ab	0.38b	0.27b
70% ETc	53.89c	92.89c	39.1b	20.69c	6.04b	0.41c	0.29bc
50% ETc	51.67d	91.67d	37.48c	15.23d	5.47c	0.49c	0.34c
SE	0.39	0.4	0.54	0.91	0.24	0.13	0.09
LSD	0.81	0.83	1.12	1.88	0.5	0.27	0.19
3 day	58a	94.83a	41.11a	23.6a	6.45a	0.46a	0.32a
5 day	57.08b	93.5b	39.57b	20.87b	6.14ab	0.41b	0.28b
7 day	55.33b	92.17c	38.04c	19.01c	5.79b	0.37c	0.26c
SE	0.34	0.35	0.47	0.79	0.21	0.11	0.10
LSD	0.7	0.72	0.97	1.63	0.43	0.24	0.17

*Means followed by the same letter are not significantly different ($p < 0.05$)

Where: DF= days to 50% flowering, DM=days to maturity, PH=plant height, NP/P=number of pods/plant, NS/P=number of seeds/pod and SE= standard error.

Table 10. Interaction effect of irrigation level and interval results on days to 50% flowering, maturity, plant height, number of pods per plant, number of seeds per pod, CWUE and FWUE.

Treatments								
II	IL	DF	DM	PH(cm)	NP/P	NS/P	CWUE(kg/m ³)	FWUE(kg/m ³)
3 day	100%							
	ETc	64.33a	97a	43.3a	28.2a	6.9a	0.42cd	0.29cd
	85%							
	ETc	60bc	95.33bc	41.63ab	24.27bc	6.6ab	0.44bc	0.31bc
	70%							
ETc	55e	94cd	40.47bc	22.67bcd	6.33abc	0.44bc	0.31bc	
50%								
ETc	52.67f	93de	39.03cd	19.27e	5.97bc	0.54a	0.38a	
5 day	100%							
	ETc	63.67a	95.67ab	41.43ab	25.67ab	6.6ab	0.34ef	0.24ef
	85%							
	ETc	59c	94cd	40.43bc	23.33bcd	6.33abc	0.38de	0.26de
	70%							
ETc	54.33e	93de	39.1cd	21de	6bc	0.43bc	0.3bc	
50%								
ETc	51.33fg	91.33fg	37.3de	13.47f	5.63cd	0.47b	0.33b	
7 day	100%							
	ETc	61b	94cd	40.23bc	23.4bcd	6.53ab	0.32f	0.23f
	85%							
	ETc	57d	92.33ef	38.1d	21.27cde	6.03bc	0.34ef	0.24ef
	70%							
ETc	52.33fg	91.7efg	37.7dde	18.4e	5.8bc	0.36ef	0.31bc	
50%								
ETc	51g	91.33fg	36.1e	12.97f	4.80d	0.46bc	0.32bc	
SE		0.67	0.69	0.93	1.57	0.42	0.23	0.16
LSD		1.40	1.44	1.94	3.26	0.86	0.47	0.33

*Means followed by the same letter are not significantly different ($p < 0.05$)

Where : DF= days to 50% flowering, DM=days to maturity, PH=plant height, NP/P=number of pods/plant, NS/P=number of seeds/pod and SE = standard error.

4.4.2. Plant Height

Effect of Irrigation Level

The irrigation level were very high significantly different from each other in plant height ($P < 0.001$) (Appendix Table 10). The highest plant height of 41.66 cm was recorded in treatment 100% ET_c, while the lowest value of 37.47 cm observed in treatment 50% ET_c water amount applied (Table 9). Akinci (2009) and Losel (2010) reported that water stress caused major reductions in plant height, leaf number, leaf area index, fresh and dry weight of cotton plants and some *Cucurbitaceae* members. Elnadi (1969) found that water stress decreased plant height and number of nodes when imposed during the vegetative phase. Similarly, Wein *et al.* (1979); Hebblethwaite (1981) and Husain *et al.* (1990) reported that water stress reduces plant height.

Effect of Irrigation Interval

With regards to plant height, very high significant differences were observed among irrigation interval ($P < 0.001$) (Appendix Table 10). The maximum plant height of 40.11 cm was recorded in treatment 3 day irrigation interval, while the lowest value of 38.04 cm observed in treatment 7 day irrigation interval (Table 9). Elnadi (1970) reported that prolonging the watering interval decreased the mean plant height compared with frequent watering treatment for guar plant.

Interaction Effect

From the analysis not significant difference were observed due to the interaction effect of irrigation level and irrigation interval in plant height ($P < 0.05$) (Appendix Table 10). The largest plant height of 43.3 cm was recorded in treatment interaction of 100% ET_c with 3 day irrigation interval, while the lowest value of 36.1 cm observed in treatment interaction of 50% ET_c with 7 day irrigation interval (Table 10). The interaction between the irrigation interval and irrigation treatments was not significant for height of black cumin (Higran, 2003).

4.4.3. Thousand Seed Weight

Effect of Irrigation Level

The irrigation level were very high significantly different from each other in 1000-seed weight ($P < 0.001$) (Appendix Table 16). 100% ETc (138.64g) water stress regime showed the highest thousand seed weight, while 50% ETc (121.5g) water stress regime showed the lowest thousand seed weight (Table 11). Kalima (2013) reported that hundred seed weight of haricot bean at 75% ETc irrigation with KE4 genotype had similar result with 100% ETc irrigation. Sisay (2011) also reported that the weight of thousand seeds was significantly influenced by the different levels of irrigation water application for mungbean.

Effect of Irrigation Interval

With regards to thousand seed weight, very high significantly differences were observed among the irrigation interval ($P < 0.001$) (Appendix Table 16). 3 day irrigation interval (135.82g) gave the highest value of thousand seed weight, while 7 days irrigation interval (123.66g) had the lowest thousand seed weight (Table 11). Elnadi (1970) reported that frequent irrigation during late reproductive phase produce heavier seeds.

Interaction Effect

Interaction effect of irrigation intervals and irrigation levels very high significantly affect the weight of 1000-seeds ($P < 0.001$) (Appendix Table 16). 3 days irrigation interval with 100% ETc irrigation level regime showed the highest thousand seed weight (142.7g), while 7 days irrigation interval with 50% ETc irrigation regime had the lowest thousand seed weight (109.1 g) (Table 12).

4.4.4. Number of Pods per Plant

Effect of Irrigation Level

The irrigation level were very high significantly different from each other in number of pods per plant ($P < 0.001$) (Appendix Table 11). The highest number of pods per plant of 25.76 were recorded in treatment 100% ET_c, while the lowest value of 15.23 observed in treatment 50% ET_c water amount applied (Table 9). Metwally (2011) indicated that the higher irrigation water depth applied produced higher vegetative parameters.

Effect of Irrigation Interval

With regards to number of pods per plant, very high significantly differences were observed among irrigation interval ($P < 0.001$) (Appendix Table 11). The maximum number of pods per plant of 23.6 were recorded in treatment 3 day irrigation interval, while the lowest value of 19.01 observed in treatment 7 day irrigation interval (Table 9). Shouse *et al.* (1981) reported that pod density was reduced by water stress imposed at any stage of cowpea growth.

Interaction Effect

From the analysis not significant difference were observed due to the interaction effect of irrigation level and irrigation interval in number of pods per plant ($P < 0.05$) (Appendix Table 11). The largest number of pods per plant of 28.2 was recorded in treatment interaction of 100% ET_c with 3 day irrigation interval, while the lowest value of 12.97 observed in treatment interaction of 50% ET_c with 7 day irrigation interval (Table 10).

Table 11. Results of irrigation interval and irrigation level effect on haricot bean yield and above ground biomass.

Treatments	NL/P	1000SW/T (g)	YLD (kg/ha)	AGDB (kg/ha)	PW (cm)	PL (cm)	LAI	HI (%)
100% ETc	93.53a	138.64a	1908.7a	3783.3a	0.85a	9.60a	10.23a	41.66a
85% ETc	86.87b	134.3b	1728.2b	3321.4b	0.77b	9.35a	8.71b	40.06b
70% ETc	79.17c	126.79c	1519.8c	2114.3c	0.74b	8.9b	7.43c	39.1b
50% ETc	70.21d	121.5d	1301.6d	1642.9d	0.72b	8.33c	5.79d	37.48c
SE	1.91	0.89	58.11	164.14	0.03	0.15	0.35	0.54
LSD	3.96	1.85	120.52	340.42	0.06	0.31	0.73	1.12
3 day	88.83b	135.82a	1811a	3078a	0.79a	9.25a	9.26a	41.11a
5 day	80.63b	131.44b	1589.3b	2722.6b	0.77a	9.06ab	7.78b	39.57b
7 day	77.88b	123.66c	1443.5c	2345.8c	0.75a	8.83b	7.08c	38.04c
SE	1.65	1.03	50.33	142.15	0.03	0.13	0.30	0.47
LSD	3.43	2.13	104.37	294.81	0.05	0.27	0.63	0.97

*Means followed by the same letter are not significantly different ($p < 0.05$)

Where NL/P=number of leaf per plant, 1000SW/T=thousand seed weight/treatment, YLD=yield, AGDB=above ground dry biomass, PW=pod width, PL=pod length, LAI=leaf area index, HI=harvest index and SE=standard error.

Table 12. Interaction effect of irrigation interval and irrigation level results on haricot bean yield and above ground biomass.

Treatments									
II	IL	NL/P	1000SW/T (g)	YLD (kg/ha)	AGDB (kg/ha)	PW (cm)	PL (cm)	LAI	HI (%)
3 day	100%								
	ETc	102.9a	142.7a	2202.4a	4400a	0.91a	9.79a	11.91a	43.3a
	85%								
	ETc	91.9b	135.87bc	1964.3b	3497.6bc	0.79bc	9.67ab	9.74b	41.63ab
	70%								
	ETc	83.9cde	133.43cd	1642.9cde	2373.8d	0.74c	9.24bcd	8.41de	40.47bc
	50%								
	ETc	76.6fg	131.3de	1434.5efg	2040.5de	0.73c	8.32f	6.98fg	39.03cd
5 day	100%								
	ETc	90.3bc	137.37b	1821.4bc	3726.2b	0.85ab	9.62ab	9.71bc	41.43ab
	85%								
	ETc	85.5bcd	134.57bcd	1696.4cd	3473.8bc	0.78bc	9.39abc	8.48cde	40.43bc
	70%								
	ETc	78.1efg	129.73e	1589.3de	2133.3de	0.73c	8.83def	6.59gh	39.1cd
	50%								
	ETc	68.6h	124.1f	1250gh	1557.1ef	0.713c	8.38f	5.64hi	37.3de
7 day	100%								
	ETc	87.4bcd	135.87bc	1702.4cd	3223.8bc	0.80bc	9.39abc	9.07bcd	40.23bc
	85%								
	ETc	83.2def	132.47cde	1523.8def	2992.9c	0.76bc	8.98cde	7.91def	38.1d
	70%								
	ETc	75.5g	117.2g	1327.4fgh	1836def	0.73c	8.63ef	6.59gh	37.73de
	50%								
	ETc	65.43h	109.1h	1220.2h	1331f	0.71c	8.3f	5.64hi	36.1e
SE		3.31	1.78	100.66	284.31	0.05	0.26	0.61	0.93
LS									
D		6.86	3.70	208.75	589.62	0.11	0.54	1.26	1.94

*Means followed by the same letter are not significantly different (p < 0.05)

Where, NL/P=number of leaf per plant , 1000SW/T=thousand seed weight/treatment, YLD=yield, AGDB=above ground dry biomass, PW=pod width, PL= pod length, LAI=leaf area index, HI=harvest index

4.4.5. Yield and Yield Response Factor

Yield

Effect of Irrigation Level

Very high significant differences were observed among the various irrigation levels on yield ($P < 0.001$) (Appendix Table 17). 100% ETc (1908.7 kg/ha) was recorded the highest yield under all irrigation levels, while 50% ETc (1301.6 kg/ha) were recorded the lowest yield under all irrigation levels (Table 11). Ramirez and Kelly (1998) reported that both the quality and the yield of beans are negatively affected by brief periods of water shortage. The result of optimum irrigation (100% ETc) grain yield of haricot bean was in lined with the yield recorded at research sites in South Africa in the ranges of 1.5 to 2.5 tone/ha of haricot bean (DAFF, 2011). Threshing and yield of haricot bean are presented in Appendix figure 7 and 8, respectively.

Effect of Irrigation Interval

The yields under the three irrigation intervals were found to be very high significantly different ($P < 0.001$) (Appendix Table 17). The maximum grain yield was obtained under 3 day (1811 kg/ha) irrigation interval, whereas the lowest yield was obtained under the 7 day (1443.5 kg/ha) irrigation interval (Table 11). Sunusi (2014) reported that statistically, similar yield were obtained at 3 day and 5 day irrigation interval for tomato and short day of watering intervals increased total yield compared to long days watering intervals.

Interaction Effect

The yield of haricot bean was insignificant by their interaction effect of irrigation level and irrigation interval ($P < 0.05$) (Appendix Table 17). The maximum grain yield was obtained under 3 day irrigation interval with 100% ETc (2202.4 kg/ha), whereas the lowest yield was obtained under the 7day irrigation interval with 50% ETc (1220.2 kg/ha) (Table 12).

Yield Response Factor

The yield response factors (K_y) of haricot bean was calculated using the known values of actual crop water (ET_a), maximum potential crop water (ET_m), actual crop yield (Y_a) and maximum potential crop yield (Y_m) and the results are presented in Table 13. According to Kirda *et al.* (1999), the K_y value for field crops goes from 0.2 to 1.15 which agrees with the reported result of the study. Doorenbos and Kassam (1979) reported that the yield response factor of bean was 0.2 at initial stage, 1.1 at development stage, 0.75 at mid stage, 0.2 at late stage and 1.15 for total growing period. So, there was big difference from the Table below results of yield response factor of haricot bean. If $K_y < 1$: crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. This indicates that sensitivity growth period of haricot bean for water deficit was low in study area.

Table 13. Results of yield response factor

II (day)	IL (% ET_c)	YLD (kg/ha)	ET _a		Y _a /Y _m	1-(ET _a /ET _m)	1-(Y _a /Y _m)	K _y
			(mm/season)	ET _a /ET _m				
5	100	1821.4	530.31	1.00	1.00	0.00	0.00	-
5	85	1696.4	450.8	0.85	0.93	0.15	0.07	0.46
5	70	1589.3	371.07	0.70	0.87	0.30	0.13	0.42
5	50	1250	265.1	0.50	0.69	0.50	0.31	0.63
7	100	1702.4	530.31	1.00	1.00	0.00	0.00	-
7	85	1523.8	450.8	0.85	0.90	0.15	0.10	0.70
7	70	1327.4	371.07	0.70	0.78	0.30	0.22	0.73
7	50	1220.2	265.1	0.50	0.72	0.50	0.28	0.57
3	100	2202.4	530.31	1.00	1.00	0.00	0.00	-
3	85	1964.3	450.8	0.85	0.89	0.15	0.11	0.72
3	70	1642.9	371.07	0.70	0.75	0.30	0.25	0.85
3	50	1434.5	265.1	0.50	0.65	0.50	0.35	0.70

4.4.6. Number of Seeds per Pod

Effect of Irrigation Level

Very high significant differences in number of seeds per pod were observed among the various irrigation water levels ($P < 0.001$) (Appendix Table 12). The highest number of seeds per pod of 6.68 were recorded in treatment 100% ET_c, while the lowest value of 5.47 observed in treatment 50% ET_c water amount applied (Table 9). Sisay (2011) reported that average number of seeds per pod was significantly influenced by different level of irrigation water application throughout and at different growth stages of mungbean.

Effect of Irrigation Interval

The number of seeds per pod were significant by the effect of irrigation interval ($P < 0.05$) (Appendix Table 12). The maximum number of seeds per pod of 6.45 were recorded in treatment 3 day irrigation interval, while the lowest value of 5.79 observed in treatment 7 day irrigation interval (Table 9).

Interaction Effect

The numbers of seed per pod were insignificant by their interaction effect of irrigation level and irrigation interval ($P < 0.05$) (Appendix Table 17). The largest numbers of seed per pod of 6.9 were recorded in treatment interaction of 100% ET_c with 3 day irrigation interval, while the lowest value of 4.8 observed in treatment interaction of 50% ET_c with 7 day irrigation interval (Table 10). The interaction between water quantity and irrigation interval was insignificant for black cumin on number of seeds per pod (Higran, 2003).

4.4.7. Above Ground Dry Biomass (AGDB)

Effect of Irrigation Level

The irrigation level were very high significantly different from each other in above ground dry biomass ($P < 0.001$) (Appendix Table 18). The maximum AGDB (3783.3 kg/ha) at final harvest was found under 100% ET_c, while the minimum AGDB value (1642.9 kg/ha) was found under

50% ETc of irrigation water applied. Generally, the dry matter production under the 100% ETc irrigation was higher than those under the deficit irrigation treatment (Table 11). Emam *et al.* (2010) reported that leaf area and total dry weight of two haricot bean cultivars with contrasting growth habit decreased significantly due to water stress.

Effect of Irrigation Interval

Irrigation interval were very high significantly different from each other in above ground dry biomass ($P < 0.001$) (Appendix Table 18). With regards to the effect of irrigation interval on the above ground dry biomass, a decrease in AGDB found as a result of an increase in irrigation interval. The maximum AGDB of 3078 kg/ha at final harvest was recorded under 3 day irrigation interval, while the minimum AGDB was found to be 2345.8 kg/ha under 7 day irrigation interval (Table 11). It was generally agreed that irrigation applied at frequent intervals was found to increase dry matter content (Hossain *et al.*, 2010).

Interaction Effect

Interaction effect of irrigation level and irrigation interval were insignificant different from each other in above ground dry biomass ($P < 0.05$) (Appendix Table 18). Significantly higher value was obtained as 4400 kg/ha under treatment 3 day irrigation interval with 100% ETc of irrigation water applied, while 7 day irrigation interval with 50% ETc resulted in the lowest AGDB (1331 kg/ha) (Table 12).

4.4.8. Pod Width and Length

Effect of Irrigation Level

Irrigation levels were very high significant in pod width (Appendix Table 13) and pod length (Appendix Table 14) ($P < 0.001$). The highest pod width and length of 0.85 cm and 9.6 cm, respectively, were recorded in treatment 100% ETc, while the lowest value of pod width and length of 0.72 cm and 8.33 cm, respectively, observed in treatment 50% ETc water level applied (Table 11). Haricot bean is a sensitive plant to high moisture stress levels that substantial influence on haricot bean yield and its component (Ndimbo *et al.*, 2015).

Effect of Irrigation Interval

The irrigation intervals were insignificant in pod width (Appendix Table 13) and significant pod length of haricot bean (Appendix Table 14) ($P < 0.05$). The maximum pod width and length of 0.79 cm and 9.25 cm, respectively, were recorded in treatment 3 day irrigation interval, while the lowest pod width and length of 0.75 cm and 8.83 cm, respectively, were recorded in treatment 7 day irrigation interval (Table 11).

Interaction Effect

From the analysis not significant difference were observed due to their interaction effect of irrigation level and irrigation interval in pod width (Appendix Table 13) and pod length (Appendix Table 14) ($P < 0.05$). The largest pod width and length of 0.91 cm and 9.79 cm, respectively, were recorded in treatment interaction of 100% ETc with 3 day irrigation interval, while the lowest value of pod width 0.71 cm observed in treatment interaction of 50% ETc with 7 day irrigation interval and statistically, similar with the interaction of 3 day irrigation interval with 70% ETc (0.74 cm), 5 day irrigation interval with 70% ETc (0.73 cm), 7 day irrigation interval with 70% ETc (0.73 cm), 3 day irrigation interval with 50% ETc (0.73 cm) and 5 day irrigation interval with 50% ETc (0.71 cm) and also the lowest pod length of 8.3 cm observed in treatment interaction of 50% ETc with 7 day irrigation interval (Table 12).

4.4.9. Leaf Area Index

Effect of Irrigation Level

The irrigation levels were high significantly affect the leaf area index ($P < 0.001$) (Appendix Table 19). Higher leaf area index 10.23 was recorded under 100% ETc, while the lowest leaf area index 5.79 was recorded under 50% ETc (Table 11). Salma (2016) reported that the maximum leaf area index was observed at 100% ETc and the minimum leaf area index was observed at 80% ETc.

Effect of Irrigation Interval

Very high significantly difference were observed in leaf area index among irrigation intervals ($P < 0.001$) (Appendix Table 19). Higher leaf area index 9.26 was observed at 3 day irrigation interval, while lower leaf area index 7.08 was observed at 7 day irrigation interval (Table 11). Nimir (2002) reported that watering intervals had significant effect on leaf area index of the plant.

Interaction Effect

From the analysis not significant difference were observed due to their interaction effect of irrigation level and irrigation interval in leaf area index ($P < 0.05$) (Appendix Table 19). Significantly higher value of leaf area index was obtained as 11.91 under 3 day irrigation interval with 100% ET_c, while 7 day irrigation interval with 50% ET_c resulted the lowest leaf area index of 4.76 (Table 12).

4.4.10. Harvest Index

Effect of Irrigation Level

The irrigation levels were very high significantly different from each other in harvest index ($P < 0.001$) (Appendix Table 20). Significantly higher harvest index 41.66% was recorded at 100% ET_c, while the lowest harvest index 37.48% was recorded at 50% ET_c (Table 11). Hossain *et al.* (2010) reported that soil moisture stress on mung bean had resulted in reduced grain yield, yield components and then ultimately harvest index.

Effect of Irrigation Interval

The irrigation intervals were insignificantly different from each other in harvest index ($P < 0.05$) (Appendix Table 20). Higher harvest index of 41.11% was recorded at 3 day irrigation interval, while lower harvest index of 38.04% was recorded at 7 day irrigation interval (Table 11).

Interaction Effect

The harvest index of haricot bean insignificantly affected by their interaction effects of irrigation interval and irrigation level ($P < 0.001$) (Appendix Table 20). Higher harvest index of 43.3% was recorded at 100% ETc with 3 day irrigation interval, while lower harvest index of 36.1% was recorded at 50% ETc with 7 day irrigation interval (Table 12).

4.4.11. Number of Leaves per Plant

Effect of Irrigation Level

Irrigation levels were very high significant in number of leaves per plant ($P < 0.001$) (Appendix Table 14). The highest number of leaves per plant of 95.33 were recorded in treatment 100% ETc, while the lowest value of 70.21 observed in treatment 50% ETc water amount applied (Table 11). El-Oksh *et al.* (1993) and Al-Moshileh (2007) reported that number of leaves increased with increasing soil moisture level. Gwathmey *et al.* (1992) also reported that in the presence of drought, plants tend to reduce leaf number and leaf area.

Effect of Irrigation Interval

Irrigation intervals were very high significant in number of leaves per plant ($P < 0.001$) (Appendix Table 14). The maximum number of leaves per plant of 88.25 were recorded in treatment 3 day irrigation interval, while the lowest value of 77.88 observed in treatment 7 day irrigation interval (Table 11). Similar observations were pointed out by Nimir (2002) reported that increase in leaf numbers per plant with short period of watering intervals, while long period intervals were associated with smaller number of leaves per plant.

Interaction Effect

From the analysis not significant difference were observed due to their interaction effect of irrigation level and irrigation interval in number of leaves per plant ($P < 0.05$) (Appendix Table 15). The largest number of leaves per plant of 102.9 were recorded in treatment interaction of 100% ETc with 3 day irrigation interval, while the lowest value of 68.6 observed in treatment interaction of 50% ETc with 7 day irrigation interval (Table 12).

4.4.12. Water Use Efficiency

The irrigation levels and irrigation intervals were very high significant in crop water use efficiency (Appendix Table 21) and field water use efficiency of haricot bean (Appendix Table 22) ($P < 0.001$) and also the interaction effect of irrigation level and irrigation interval were insignificant effect in crop water use efficiency (Appendix Table 21) and field water use efficiency (Appendix Table 22) ($P < 0.05$).

The highest value obtained at 50% ET_c irrigation level were 0.49 and 0.34 kg/m³ of CWUE and FWUE, respectively, while the lowest value of CWUE and FWUE obtained at 100% irrigation level were 0.36 and 0.25 kg/m³, respectively. The highest value obtained at 3 day irrigation interval were 0.46 and 0.32 kg/m³ of CWUE and FWUE, respectively, while the lowest value of CWUE and FWUE obtained at 7 day irrigation interval were 0.369 and 0.256 kg/m³, respectively. The highest value obtained at 50% ET_c irrigation level with 3 day irrigation interval were 0.54 and 0.38 kg/m³ CWUE and FWUE, respectively, while the lowest value of CWUE and FWUE obtained at 7 day irrigation interval with 100% ET_c were 0.32 and 0.23 kg/m³, respectively. Webber *et al.* (2008) reported that, mung bean had greater potential to increase water use efficiency under deficit irrigation. According to Geerts and Raes (2009), by review selected research works around the world confirms that deficit irrigation increase water productivity for various crops.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary

Water is the most important factors affecting life in many regions of the world. Water demand increases in the sectors of agriculture, power generation, and industry. Measures have been sought to produce more food with limited water by increasing water productivity through effective development of new water management technologies in arid and semi-arid regions for better utilization of the limited water resource. One of these technologies is regulated deficit irrigation and better irrigation interval .Especially in water-shortage regions, deficit irrigation strategies have become important tool to attain higher water use efficiency and reduce cost of water. Reduced yield as the result of deficit irrigation, especially under water scarcity situations, may be compensated by increased production by irrigating other area. Proper irrigation interval is also used to utilize scarce water resources efficiently and effectively by applying the required amount of water when it is needed. However, deficit irrigation and irrigation interval needs testing under specific conditions for a given crop.

This experiment was conducted at the experimental site of Adami Tullu Agricultural Research Centre (ATARC) in 2018 G.C in the dry season. The experiment was aimed to investigate the response of yield and above ground biomass of haricot bean crops under deficit irrigation and varying irrigation intervals in Adami Tullu, Oromia,Ethiopia. The three irrigation intervals were 3 day, 5day and 7 day and the four levels of water applications were 100% ETc, 85% ETc, 70% ETc and 50% ETc. The experiment was designed as a two-factor twelve treatment combinations replicated three times in Randomized Complete Block Design (RCBD).

The effect of irrigation level and irrigation interval were tested using crop parameters such as days to 50% flowering and maturity, plant height, leaf area index, number of pods per plant, number of seeds per pod, above ground dry biomass, pod width, pod length, number of leaves per plant ,harvest index, yield and thousand seed weight. The water in terms of CWUE and FWUE for each irrigation treatment was also evaluated.

1000 seed weight of haricot bean result were very high significantly ($P < 0.001$) affected by the effects of irrigation interval, deficit irrigation and by their interaction. The number of seeds per

pod and pod length of haricot bean was very high significant ($P < 0.001$) by irrigation level and high significant ($P < 0.01$) by irrigation interval but insignificant ($P < 0.05$) by their interaction. Days to 50% flowering, days to maturity, above ground dry biomass, plant height, number of pods per plant, number of leaves per plant, yield, leaf area index, crop water use efficiency and field water use efficiency were very high significance ($p < 0.001$) among irrigation level and interval and also insignificant ($p < 0.05$) among their interaction effect of irrigation level and irrigation interval. Pod width and harvest index were no significance difference ($P < 0.05$) among irrigation interval and the interaction effect of irrigation level and irrigation interval but very high significant ($P < 0.001$) among irrigation levels.

5. 2. Conclusion

From the results days to 50% flowering and maturity, crop water use efficiency, field water use efficiency, above ground dry biomass, leaf area index, harvest index ,yield and thousand seed weight ,plant height, number of pods per plant, number of leaves per plant, pod width, pod length and number of seed per pod significantly affected by deficit irrigation and irrigation interval as well as by interaction effect of deficit irrigation and irrigation interval which implies that prolonged stress and days to irrigation interval over the growing season have reduction impact.

Generally, in water scarcity area among all irrigation treatments 85% ETc deficit level applied with 5 day irrigation interval was efficient in conserving significant irrigation water and reduce number of irrigation. Therefore, it could be concluded that increased water saving and water productivity through irrigation at 85% ETc deficit level with 5 day irrigation interval would ensure the scope of further irrigation development.

5.3. Recommendation

Based on the overall findings of this research, the following recommendations are developed:-

- ✓ To validate the results of this finding the experiment needs to be repeated for more seasons on the same area before reaching to the final recommendation.
- ✓ According to the results of this research 85% ETc of irrigation level with 5 day irrigation interval could be recommended to increase water saving and water productivity under water scarcity area.

6. REFERENCES

- Abebe. G.2009.Effect of NP fertilizer and moisture conservation on the yield and yield component of haricot bean (*phaseolus vulgaris L.*) in the semi arid zones of the Central Rift Valley in Ethiopia. *Advances in Environmental Biology* 3(3), 302-307.
- Acosta-Gallegos and Mario Domingo. 2009. Adaptation traits in dry bean cultivars grown under drought Stress. *Características De Adaptación En Variedades De Frijol Bajo Sequía* 35: 416–425.
- Ahmed, A. K., R. Tawfic and Z.A. Abdel-Gawad. 2008. Tolerance of seven faba bean varieties to drought and salt stress. *Journal of Agriculture and Biology science* 4: 175-186.
- Akinci, S.2009. The soluble sugars determination in Cucurbitaceae species under water stress and recovery periods. *Adv. Environ. Biol.*, 3(2):175-183.
- Ali,K. Gemechu,A.S,M.R,Beniwal,S.Makkouk and Halila. M. 2003. Food and forage legumes of Ethiopia; progress and prospects on food and forage legume proceeding of the workshop, 22-26 September 2003, Addis Ababa, Ethiopia.
- Allen, R.G., Pereira L.S., Raes D. and Smith M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. *Irrigation and Drainage paper Number, 56*. FAO, Rome.
- Al-Moshileh, A. 2007. Effects of planting date and irrigation water level on onion (*Allium cepa L.*) production under central Saudi Arabian conditions. *Journal of Basic and Applied Sciences* 8(1): 14-28.
- Al-Suhaibani N. A. 2009. Influencing of early water deficit on seed yield and quality of faba bean under arid environment of Saudi Arabia. *Journal of Agriculture and Environmental Science*, 5: 649-654.
- Amare A. and Haile K.1989.Proceeding of a workshop on bean varietal improvement.

- Amreeta Champatiray.2014. Experimental study for determination of infiltration rate of soils in field using double ring infiltrometer. Msc thesis. National Institute of Technology .Rourkela.India.72p.
- Andarzian, B., Bannayan, M., Steduto, P., Mazraeh, H., Barati, M. E., Barati, M. A.& Rahnama, A. 2011.Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran .Agricultural Water Management, 100, 1-8. <http://dx.doi.org/10.1016/j.agwat.2018.08.023>.
- Arsano, Y. 2007. Ethiopia and the Nile dilemmas of national and regional hydroponics, Centre for Security Studies, Swiss Federal Institute of Technology, Zurich, Switzerland. Zurich, thesis presented to the faculty of arts of the University of Zurich, for the degree of doctor of philosophy.
- Awulachew, B., D. Aster, L. Makonnen, L. Willibald, A. Mekonnen and A. Tena.2007. Water Resources and Irrigation Development in Ethiopia. International Water Management Institute. Working Paper 123. Colombo, Sri Lanka.
- Bangladesh Agricultural Research Council. 2005.Fertilizer recommendation guide.
- Bashari Ibrahim.2004. Effect of watering intervals on performance of three sesame cultivars (*sesamum indicum l.*). Degree of Master of Science in Agronomy. Msc thesis. University of Khartoum.Khartoum – Sudan.59p.
- Beebe, S.E. 2012. Common bean breeding in the tropics. Plant Breeding Reviews 36: 357-426.
- Belete Berhanu, Yilma Seleshi and Assefa M. Melesse.2014.Surface Water and Groundwater Resources of Ethiopia: Potentials and Challenges of Water Resources Development. Ethiopian Institute of Water Resources (EIWR), Addis Ababa University, Addis Ababa, Ethiopia.
- Berhanu Debele.1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia.

- Central Statistical Agency (CSA). 2007. Report on area and production of crops (Private Peasant Holdings, Meher Season). The Federal Democratic Republic of Ethiopia Central Statistical Agency. Agricultural Sample Survey. Statistical Bulletin 388: I.
- Central Statistical Agency Agricultural Sample Survey, 2016. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season).
- Christmann, A. and E. Grill.2009. Are GTGs ABA's biggest fans?. *Cell*. 136: 21–23.
- DAFF (Department of Agriculture, Forestry and Fisheries).2011. Production guideline for Bambara groundnuts. Directorate Agriculture Information Services. Pretoria, South Africa.
- Dejuan, JA, J.M. Tarjuelo, M.Valiente and P, Garcia. 1996. Model for Optimal Cropping Patterns within the Farm Based On Crop Water Production Functions and Irrigation Uniformity. I: Development of a Decision Model. *Agricultural water Management*, Vol. 31, pp: 115-143.
- Doorenbos and Kassam .1979. Yield Response to water. *FAO Irrigation and Drainage paper* 33. Rome, Italy.
- Doorenbos, J.and Pruitt, W.O. 1977. Guidelines for Predicting Cropwater Requirements. *Irrigation and Drainage No.24*, FAO, Rome, Italy, pp: 144.
- Elnadi, A.H.1969. Water relation of beans. I. Effect of water stress on growth and flowering. *Expl. Agric.* 5: 195-207.
- Elnadi, A.H. 1970. Water relation of beans. II. Effect of differential irrigation on yield and seed size of broad beans. *Expl. Agric.* 6:107-111.
- El-Oksh, I.I., A.M. El-Gizawy, M.M.F. Abdallah, A.R.A.G. Mohamed and. A.A.G. Abdalla. 1993. Effect of soil moisture and nitrogen fertilizer levels on onion grown in mixture of talfa and sand. *Bull. Fac. Agric. Univ.* 44(1): 145-156.

- Emam, Y., A. Shekoofa, F. Salehi, and A. H. Jalali. 2010. Water Stress Effects on Two Common Bean Cultivars with Contrasting Growth Habits. *J. Irrig. Drain. E. ASCE* 116, 399–412.
- English, M. 1990. Deficit irrigation. I. Analytical framework. *J. Irrig. Drain. E. ASCE* 116, 399–412.
- English, M. 2002. Irrigation advisory services for optimum use of limited water. *Irrigation Advisory Services and Participatory Extension in Irrigation Management*. FAO-ICID Workshop. Montreal, Canada.
- FAO (Food and Agricultural Organization). 1989. *Guidelines for Designing and Evaluating Surface Irrigation Systems*. Irrigation and Drainage paper No. 45. Rome, Italy: FAO
- FAO (Food and Agricultural Organization). 1995. *Production Year book*. Rome, Italy.
- FAO (Food and Agriculture Organization). 1998. *Crop evapotranspiration. Guideline for computing crop water requirements*. FAO Irrigation and Drainage, Paper. No 56. Rome, Italy.
- FAO . 1996. *Irrigation Scheduling: From theory to practice*. Water Reports 8. Food and Agricultural Organization of the United Nations. Rome, Italy
- Ferris S and Kaganzi E. 2008. *Evaluating marketing opportunities for haricot beans in Ethiopia. IPMS (Improving Productivity and Market Success) of Ethiopian Farmers Project Working Paper 7*. ILRI (International Livestock Research Institute), Nairobi, Kenya. 68 pp.
- Gebregwergis fitsum. 2014. *Effect of irrigation depth and nitrogen levels on growth and bulb yield of onion (*allium cepa* l.) at Alage, Central Rift Valley of Ethiopia*. Msc thesis. Haramaya University .Haramaya.85p.
- Geerts, S., and Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management*. 96, p. 1275–1284.

- Girma Abebe. 2009. Effect of NP Fertilizer and Moisture Conservation on the Yield and Yield Components of haricot Bean (*Phaseolus Vulgaris* L.) In the Semi-Arid Zones of the Central Rift Valley in Ethiopia. *Advances in Environmental Biology*, 3: 302-307.
- Gwathmey, C.O.; Hall, A.G. and M.A. Modara.1992. Adaptive attributes of cow pea genotypes with delayed monocarpic leaf senescence traits. *Crop Sci.* 32: 765-772.
- Hebblethwaite, P.1981. The effect of water stress on the growth, development and yield of (*vicia faba* L.). International conference on faba beans, Cairo, 7-11 March 1981.
- Heydari, N. 2014. Water productivity in agriculture: challenges in concepts, terms and values. *Irrig. and Drain.* 63: 22-28.
- Higran Hamid.2003.Effect of water quantity and irrigation intervals on vegetative growth and yield of black cumin (*nigella sativa* l.).MSc thesis.University of Khartoum,Khartoum.
- Hillel Daniel. 2004. Introduction to Environmental Soil Physics. Elsevier science, USA. PP494.
- Hossain Beyayet M., M.Wuluir Rahman, M.N.Rahman, A.H.M.Noorul Anwar and A.K.M.M.Hossen. 2010. Effect of Water Stress on Yield Attributes and Yield of Different Mung bean Gnotypes. *International Journal of Sustainable Crop Production.* 5(1): 19-24.
- Howell, T.A.1994. Irrigation engineering, evapotranspiration. In: Arntzem, C.J., Ritter E.M. (Eds.), *Encyclopedia of Agricultural Science*, vol. 2, pp. 591-600.
- Hunt N and Gilkes R .1992. *Farm Monitoring Handbook*. The University of Western Australia: Nedlands, WA.
- Husain, M.M.; Reid, J.B.; Othman, H. and Gallagher.1990. Growth and water use of faba beans (*Vicia faba*) in subhumid climate. Root and shoot adaptations to drought stress. *Field Crops Rresearch.* 23(1) 1-17.

- Jafar, M.S., M.H.E Slam, A.S. R., Amir, N. Ghorban and Z.Ghasem. 2007. The effects of water deficit during growth stages of canola (*Brassica napus* L.). American- Eurasian. J. Agric and Environ., Sci., 2 (4):417-422.
- Jones and Benton. 2003. Agronomic Handbook: Management of Crops, Soils, and Their Fertility.CRC Press LLC, Boca Raton, Florida, USA. 482p.
- Jury W.A., and Vaux J.H.2005. The role of science in solving the world's emerging water problems. Proceedings of the National Academy of Sciences, USA, 102:15715-15720.
- Kalima salyula Philip.2013. Physiological responses of common bean (*phaseolus vulgaris* l.) genotypes to water stress. MSc thesis. University of zambia.lusaka.91p.
- Kamara, A. B., Van Koppen, B. & Magingxa, L.2002. Economic Viability of Small Scale Irrigation Systems in the Context of State Withdrawal.The Arabie Scheme in the Northern Province of South Africa. Physics and Chemistry of the Earth 27: 815-823.
- Kandiah, A.1981. Guide for measurement of irrigation water using Parshall flumes and siphons: Technical bulletin No 1. Addis Ababa, Ethiopia. p. 2.
- Kassam A. H., Molden, D., Fereres, E., and Doorenbos, J. 2007. Water productivity: science and practice– introduction. Irrigation Science. 25: 185–188.
- Katungi E,Farrow A,Chianu J,Sperling L,Beebe S.2009.Common bean in Eastern and Southern Africa:A Situation and Outlook Analysis. International Center for tropical Agriculture,61pp.Available online:<http://www.icrisat.org/what-we-do/impi/project/t12-publications/regional-situation-outlook-reports/rso-common-bean-esa.pdf>.
- Khepar, S.D. and Chaturvedi, M.C. 1982. Optimum Cropping and Groundwater Management. Water Resources Bulletin, Vol. 18, NO.4, pp: 655-660.
- Kirda, C. 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance .Cukuroya University, Adana, Turkey.

- Kirda, C., R. Kanber and K. Tulucu. 1999. Yield response of cotton, maize, soybean, sugar beet, sunflower and wheat to deficit irrigation. In: C. Kirda, P. Moutonnet, C. Hera and D.R. Nielsen (eds.), Crop yield response to deficit irrigation. Kluwer Academic Publishers, Dordrecht, Netherland.
- Labidi N, Mahmoudi H, Dorsaf M, Slama I, and Abdelly C. 2009. Assessment of intervarietal differences in drought tolerance in chickpea using both nodule and plant traits as indicators. *Journal of Plant Breeding and Crop Science* 1: 80–86.
- Leenaars, Hengl, Ruiperez Gonzalez, Mendes, Heuvenlink, Wolf, Van Bussel, Claessens, Yang and Cassman. 2015. Root zone plant available water holding capacity of the Sub-Saharan Africa soil. *World soil information*. Wageningen University, Netherland, 114p.
- Losel, D.M. 2010. The effects of water stress and recovery periods on soluble sugars and starch content in cucumber cultivars. *Fresen. Environ. Bull.*, 19(2):164-171.
- Ludlow, M.M. and R.C. Muchow. 1990. A critical evaluation of traits for improving crop yields in water-limited environments. *Adv. Agron.* 43: 107-153.
- Mannocchi F. and Mecarelli P. 1994. Optimization Analysis of Deficit Irrigation Systems. *Journal of Irrigation and Drainage Engineering*, ASCE, Vol. 120, NO.3, pp: 484-503.
- Mckenzie NJ, Jacquier DJ, Isbell RF, Brown KL .2004. *Australian Soils and Landscapes An Illustrated Compendium*. CSIRO Publishing: Collingwood, Victoria.
- Meseret Turuko and Amin Mohammed. 2014. Effect of different phosphorus fertilizer rates on growth, dry matter yield and yield components of common bean (*Phaseolus vulgaris* L.). *World Journal of Agricultural Research*, Vol. 2, No. 3, 1-5pp.
- Metwally, A.K. 2011. Effect of Water Supply on Vegetative Growth and Yield Characteristics in Onion (*Allium cepa* L.). *Aust. J. Basic & Appl. Sci.* 5(12): 3016-3023.

- Michael, A.M. 1978. Irrigation theory and practices. Indian Agricultural Research Institute. New Delhi, India.
- Mofoke A.L.E., Ahmed A. and Mudiare O.J. 2002. Evaluation of Fadama Irrigation Efficiencies around Samaru, Zaria, Nigeria. Journal of Agriculture and Environment. 3(2): 319-329, Faculty of Agriculture, Usman Danfodiyo University, Sokoto Nigeria.
- Mohamed, M.F. 2000. Useful terry and cowpea lines in rationalizing water use for pulse legume production in southern Egypt. Acta Horticulture 537: 813-819.
- Molina, J.C., V. Moda- Carino, N. Da S.F.Junior, R.T. De Faria and D. Destro.2001. Response of common bean cultivars and lines to water stress. Crop Breed. Appl. Biotech., 1:363-372
- MoWR(Ministry of Water Resources).2006. Five Year Irrigation Development Programme (2005/06–2009/10), Addis Ababa, Ethiopia.
- Ndimbo, Nchimbi-Msolla, Semu.2015. Effects of moisture stress levels at different growth stages on nodulation and nitrogen fixation in common bean (*phaseolus vulgaris* l.) genotype. Asian Journal of Agriculture and Rural Development. Volume 5(8).pp15.
- Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston and M.E. Sumner (eds.), Methods of Soil Analysis. Part 3: Chemical Methods. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA. 9: 961-1010.
- Nimir, E. S. N.2002. Effect of water stress applied at different stages of growth on the performance of two sesame (*Sesamum indicum* L.)cultivars. M. Sc. Thesis. U of K.
- OESPO.2003. Regional Government of Oromia; Oromia Economic Study Project Office.Adami Tullu-Jido Kombolcha Woreda Based Development Programme.

- Okalebo, J.R., K.W. Gathua and P.L. Woomer. 2002. Laboratory methods of soil and plant analysis: A working manual 2nd ed. TSBF-CIAT and SACRED Africa, Nairobi, Kenya.
- Olsen, S.R. and L.E. Sommer. 1982. Phosphorus. In: A.L. R.H, Miller and D.R. Keeneys (Ed). Method of soil analysis chemical and biological properties. Am. Soc. pp. 403-430.
- Osman, Y., Oner, C., Demet, U. and Hasan, B. 2001. Irrigation scheduling of Drip-irrigated Tomato using A pan evaporation, Turkey Journal of Agriculture, 26(2002)171-178.
- Plaut, Z. and A. Meiri. 1994. Crop irrigation. In: K.K. Tanji and B. Yaron (Eds). Management of water use in Agriculture: Advanced series in Agricultural Sciences 22. Verlag Berlin Heidelberg, Germany. pp 47-102.
- Ramirez-Vallejo, P., Kelly, J.M. 1998. Traits related to drought resistance in common bean. Euphytica. 99, 127-136
- Salma Mohamed Hafez. 2016. The Effect of Irrigation Frequency and Rates on Green Bean Under Trickle Irrigation in Clay Loam Soil. MSc thesis. Department of Agricultural Engineering. Faculty of Agriculture Cairo University EGYPT.
- Samson Laike, Ketema Tilahun and Tilahun Hordofa. 2006. Crop Coefficient of haricot bean at Melkassa, Central Rift Valley of Ethiopia. Journal of Agriculture and Rural Development in the Tropics and Subtropics Volume 107, No. 1, pages 33–40. Shah, Mistry, Amin, Parmar, Shaikh. 2015. Irrigation scheduling using CROPWAT. International Journal of Advance Research in Engineering, Science & Technology (IJAREST), ISSN(O): 2393-9877, ISSN(P): 2394-2444, Volume 2, Issue 4, 10p.
- SAS Institute .1996. SAS Users' guide. Version 6 SAS Institute Cary, NC.
- Shouse, P. Samuel Desberg, W.A. Jory, and Stolzy L.H. 1981. Water deficit effects on water potential, yield and water use of cowpea. J. Agron. 73: 333-336.

- Simsek, M., N., Comlekcioglu and I. Ozturk.2011. The effects of the regulated deficit irrigation on yield and some yield components of common bean (*Phaseolus vulgaris* L.) under semi-arid conditions. African Journal of Biotechnology. 10(20): 4057- 4064.
- Singh, S.P. 1995. Selection for water-stress tolerance in interracial populations of common bean. Crop Sci 35: 118–124.
- Sisay Ambachew.2011. Effect of deficit irrigation on yield and yield components of mung bean in North wollo, MSc. Thesis, Department of Irrigation Engineering, Haramaya University, Ethiopia.
- Smesrud, J., B. Mansour, M. Hess and J. Selker.1997. Oregon State University Western Oregon Green Bean Irrigation Guide, vol. 541. Department of Bio-resource Engineering, 116 Gilmore Hall,Corvallis, pp. 737–6304 (or 97331–3906).
- Stakman, W.P., G.A. Valk, and G.G. Van Der Harst.1969. Determination of soil moisture retention curves: I. Sand-box apparatus-range pF 0 to 2.7. Third rev. ed., Institute for Land and Water Management Reseach, Wageningen, the Netherlands.
- Stewart, J.I., Cuenca, R.H., Pruitt, W.O., Hagan R.M., and Tosso, J. 1977. Determination and utilization of water production functions for principal California crops. W-67 California Contributing Project Report. Davis, United States of America, University of California
- Sunusi Amin abubakar.2014. Optimum irrigation schedules for tomato production under *fadama* conditions in the guinea savannah region of nigeria.Msc thesis. department of agricultural engineering faculty of engineering Ahmadu Bello University, Zaria, Nigeria
- Tekalign Tadese. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

- Teshale, Assefa, Girma, Abebe, Chemed, Fininsa, Bulti, Tesse & Abdel-Rahman M. Al-Tawaha. 2005. Participatory Bean Breeding with Women and small holder farmers in eastern Ethiopia. *World Journal of Agricultural Sciences*, 1: 28-35.
- Toker C, and Çagırgan M. 1998. Assessment of response to drought stress of chickpea (*Cicer arietinum* L.) lines under rain field conditions. *Turkish Journal of Agriculture and Forestry* 22: 615–621.
- Torres MA, Jones JD, Dangl JL .2006. Reactive oxygen species signaling in response to pathogens. *Plant Physiol.* 141: 373-378
- Walegn Worku. 2002. Growth and Productivity of Haricot Bean (*Phaseolus vulgaris* L.) Under Different Moisture and Light Regimes. Ph.D. Thesis. Agricultural University of Norway.
- Walkley, A. and C.A. Black. 1934. An examination of different methods for determining soil organic matter and the proposed modification by the chromic acid titration method. *Soil Science*, 37: 29-38.
- Webber, H.A, C.A, Madramootoo, M. Bourgault, M.G. Horst, G. Stulina and D.L. Smith. 2006. Water use efficiency of common bean and green gram grown using alternate furrow and deficit irrigation. *Agricultural Water Management*. 86: 259-268.
- Webber, H.A, C.A, Madramootoo, M. Bourgault, M.G. Horst, G. Stulina, D.L. Smith. 2008. Plant and Soil Water Dynamics of Alternate Furrow and Regulated Deficit Irrigation for Two Legume Crops. *American Society of Agricultural and Biological*. 51(5): 1341-1350.
- Wien, H.C.; Littleton, E.G. and Ayanabab, A.A.1979. Drought stress of cowpea and soy bean under tropical conditions. P. 283-30. In: H. Mussel and R.C. staples (eds.). *Stress physiology in crop plants*. Wiley Inter. Science. New York.
- World Bank.2006. *Managing Water Resources to Maximize Sustainable Growth: A World Bank Water Resource Assistance Strategy for Ethiopia*. Agriculture and Rural Development Department, World Bank, Washington, USA.

Yemane Mebrahtu.2017. Response of onion to deficit irrigation under different furrow irrigation water management techniques in raya valley, northern ethiopia. MSc thesis. Hawassa University.Hawassa.97p.

Zelalem shelemew.2015. Response of maize to deficit irrigation under three furrowirrigation systems in Adami TuLlu Rift Valley,Central Ethiopia. Msc thesis. Haramaya univeristy, Haramaya.

Zhang, Y.L., Qin, B.Q., Chen, W.M. 2004. Analysis of 40 year records of solar radiation data in Shanghai, Nanjing and Hangzhou in Eastern China. Theor. Appl. Climatol. 78,217-227.

7. APPENDICES

Appendix A. Tables

Appendix Table 1. Long term maximum temperature of the study area in degree celsius

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	27	30.7	26.8	26.1	29.9	29.9	25	24.8	24.6	27.1	27.1	26
1982	28	28.2	30.4	27.6	28.7	27.7	25	24.1	25	25.5	26.6	26.8
1983	27	28.4	30.3	28.1	28.4	27.5	25	22.1	24.3	26.8	27.5	26.6
1984	27	28.1	30.3	29.1	25.9	26	24	23.7	25.1	28.3	28.1	26.4
1985	28	27.9	30	26.4	27.5	28.4	24	23.6	26.1	27.6	27.6	26.8
1986	27	28	29.2	27.8	28.4	25.5	24	26.2	26.6	28.3	28.3	27.2
1987	27	28.2	28.5	30.8	27.5	26.8	27	26.4	28.3	28.9	28.3	28.4
1988	28	29	31.4	30.1	30.7	27.7	24	24.6	25.6	26.5	26.7	26.5
1989	26	27	29.2	25.9	29.6	26.7	24	25	25.4	26.9	27.1	27.3
1990	27	26.8	27	28.1	29.7	27.6	25	24.6	25	27.6	27.8	26.9
1991	29	26.2	29.4	29.4	30.6	29.2	24	24.1	26.3	27	27	26.8
1992	27	27.4	30.8	30.2	30.2	27.8	25	23.7	25.3	26.2	26.6	27
1993	27	27	30.8	27.2	26.8	26.6	24	25.1	25.9	27.5	27.6	27.3
1994	28	29.1	30.2	30.8	30	25.6	24	24.2	25.2	28.1	27	26.4
1995	28	29.5	29.7	28.4	29.8	29.8	26	25.2	26.6	28.9	28.2	27.8
1996	27	30.2	29.6	29.6	27.9	25.7	25	24.5	25.7	28.2	27.6	27.2
1997	28	28.7	30.4	27.9	30	28	25	25.5	28.4	27.7	27.7	27.6
1998	28	29.2	29.5	31.6	30.1	28.9	25	24.9	26.5	26.9	27.5	26.9
1999	28	30.5	29.4	31.3	30.1	27.8	24	25.8	27.1	25.7	26.7	26.9
2000	28	29.6	31.2	30.9	28.7	28.1	25	25.2	26.6	26.5	26.9	27.3
2001	27	29.3	28.4	30.4	28.8	26.9	26	25.6	27	29.6	28.4	28.2
2002	28	30.4	30.1	30.9	26.8	28.6	28	26.5	27.3	29.9	29.1	27.6
2003	28	30.8	30.8	30.3	32.3	27.9	25	25.8	28.1	29.9	29.1	29.5
2004	31	32.6	31.5	28.4	30.7	29.4	28	27.2	27.8	28	28.6	29.5

2005	30	31.5	31	32.5	28.7	28.8	23	27.3	28	28.5	28.6	27.7
2006	28	30.2	30	29.1	25.4	29.4	27	24.8	26.2	30.5	27.8	21.3
2007	30	30.2	31.7	30.5	28.9	26.5	25	25.3	26.7	27.9	27.9	27.4
2008	29	26.2	31.3	28	29.6	27.4	24	24.1	26.5	27.9	26.2	26.1
2009	28	30.1	31.5	30.8	30.8	30.5	25	25.5	26.9	27	28.6	27.4
2010	28	27.6	28.1	29.7	28.5	27.8	24	25.4	26.1	29.5	29.2	28.2
2011	29	30.7	28.8	32.3	29.8	27.7	26	24.6	25.5	29.4	27.8	27.9
2012	30	31.1	32	29.7	31.7	28.4	24	24.1	25.9	27.9	28.9	28.9
2013	29	31.8	32	31.2	29	27.3	24	24.5	26.8	28	28.8	28.4
2014	30	29.7	30.9	31.7	29.5	29.3	26	25.1	25.8	27.2	28.4	28.1
2015	29	31.9	32.4	32.6	30.8	28.4	28	26.9	28.2	33.1	32	31
2016	31	32.7	34.9	31	29.6	28.5	26	26.9	27.9	29.4	29.2	28.9
2017	30	30.2	32.8	32.5	30	30.6	26	25.8	26.5	30	30.1	29.3

Appendix Table 2. Long term minimum temperature of the study area in degree celsius

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	14	9.1	9.4	7.9	6.4	7.4	7.3	14.7	13.6	9.8	9.5	9.2
1982	14	14.1	13.2	15	14.2	14.7	15	14.7	13.4	11.6	12.7	12.5
1983	11	15.1	15.6	15.1	18.9	14.8	15	14.9	13.3	8.9	7.9	10.6
1984	8.8	7.8	10.1	10.1	14.6	14.2	12	13.6	12.3	7.9	10.6	13.4
1985	10	10.6	12.4	14.2	13.5	14	14	14.3	13.2	11.4	10.6	10.2
1986	9.5	14.5	13.8	15.8	14.8	15.3	14	12.9	12.3	10.2	10	11.4
1987	9.4	12	14.9	13.2	14.7	14.7	14	14	13.4	12.4	10.8	11.2
1988	14	14.2	13.9	15.1	14.8	14.9	15	14.4	12.6	11.2	8.4	9.5
1989	10	12.1	13.3	13.6	12	14	14	13.5	13	9.6	9.6	12.5
1990	10	14.8	12.8	13.4	14.2	13.9	14	14.1	13.9	10.3	9.6	9.8
1991	12	13	13.9	13.6	14	15.9	14	14.3	13	10	10.3	9.5
1992	13	15	14.4	15.1	14.6	15.1	15	14.9	12.5	11.4	10.8	11.8
1993	13	12.8	10.5	14.6	15.1	13.5	15	14.4	13.6	12.5	10.1	9.9

1994	9.5	12.3	14.9	15.5	15.6	15.4	15	15	13.7	10.5	11.1	9.6
1995	10	13.8	14.7	15.4	14.6	15.4	16	15	14.4	12.7	10.7	12.8
1996	14	12.5	14.9	15.1	15.2	15.1	15	14	13.4	10	9.9	8.8
1997	12	11.2	14.1	14.5	14.5	15.2	15	14.3	15.1	14.6	14.6	11.9
1998	15	15.9	15.5	15.8	16.8	16.2	16	15.5	14.8	14	10	9
1999	11	11.3	14.6	14.6	15.6	15.1	13	14.2	13.6	12.6	8.9	8.4
2000	8.3	10.1	11.7	15.8	14.9	14.5	14	15.7	13.1	12.2	11.1	10.1
2001	10	11.5	14	13.6	15.3	14.5	15	15.3	13.4	12.4	10.5	10.9
2002	13	12.1	13.5	13	15	16	15	16.6	11.8	6.8	4.3	6.9
2003	6.4	9	10.8	11.9	13.2	16.4	17	14.1	11.8	13	8.9	8.3
2004	13	12.5	13	13.3	15.7	13.1	13	10.4	12.8	11.5	10.5	8.3
2005	11	10.8	13.2	13.4	15.6	13.9	15	14.8	14.6	11.2	9.2	7.8
2006	11	11.7	13.3	14.6	13.9	14.7	16	14.8	13.2	13	11.5	9.1
2007	11	13	12.4	14.4	14.7	15.7	20	14.9	13.7	9.7	10.3	8.1
2008	10	10.2	10.8	13.8	16	14.8	15	14.9	13.7	11	10.3	7.8
2009	10	10.3	12	14.7	14.6	13.6	15	14.9	15.3	11.9	9.8	13.1
2010	11	14.9	13.6	15	16.5	15.6	15	15.4	13.7	11.4	9.5	9.2
2011	11	11.3	13.6	13.5	16.3	16.2	15	14.1	13.3	9.9	11.5	9.1
2012	9.8	10	12.4	15.4	15	15.6	15	14.8	13.3	9.7	9.4	9.3
2013	11	10.6	12.2	13.2	15	14.5	14	13.4	11.8	10.2	9.9	6.2
2014	9.2	11.9	11.4	12.6	14.2	14.2	15	13.7	12.7	11	9.1	7.6
2015	8	9.1	11.4	13.5	16	16.8	16	15.3	14.6	12.7	11.4	12.8
2016	14	13.2	15.1	16.9	16	15.2	15	14.8	14.4	12.5	11	9.5
2017	6.7	13.2	11.5	13.6	16	16	16	15.4	10.6	12.5	11.8	7.8

Appendix Table 3. Long term relative humidity of the study area in percent

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	59	45	84	94	85	78	87	75	76	59	49	46
1982	59	59	45	64	61	60	66	72	71	65	63	60
1983	54	67	65	64	66	62	61	72	75	60	56	81
1984	65	65	50	69	71	67	67	74	87	51	52	66
1985	58	45	50	70	85	72	70	73	69	54	45	47
1986	39	53	51	60	63	66	68	64	65	48	43	53
1987	50	46	60	60	65	66	63	64	59	52	41	45
1988	47	55	39	50	52	60	71	72	71	58	45	49
1989	50	52	55	73	53	61	73	71	72	56	49	61
1990	51	66	64	61	56	58	67	71	69	50	47	40
1991	49	51	60	57	52	58	62	75	62	55	45	50
1992	58	64	31	49	53	60	70	73	70	60	51	57
1993	61	65	45	60	51	66	70	67	69	57	50	51
1994	47	45	50	52	59	68	74	72	73	48	53	54
1995	46	49	58	62	57	59	68	70	67	48	44	54
1996	58	44	54	56	67	70	71	74	71	51	48	49
1997	57	48	56	65	56	62	69	70	62	62	61	52
1998	60	63	42	53	62	65	74	75	70	69	47	40
1999	44	35	54	43	51	61	70	68	65	71	60	57
2000	55	32	33	51	62	57	69	68	68	65	57	52
2001	52	45	63	55	64	65	70	72	71	58	48	50
2002	35	42	54	51	54	58	59	67	62	42	40	55
2003	50	44	54	53	49	62	74	73	69	51	53	52
2004	53	44	40	63	46	58	64	68	67	63	44	44
2005	53	53	61	53	66	62	65	64	64	49	47	44
2006	52	51	53	58	70	58	63	67	64	56	47	43
2007	50	30	43	49	60	73	70	70	67	48	45	46
2008	49	43	34	41	57	61	72	73	70	59	86	55

2009	55	45	47	58	51	56	70	70	65	62	45	61
2010	56	60	62	65	72	67	74	74	74	54	50	50
2011	54	47	50	47	54	62	73	73	72	50	56	49
2012	49	44	38	59	53	59	77	76	75	57	53	51
2013	50	51	56	64	70	68	75	81	71	61	55	54
2014	55	60	58	56	65	62	70	73	72	65	59	55
2015	52	49	49	42	56	59	64	63	64	56	49	50
2016	54	44	44	62	67	65	74	66	65	52	49	47
2017	41	49	49	44	63	55	72	66	72	59	49	44

Appendix Table 4. Long term annual sunshine hour in hr/day data of the study area

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	8.7	10.1	4.6	5.8	9.1	9	5.3	7.2	6.6	9.2	9.7	9.9
1982	8.8	7.5	9.3	7.6	8.3	8.5	6.1	5.3	7	8	7.1	8.7
1983	8.8	7.5	8	7.3	7.3	8.3	6.4	6	6.5	8.6	9	9.6
1984	9.8	9.9	9.3	9.1	6.9	7.8	5.8	6.8	6.7	10	9.7	9.5
1985	9.5	8.6	8.3	6.6	7.7	8.5	5.1	6.1	7.2	8.7	9.6	9.7
1986	10	7.9	8.4	6.6	8.7	6.2	6.8	7.7	6.9	8.8	9.6	9.3
1987	9.4	7.6	6.9	8.3	7.1	8	8.3	6.5	7.5	8.6	10.2	9.9
1988	8.8	8.3	9	6.7	9.5	7.8	3.8	6.1	6.1	8.8	10.6	9.8
1989	8.4	9	7.8	7	10	7.9	5.4	6.3	6	8.8	9.4	7.9
1990	10	6.3	7.9	8	8.7	9	5.6	5.7	6.8	9.6	9.9	9.6
1991	9.4	7.6	7.7	8.7	8.1	7.8	5.3	5	7.1	9.5	9.2	8.5
1992	7.3	7.6	8.3	8	8.1	7.2	5.4	5	6.8	8.2	9.3	8.7
1993	7.8	7.8	9.7	6.9	7.3	7.3	4.8	6.6	6.7	7.9	10.1	9.8
1994	9.6	9	7.5	7.8	8.5	7.4	5.7	6.3	6.7	9.1	9.3	10
1995	9.9	8.7	10.9	7.5	9.4	9.2	5.5	5.7	6.8	9.2	10.3	9.3
1996	8.5	9.8	7.7	7.3	7.7	6.3	5.9	5.5	6.6	9.5	9.3	9.9
1997	7.9	10.3	8.4	7.3	9.5	7.6	6.2	7.3	7.8	7.5	7.9	9.6
1998	7.7	7.8	7.4	8.6	8.5	8.3	5	6.9	6.4	6.9	10.1	10

1999	9.5	9.9	8	9.5	8.8	8.8	5.9	6.1	7	6.8	9.8	10
2000	10	10.5	9.5	8.1	8.9	8.4	6.2	6.2	6.2	7.5	9.3	9.6
2001	8.6	9.7	7	9.3	8.3	7.8	6.9	5.6	7.7	8.6	10	9.9
2002	9.1	7.7	7.7	9	9	8.5	7.9	6.1	7.3	9.2	10.1	7.9
2003	9	8.6	8.6	7.5	9.4	6.1	4.3	5.4	7.2	9.1	8.7	8.8
2004	9	9.3	9.3	7.9	3.7	6.3	3.5	7.3	7	9.2	9.9	10
2005	8.8	8.5	8.5	8	6.6	7.4	5.3	7.3	5.7	3.5	11	10
2006	9.5	7.3	7.3	7.6	8.3	8.2	6.2	6.6	8.4	8.1	9.3	8.6
2007	8.9	10.4	10.4	8.7	9.4	5.8	5.5	5.7	5.9	8.3	10	11
2008	9.4	10.9	10.9	8.9	6.6	6.3	5	6.7	6.8	6.4	8.7	10
2009	8.4	9.4	9.4	8.6	9	8.5	6.9	6.3	6.7	8.1	9.4	7.4
2010	8.6	7.7	7.7	7.2	7	7.3	5.6	6.3	5.7	9.3	9.4	8.9
2011	9	8.8	8.8	8.7	7.8	7.2	5.7	5.3	5.9	9.5	8.3	9.7
2012	9.4	8.9	8.9	7.6	8.9	7.2	4.3	4.9	5.9	9	9.5	9.3
2013	8.8	8	8	5.9	7.6	7.8	4.6	5.5	6.7	7.9	8.6	9.1
2014	8.8	8.8	8.8	8.6	7.8	8.6	6.2	6.4	5.5	8	9	9.2
2015	9.5	9.1	9.1	9.3	7.8	7.5	8.1	7.8	7.4	8.5	8.6	8.6
2016	8.2	8.7	8.7	6.7	8.4	7.3	5.6	6.7	6.7	9.7	8.5	10
2017	10	9.3	9.3	9.2	7.8	8.9	5.4	5.4	6.1	9.2	10.2	10

Appendix Table 5. Long term annual wind speed data of the study area in meter per second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	8.6	9	5.8	5.4	7	9.75	9.4	7.8	4.3	6.3	9.7	9
1982	8.7	7.7	9.1	5.9	6.7	9.9	10	6.8	1.3	3.5	5.7	8.1
1983	8.7	9.9	7.6	6.3	5.9	7.7	9.2	8.6	5.9	5.8	7.6	8.7
1984	9.7	9.2	7.4	9.4	7.3	9.9	10	7.8	5.8	8.4	9.3	9.9
1985	9.2	10.5	9.4	8.35	7.31	11.8	9.7	9.55	6.2	8.5	9.27	9.6
1986	8.5	7.58	8.87	6.81	7.17	9.69	10	8.3	6.53	7.43	8.92	10
1987	9.8	7.12	6.56	6.62	7.03	9.53	11	8.5	6.62	7.69	8.77	9.3

1988	9.7	8.04	9.93	7.34	9.71	11.4	11	8.05	6	6.06	7.4	8.6
1989	9	9.19	6.26	5.17	7.66	10	11	7.63	5.52	6.5	8.63	7.8
1990	8.4	5.72	7.02	6.17	8.58	11	9.4	8.1	5.15	6.54	6.91	8
1991	7.4	6.25	5.54	7.04	7.51	10.4	10	6.91	4.99	4.8	7	8
1992	6.8	7.36	7.34	6.88	6.8	10.1	8.7	8.1	5.18	5.62	7.19	8
1993	7.5	6.39	6.23	5.83	5.92	9.51	9.2	8.1	5.92	5.93	6.59	6.9
1994	6.8	7.45	6.66	7.27	8.11	10.4	8.8	8.12	4.6	6.13	7.83	7.5
1995	6.9	6.42	6.31	4.84	6.6	9.42	10	8.87	5.14	7.23	6.08	6.5
1996	6.6	6.47	5.86	5.61	5.21	6.31	8.9	6.9	4.32	4.99	5.7	5.3
1997	4.8	7.42	5.79	5.42	6.72	8.5	9.7	6.77	5.43	5.57	6.98	7.1
1998	6.2	5.38	5.11	5.9	7.22	11.4	11	5.72	4.85	4.64	6.75	7
1999	7.4	7.95	6.36	7.5	9.19	9.9	8.7	7.15	5.18	4.25	6.6	7
2000	7.4	7.99	7.63	6.73	6.32	13.6	9.1	8.29	4.63	3.1	6.4	7.2
2001	6.5	6.57	4.9	6.6	6.34	9.56	9	7.3	3.7	4.8	6.2	6.3
2002	1.6	1.34	1.08	1.5	1.7	2.18	2.2	1.64	1.02	1.51	1.63	1.5
2003	1.3	1.48	1.57	1.37	1.69	2.16	1.9	1.56	2	1.35	1.3	1.2
2004	1.3	1.5	1.5	1.23	1.11	0.41	0.8	0.13	0.14	0.53	1.49	2.6
2005	2.3	2.45	2.25	2.15	1.96	2.79	2.7	2.27	2.24	1.98	2.48	2.6
2006	2.4	2.41	2.04	1.68	1.99	2.5	2.6	2.35	1.59	1.86	2.63	1.9
2007	2.2	1.76	1.74	1.8	2.06	2.13	1.4	1.6	1.41	1.6	2.8	2
2008	1.9	1.9	1.9	2.02	1.8	2.2	2.2	1.7	1.2	1.2	2.6	2
2009	1.2	1.32	1.4	1.58	1.78	2.14	1.8	1.65	1.42	1.3	1.44	1.3
2010	1.5	1.13	1.28	1.28	1.48	2.13	2.2	1.93	1	1.34	1.32	1.3
2011	1.4	1.52	1.5	1.53	1.64	2.2	1.8	1.62	1.13	1.41	1.29	1.5
2012	1.4	1.52	1.39	1.38	1.62	2.37	1.8	1.41	1.03	1.01	1	1.1
2013	1.1	1.17	1.12	1.16	1.42	1.89	1.5	1.51	1	0.94	1.21	1.1
2014	1.1	1.06	1.2	1.35	1.2	1.8	1.7	1.26	0.96	0.91	1.05	0.8
2015	1.1	1.01	1.15	1.28	1.36	1.9	1.9	1.54	0.98	1.02	1.14	1.1
2016	1	1.18	1.18	1.08	1.02	1.42	1.4	1.39	1.04	0.89	1.1	1.3
2017	1	1.01	0.81	1.1	1.98	2.1	1.8	1.56	1.21	1.13	1.2	1.4

Appendix Table 6. Long term annual rain fall data of the study area in millimeter

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	73	52.2	194	68.2	21.2	7.5	263	95.5	173	3.4	0	0
1982	74	13.3	23.1	116.6	78.2	74.6	145	174	97.7	181	50.4	0.2
1983	1.9	80.2	59.4	124.4	227	24	164	106	95.6	35.8	0	0
1984	0	0	11.8	0	135	57.6	127	158	77.5	0.5	0	0
1985	0	0	21.6	126.1	56.3	14.4	116	137	59.6	1.1	0	0
1986	0	48.3	23.7	86.1	124	79.3	82	76.3	69.1	31	0	3.3
1987	0	19.1	110	92.4	190	64.6	45	87.4	33.3	9.9	0	0
1988	5	18.7	5.1	26.3	8.8	57.1	113	128	122	73.2	0	0.8
1989	19	49.6	228	93.4	0.1	141	143	137	134	15.8	0	34
1990	0	167	44.8	91.2	73.8	49.1	174	161	113	0	0	0
1991	8.8	109	137	4.3	51.2	46.6	200	185	45.5	0	40	2
1992	36	49.1	8.1	45	41.7	140	170	188	24.4	108	4.7	2.3
1993	93	160	0	97.2	125	87.2	185	149	44.5	0	0	0
1994	0	0	15.4	16.5	38.7	209	111	140	118	0	9	0
1995	0	15.7	47.1	117.6	69	39.8	74	146	32.4	4.8	0	7
1996	3.2	0.4	46.4	76.1	107	96.7	137	123	103	0	4.5	0
1997	16	0	41.1	173.1	12.9	83.6	198	83.4	35.3	84.7	0	0
1998	36	110	115	78.4	122	70.6	172	156	36.6	77.7	0	0
1999	4.3	0	76	17.8	70.4	78.2	135	101	89.3	178	0	0
2000	0	0	0	115.6	105	29.2	168	104	142	44.4	36.9	38
2001	0	19.3	163	38.7	97.5	85.7	111	173	84.4	0	0	0
2002	12	21.1	82.9	36.3	79	111	90	100	107	1.6	0	29
2003	0	4.3	33.2	70	49.8	92.1	181	172	0	0	0	0
2004	21	0	8.1	158	1.7	95.2	73	76.3	112	29.4	0	0
2005	58	1.4	148	14.2	141	56.7	104	74.8	102	3.7	0	0
2006	0	11.6	74.7	222.5	106	64.5	186	91	41.8	59.5	0	0
2007	25	0	12	89.4	151	153	183	166	122	36.7	0	0

2008	0	5	0	7.5	80.7	119	305	136	75.5	44.5	197	0
2009	25	2.1	58.7	10.8	52.7	66.9	161	84.1	61.8	138	0	56
2010	0	125	89	60.4	136	77.8	167	104	61.8	0.8	0	7.8
2011	0	5.1	63.3	26.6	67.1	129	134	115	83.1	0	8.3	0
2012	0	1.1	2.9	85.9	37.9	57.5	320	161	158	9.7	0	0
2013	0	0	75.5	43.4	79.1	128	250	88.6	64.6	50.9	2.9	0
2014	0	62.3	37.2	19.1	161	24.4	150	154	74.4	228	0	0
2015	0	0	28.7	0	81.7	111	148	101	66.5	0	0	0
2016	35	6.6	24.8	154.1	146	160	206	51.2	196	1.2	0	0
2017	0	11	45.6	23.9	69	53.6	203	91.6	166	0	0	0

Appendix Table 7. Infiltration test data using double ring infiltrometer

Time (minute)	Test 1		Test 2		Test 3		Average		Cumulative infiltration rate (mm/hr)	Cumulative infiltration (cm)			
	Time (min)	Recharge (cm)	Time (min)	Recharge (cm)	Time (min)	Recharge (cm)	Time (min)	Recharge (cm)					
0	0	10	0	0	10	0	0	10	0	0	0		
3	3	9.55	0.45	0.45	9.56	0.44	0.44	9.54	0.46	0.46	0.45	90	0.45
3	6	9.6	0.4	0.85	9.62	0.38	0.82	9.58	0.42	0.88	0.4	80	0.85
5	11	9.54	0.46	1.31	9.57	0.43	1.25	9.51	0.49	1.37	0.46	55.2	1.31
5	16	9.64	0.36	1.67	9.65	0.35	1.6	9.63	0.37	1.74	0.36	43.2	1.67
5	21	9.68	0.32	1.99	9.7	0.3	1.9	9.66	0.34	2.08	0.32	38.4	1.99
10	31	9.49	0.51	2.5	9.52	0.48	2.38	9.46	0.54	2.62	0.51	30.6	2.5
10	41	9.58	0.42	2.92	9.61	0.39	2.77	9.56	0.44	3.06	0.42	25.2	2.92
15	56	9.56	0.44	3.36	9.6	0.4	3.17	9.52	0.48	3.54	0.44	17.6	3.36
15	71	9.61	0.39	3.75	9.65	0.35	3.52	9.57	0.43	3.97	0.39	15.6	3.75
25	96	9.37	0.63	4.38	9.4	0.6	4.12	9.34	0.66	4.63	0.63	15.12	4.38
25	121	9.42	0.58	4.96	9.47	0.53	4.65	9.37	0.63	5.26	0.58	13.92	4.96
30	151	9.4	0.6	5.56	9.42	0.58	5.23	9.38	0.62	5.88	0.6	12	5.56
30	181	9.4	0.6	6.16	9.42	0.58	5.81	9.38	0.62	6.5	0.6	12	6.16
30	211	9.4	0.6	6.76	9.42	0.58	6.39	9.38	0.62	7.12	0.6	12	6.76
30	241	9.4	0.6	7.36	9.42	0.58	6.97	9.38	0.62	7.74	0.6	12	7.36

Appendix Table 8. Free flow discharge values for different size parshall flumes

Head(cm)	Throught width(cm)				
	2.54	5.08	7.62	15.24	22.86
	Discharge (l/s)				
2	0.14	0.28			
3	0.26	0.53	0.77	1.5	2.5
4	0.41	0.82	1.21	2.36	3.89
5	0.58	1.16	1.71	3.35	5.47
6	0.77	1.54	2.26	4.47	7.23
7	0.98	1.96	2.87	5.71	9.16
8	1.21	2.41	3.53	7.05	11.23
9	1.45	2.89	4.24	8.49	13.45
10	1.7	3.4	4.99	10.03	15.8
11	1.97	3.94	5.79	11.66	18.28
12	2.26	4.51	6.62	13.37	20.89
13	2.56	5.11	7.5	15.18	23.61
14	2.87	5.73	8.41	17.06	26.44
15	3.19	6.38	9.36	19.03	29.38
16	3.53	7.05	10.34	21.07	32.43
17	3.88	7.74	11.36	23.19	35.59
18	4.23	8.46	12.41	25.38	38.84
19	4.6	9.2	13.5	27.64	42.19
20	4.99	9.96	14.62	29.98	45.63
21	5.38	10.74	15.76	32.38	49.17
22		11.55	16.94	34.85	52.79
23			18.15	37.38	56.51
24			19.39	39.98	60.31

Appendix Table 9. Factorial ANOVA Table for days to 50% flowering

Source	DF	SS	MS	F	P
Rep	2	7.056	3.528		
II	2	44.056	22.028	32.43	0
IL	3	690.75	230.25	338.96	0
II*IL	6	4.833	0.806	1.19	0.3498
Error	22	14.944	0.679		
Total	35	761.639			
Grand Mean	56.806				
CV	1.45				

Appendix Table 10. Factorial ANOVA Table for maturity day

Source	DF	SS	MS	F	P
Rep	2	2.167	1.0833		
II	2	42.667	21.3333	29.64	0
IL	3	73	24.3333	33.81	0
II*IL	6	1.333	0.2222	0.31	0.9256
Error	22	15.833	0.7197		
Total	35	135			
Grand Mean	93.5				
CV	0.91				

Appendix Table 11. Factorial ANOVA Table for plant height

Source	DF	SS	MS	F	P
REP	2	72.862	36.4311		
II	2	56.427	28.2136	21.59	0
IL	3	82.652	27.5507	21.09	0
II*IL	6	1.526	0.2544	0.19	0.975
Error	22	28.744	1.3066		
Total	35	242.212			
Grand Mean	39.572				
CV	2.89				

Appendix Table 12. Factorial ANOVA Table for number of pod per plant

Source	DF	SS	MS	F	P
REP	2	160.965	80.483		
II	2	128.032	64.016	17.33	0
IL	3	537.214	179.071	48.48	0
II*IL	6	22.028	3.671	0.99	0.4537
Error	22	81.268	3.694		
Total	35	929.508			
Grand Mean	21.158				
CV	9.08				

Appendix Table 13. Factorial ANOVA Table for number of seed per pod

Source	DF	SS	MS	F	P
REP	2	5.7245	2.86223		
II	2	2.6106	1.30531	5.04	0.0158
IL	3	7.0721	2.35737	9.1	0.0004
II*IL	6	0.7161	0.11935	0.46	0.8296
Error	22	5.6976	0.25898		
Total	35	21.8209			
Grand Mean	6.1275				
CV	8.31				

Appendix Table 14. Factorial ANOVA Table for pod width

Source	DF	SS	MS	F	P
Rep	2	1.03994	0.51997		
II	2	0.01155	0.00577	1.47	0.2522
IL	3	0.09962	0.03321	8.44	0.0006
II*IL	6	0.01057	0.00176	0.45	0.8387
Error	22	0.08657	0.00394		
Total	35	1.24825			
Grand Mean	0.7698				
CV	8.15				

Appendix Table 15. Factorial ANOVA Table for pod length

Source	DF	SS	MS	F	P
Rep	2	0.9684	0.4842		
II	2	1.1038	0.55188	5.39	0.0124
IL	3	8.3558	2.78528	27.22	0
II*IL	6	0.4442	0.07403	0.72	0.6353
Error	22	2.2509	0.10231		
Total	35	13.1231			
Grand Mean	9.0456				
CV	3.54				

Appendix Table 16. Factorial ANOVA Table for number of leaves per plant

Source	DF	SS	MS	F	P
Rep	2	3325.96	1662.98		
II	2	777.91	388.95	23.71	0
IL	3	2726.26	908.75	55.39	0
II*IL	6	61.13	10.19	0.62	0.7115
Error	22	360.93	16.41		
Total	35	7252.19			
Grand Mean	82.444				
CV	4.91				

Appendix Table 17. Factorial ANOVA Table for thousand seed weight

Source	DF	SS	MS	F	P
Rep	2	166.5	83.251		
II	2	911.29	455.643	95.61	0
IL	3	1578.58	526.192	110.41	0
II*IL	6	387.74	64.623	13.56	0
Error	22	104.85	4.766		
Total	35	3148.95			
Grand Mean	130.31				
CV	1.68				

Appendix Table 18. Factorial ANOVA Table for yield

Source	DF	SS	MS	F	P
Rep	2	188616	94308		
II	2	822119	411060	27.05	0
IL	3	1857311	619104	40.74	0
II*IL	6	134584	22431	1.48	0.2322
Error	22	334343	15197		
Total	35	3336974			
Grand Mean	1614.6				
CV	7.64				

Appendix Table 19. Factorial ANOVA Table for AGDB

Source	DF	SS	MS	F	P
Rep	2	64702.3	32351		
II	2	3217111	1608555	13.27	0.0002
IL	3	2.72E+07	9058298	74.71	0
II*IL	6	583528	97255	0.8	0.5788
Error	22	2667401	121246		
Total	35	3.37E+07			
Grand Mean	2715.5				
CV	12.82				

Appendix Table 20. Factorial ANOVA Table for leaf area index

Source	DF	SS	MS	F	P
Rep	2	63.617	31.8084		
II	2	29.671	14.8357	26.68	0
IL	3	95.962	31.9872	57.53	0
II*IL	6	1.446	0.2411	0.43	0.8485
Error	22	12.231	0.556		
Total	35	202.928			
Grand Mean	8.0405				
CV	9.27				

Appendix Table 21. Factorial ANOVA Table for harvest index

Source	DF	SS	MS	F	P
Rep	2	74.17	37.09		
II	2	175.96	87.98	1.27	0.3
IL	3	6186.59	2062.2	29.83	0
II*IL	6	653.84	108.97	1.58	0.2011
Error	22	1521.11	69.14		
Total	35	8611.67			
Grand Mean	64.268				
CV	12.94				

Appendix Table 22. Factorial ANOVA Table for CWUE

Source	DF	SS	MS	F	P
Rep	2	1.1232	0.56159		
II	2	4.8681	2.43406	31.42	0
IL	3	8.7942	2.93139	37.83	0
II*IL	6	0.434	0.07233	0.93	0.4909
Error	22	1.7045	0.07748		
Total	35	16.924			
Grand Mean	0.41				
CV	6.77				

Appendix Table 23. Factorial ANOVA Table for FWUE

Source	DF	SS	MS	F	P
Rep	2	0.55036	0.27518		
II	2	2.38538	1.19269	31.42	0
IL	3	4.30915	1.43638	37.83	0
II*IL	6	0.21264	0.03544	0.93	0.4909
Error	22	0.83522	0.03796		
Total	35	8.29275			
Grand Mean	0.29				
CV	6.77				

Appendix B. Figures



Appendix Figure 1. Double Ring Infiltrometer



Appendix Figure 2. Land preparation



Appendix Figure 3. Intial stage



Appendix Figure 4. Development stage



Appendix Figure 5. Mid stage



Appendix Figure 6. Late stage



Appendix Figure 7. During harvesting



Appendix Figure 8. During threshing



Appendix Figure 9. Yield of Haricot bean



Appendix Figure 10. During yield measurement

