EFFECT OF ALTERNATE FURROW IRRIGATION UNDER DIFFERENT MOISTURE REGIMES ON WATER USE EFFICIENCY, GROWTH, YIELD AND YIELD COMPONENTS OF COMMON BEAN (*Phaseolus vulgaris* L.) AT ALAGE, CENTRAL RIFT VALLEY OF ETHIOPIA

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE SCHOOL OF PLANT AND HORTICULTURAL SCIENCES, COLLEGE OF AGRICULTURE, SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ADVISORS' APPROVAL SHEET -I

Submission sheet -1

This is to certify that the thesis entitled **"Effect of Alternate Furrow Irrigation under Different Moisture Regimes on Water Use Efficiency, Growth, Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) At Alage, Central Rift Valley of Ethiopia",** submitted in partial fulfillment of the requirements for the degree **Master of Science** in Plant Science with specialization in **Agronomy**. Graduate program of the **School of Plant and Horticultural Sciences**, College of Agriculture, and is a record of original research carried out by **HUNDE HAYILE TOLOSA**, ID. No **SGS/Agro k/150/09**, under our supervision, and no part of the thesis has been submitted for any other degree or diploma. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Approved by Advisors:

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Name of major advisor	Signature	Date
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We, undersigned, members of the Board of Examiners of the final open defense by **Hunde Hayile** have read and evaluated his thesis entitled **"Effect of Alternate Furrow Irrigation under Different Moisture Regimes on Water Use Efficiency, Growth, Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) At Alage, Central Rift Valley of Ethiopia",** and examined the candidate. This is therefore to certify that the thesis has been accepted partial fulfillment of requirements for the degree **Master of Science** in Plant Sciences with specialization in **Agronomy**.

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DEDICATION

This thesis is dedicated to my father, Hayile Tolosa and my mother, Almaz Eshete for their contribution to the success in my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is a result of my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis, and compilation of this thesis. Any scholarly matter that is included in the thesis has been given recognition through citation and all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an advanced MSc degree at Hawassa University and is deposited at the university library to be made available to borrowers under rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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LIST OF ABBREVIATIONS AND ACRONOMY

ABA	Absisic Acid
AFI	Alternate Furrow Irrigation
ANOVA	Analysis of Variance
CAPRI	Controlled Alternate Partial Root- Zone Irrigation
CEC	Cation Exchange Capacity
CFI	Conventional Furrow Irrigation
CIMMYT	International Maize and Wheat Improvement Center
CROPWAT	Crop Water Requirement Estimation Model
CV	Coefficient of Variations
CWUE	Crop Water Use Efficiency
DI	Deficit Irrigation
EC	Electric Conductivity
ET	Evapotranspiration
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAFI	Fixed Alternate Furrow Irrigation
FAO	Food and Agriculture Organizations of the United Nations
HI	Harvest Index
Kc	Crop Coefficient
LSD	Least Significant Difference
PRD	Partial Root-Zone Drying
PRI	Partial Root Irrigation
RDI	Regulated Deficit Irrigation
VAFI	Variable Alternate Furrow Irrigation
WP	Water Productivity
WUE	Water Use Efficiency

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Effect of Alternate Furrow Irrigation under Different Moisture Regimes on Water Use Efficiency, Growth, Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) at Alage, Central Rift Valley of Ethiopia

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ABSTRACT

The farmers use common traditional irrigation methods which at times lead them to over irrigate, resulting in high water losses and low irrigation efficiency. Under such conditions understanding and application use of deficit and alternate furrow irrigation systems on crop production would enhance food security through improved water use. Thus, this study evaluated that the effect of alternate furrow irrigation under different moisture regimes on water use efficiency, growth, yield and yield components of common bean, during 2019 at Alage ATVET College. The experiment was laid out in factorial combination of two factors, following randomized complete block design in split plot arrangement with three blocks consisting twelve treatments; four irrigation levels (100% ETc (I_0), 80% ETc (I_1) 60% ETc (I_2) and 40% ETc ($I_{3)}$ as the main plot and three irrigation methods (fixed alternate furrow irrigation (FAFI), variable alternate furrow irrigation (VAFI) and conventional furrow irrigation (CFI)) as the sub plot. This experiment showed that deficit irrigation (DI) and AFI significantly ($P<0.01$) affected days to physiological maturity, No of nodules plant^{-1}, grain yield, CWUE and IWUE. DI also significantly ($P<0.05$) influenced days to 50% flowering, stand count, plant height, No of branch, shoot dry weight, nodule dry weight, No of pods plant^{-1}, No of seeds pod^{-1}, pod length, 100-seed weight and HI. The interaction effect of DI and AFI also significantly ($P<0.05$) influenced the biological yield. Maximum (5.16 t ha^{-1}) and minimum (3.38 t ha^{-1}) biological yield was recorded at I_0 and I_3 respectively with combination of FAFI and CFI, in that order. The highest grain yield was obtained under I_0 (2.45 t ha^{-1}) and the lowest (1.34 t ha^{-1}) was at I_3. On the AFI, the maximum grain yield (2.11 t ha^{-1}) was obtained under FAFI and the minimum (1.78 t ha^{-1}) was under CFI. The uppermost CWUE (1.03 kg m^{-3}) was recorded at I_3 followed by I_2 (0.92 kg m^{-3}) and the smallest was at I_0 (0.70 kg m^{-3}) followed by I_1 (0.77 kg m^{-3}). The maximum CWUE (0.92 kg m^{-3}) was recorded under FAFI followed by VAFI (0.86 kg m^{-3}) and CFI (0.79 kg m^{-3}). The partial budget analysis showed that I_0, I_1 and I_2 gave marginal rate of return above the acceptable threshold value with additional investment advantages for the later. However, there was significant yield difference between I_0 and I_1; farmers can save 20% of the irrigation water in the expenditure of the reduced yield (0.33 ton ha^{-1}). The highest net benefit was obtained from FAFI, thus the farmers option allows for FAFI at which high yield was recorded. Generally this analysis indicates that farmers at study area and related agro-ecology can use I_0 (100% ETc) in order to maximize their income from increased investment, but if there is lack of adequate irrigation water they can use I_1 (80% ETc) in order to save and use irrigation water more economically.

***Key words**: Alternate irrigation, Common bean, Deficit irrigation, Grain yield, Irrigation*

1. INTRODUCTION

The global population will continue to grow, but is predicted to plateau at some 9 billion people by the middle of this century (Muir, 2010). As a result, with rapid economic and population growth many water sources have become depleted, therefore, now water has become one of the scarce goods (Ahmad *et al.,* 2010). Roughly 70% of the world freshwater withdrawals are for agricultural use (FAO, 2010). There is a conflict in global increase in food demand and decrease in water resources that should be resolved (Lascano and Sojka, 2007). Irrigation is believed to have benefited the population by providing more food at reduced prices (Hussain and Hanjra, 2004). The irrigated area should be increased by more than 20% and the irrigated crop yield should be increased by 40% by 2025 to secure the food for 8 billion people (Lascano and Sojka, 2007). Currently, the need to increase agricultural productivity and attain food security is nowhere more pressing than in Ethiopia, which has become a typical case of recurring famines and food insecurity, and is a major recipient of foreign food aid (Lire, 2005).

Ethiopia has an estimated irrigation potential of 3.5 million hectares (Awulachew, 2007), but it will become a physically water scarce country by the year 2020 due to lack of water storage capacity and large spatial and temporal variations in rainfall. There is not enough water for most farmers to produce more than one crop per year (Awulachew, 2005). Furthermore, more than one-third of total water used in the irrigation projects is wasted, because of low irrigation efficiencies (Hanks, 1983). Improving the efficiency of the irrigation application is a key strategy for water savings in agriculture (Mancosu *et al.*, 2015).

Therefore, high efficiency in water use is of high priority (Hanks, 1983). Nowadays, many strategies are implemented to improve water productivity, starting with the optimal choice of irrigation system, followed by the application of the proper irrigation scheduling in terms of both timing and quantity of water applied and concluding with the choice of the best crop management with regards to the soil and climate conditions (Mancosu *et al.*, 2015). Farmers minimize water losses by using deficit irrigation and by transferring water immediately to the next plot. On the other hand, over-irrigation and high water losses were observed on fields irrigated by gravity-fed water (Agric, 2018).

Research effort has focused on developing new techniques to achieve high returns from restricted supply of water. Previous findings (Hanks, 1983) suggest that new innovations can be used to improve traditional irrigation practices and thereby increase effective use of water. For example, it has been reported that exposing field crops to water stress at specific growth stages may not cause significant yield reduction and therefore irrigation during these stages can be omitted. Well managed irrigation application systems have better water productivity compared to that of the traditional irrigation practices in the country (Tsegay *et al.,* 2015; Kifle and Gebretsadikan, 2016). Efficient water use has become an important issue in recent years because the lack of available water resources in some areas is increasingly becoming a serious problem. Much effort has been spent on developing techniques such as RDI (regulated deficit irrigation), AFI (alternate furrow irrigation), CAPRI (controlled alternate partial root-zone irrigation) or partial root-zone drying (PRD) to improve field and fruit crop water use efficiency (WUE) (Kang and Zhang, 2004).

In areas where water is the limiting factor for crop production, maximizing water productivity (WP) by deficit irrigation (DI) is often economically more profitable for the farmer than maximizing yield. Reduced yield under deficit irrigation especially in water limiting situations may be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation (Ali *et al.*, 2007). Moreover, irrigated yields can be stabilized at a particular level, guaranteeing a stable income for the farmer and allowing economic planning (Cicogna *et al.,* 2005). English (1990) stated that water restriction is limited to drought-tolerant phenological stages, often the vegetative stages and the late ripening period.

Deficit irrigation maximizes water productivity, which is the main limiting factor. In other words, DI aims at stabilizing yields and at obtaining maximum WP rather than maximum yields (Zhang and Oweis, 1999). WP increases under DI, relative to its value under full irrigation, as shown experimentally for many crops (Zwart and Bastiaansen, 2004; Fan *et al.*, 2005) and with increasing amount of water supply, the water use efficiency decreases (Mekonen, 2011). Water deficits, by affecting growth, development, and carbon assimilation, reduce the yield of most annual crops (Hsiao and Bradford, 1983). Deficit irrigation at different growth stages significantly influences plants transpiration and water balance. Water use of common bean is markedly influenced by the irrigation level (Calvache *et al.,* 1997). Ali *et al.* (2007) also stated that the deficit irrigation strategies affected almost all aspects of plant growth and yield attributes adversely. The reduction in yield by water deficits is caused by a decrease in biomass production and/or by a decrease in the fraction of biomass that is harvested, termed the harvest index (HI) (Fereres and Rabanales, 2007). Conversely, Calvache *et al.* (1997) stated that an increased HI under water stress is resulted because of strong reduction in vegetative growth. There is a strong interaction between root biomass production and DI. Under severe water stress, in bean, the root biomass increased (Webber *et al.*, 2006).

Alternate furrow irrigation is one of the deficit irrigation types (Wakrim *et al*., 2005). Alternate furrow irrigation is an irrigation management strategy in which one out of two adjacent furrows is irrigated. By facilitating horizontal (lateral) water movement, alternate furrow has potential to reduce water losses via deep percolation and runoff. A number of researchers have reported that using alternate furrow irrigation reduces irrigation water use, often decreases crop yield, and results in an increase in water productivity (Horst *et al.,* 2007; Slatni *et al.,* 2011). The effect of wetting and drying each side of roots are dependent on crops, growing stage, evaporative demands, soil texture and soil water balance (Saeed *et al.,* 2008). Alternate furrow irrigation has been successfully used as a water saving irrigation (Grimes *et al.,* 1968). Common bean yielded slightly less when alternate furrow irrigation is implemented compared to conventional furrow irrigation because, bean partition less of its resources to seed production and more to root production under alternate irrigation (Grimes *et al.,* 1968).

Implementing deficit and alternate furrow irrigation at the same time increases the WUE of the crop (Webber *et al.,* 2006). Practical results showed that crops under alternate furrow irrigation yielded better than under DI when the same amount of water is applied. This resulted in higher water productivity (WP) and even better seed quality in beans (Kang and Zhang, 2004). Wakrim *et al*. (2005) reported that no significant difference between water use efficiencies (WUE) in AFI and DI, but they resulted in a substantial increase in WUE compared to full irrigation (FI).

The world demand for common bean is ever increasing due to its significant role in human nutrition as a source of proteins, complex carbohydrates, vitamins and minerals (Bennink, 2005). Currently, common bean form the greatest part of the Ethiopia’s pulses export (CSA, 2017). In Ethiopia, common bean is grown predominantly under smallholder producers as an important food crop and source of cash. It is one of the fast expanding legume crops that provide an essential part of the daily diet and foreign earnings for most Ethiopians (Girma, 2009). The average white and red common bean productivity is 1.41 t ha^{-1} and 1.56 t ha^{-1} respectively (CSA, 2017).

In central Rift valley, increasing population pressure and economic developments put an increasing claim on the precious fresh water resources (Hengsdijk and Jansen, 2006). There is scarcity of water at the study area (Alage) and the farmers use common traditional irrigation methods such as wild flooding, furrow and basin, application methods, which at times lead farmers to over-irrigate. This results in high water losses and low irrigation efficiency. Under such conditions understanding the response of deficit and alternate furrow irrigation systems on crop production would be useful to enhance food security through improved water use. Therefore, this study was initiated with the general objective of; evaluate the effect of deficit and alternate furrow irrigation on growth, nodulation, yield, yield components and water use efficiency of Common bean.

The specific objectives of this study were:

- To assess comparative yield responses of common bean under alternate and conventional irrigation practices
- To evaluate the performance of common bean under full and deficit level of irrigation conditions
- To determine the best combination of alternate irrigation mechanism and moisture regime at which maximum water use efficiency is obtained with minimum yield reduction

2. LITRATURE REVIEW

2.1 Origin and Distribution of Common bean

Common bean *(Phaseolus vulgaris* L.) belongs to order Rosales, family Leguminosae, subfamily Papilionideae, tribe Phaseolinae (CIAT, 1986). It is originated in tropical America (Mexico, Guatemala, and Peru), but there is also evidence for its multiple domestication within Central America (Kay, 1979; CIAT 1986). The crop is now widely distributed throughout the world and is grown in all continents except Antarctica (Singh, 1999). *Phaseolus vulgaris* became established as a food crop in Africa before the colonial era. Common bean occupied also an important place in East and South African agricultural system, and in semi-arid and dry sub-humid Savanna of West African region (Gepts, 1990). The distribution of beans in Africa is heavily dependent on rural population density and mean temperature during the growing season (Wortmann *et al.*, 1998). In Ethiopia, it is most likely to be introduced by the Portuguese in the 16th century (Wortman, 1998).

2.2 Description and Climate Requirement of Common bean

Common bean is the world's most important food legume for direct human consumption (Schoonhoven and Voysest, 1991). *Phaseolus vulgaris* L. belongs to order *Rosales*, family *Leguminosae* subfamily *Papilionideae,* tribe *Phaseolinae* (CIAT, 1986). Graham (1997) reviewed that the plant is initially tap-rooted, but adventitious roots emerge soon thereafter, and dominate the tap root which remains 10-15 cm in length. The vegetative stages are defined on basis of the number of nodes on the main stem, whereas the reproductive stages are defined on the basis of pod and seed characteristics in addition to nodes (Fageria *et al.,* 1997). The flowers are self-compatible, and almost all flowers can be self-pollinated and produce fertile seeds (Summerfield and Roberts, 1985). Seed filling periods may extend from as few as 23 days in the case of the determinate cultivars to nearly 50 days in indeterminate and climbing varieties (Graham, 1997). The bean plant is well adapted to areas that receive an annual average rainfall ranging from 500-1500 mm with optimum temperature range of 16-24 °C, where moreover, it performs best on deep, friable and well aerated soil types with optimum pH range of 6.0-7.5 and not below 5.0 and above 8.0 (Walelign, 2015). Most production is found on plateaus between 1200 and 1700 m a.s.l (Marcial and Howard, 1889).

2.3 Common bean Production and Its Importance in Ethiopia

Common bean production in Ethiopia is almost entirely based on rainfall and characterized by a dominant growing period (*meher*) and a secondary growing period (*belg*) (Farrow, 2010). It is one of the most important cash crops and source of protein for farmers in many lowlands and mid-altitude zones. As a major legume crop in Ethiopia, it contributes to the income and nutrition of more than 3.3 million smallholder farmers (CSA, 2014). Overall, common bean ranks third as an export commodity in Ethiopia, 188,248 tons was exported in 2017 (FAOSTAT, 2017).

Total national production was estimated at 543,984 ton in 2017, with a market value of US$ 257,953,708.8 (FAOSTAT, 2017). In the Central Rift Valley of Oromia region in Ethiopia, common bean is mainly a commercial crop; about 83% of the farmers grow it primarily for sale on a relatively larger scale (allocated 0.87 ha of land) as a sole crop (Farrow, 2010). Two types of common bean are grown: the canning type primarily grown for export market dominates the Oromia region and the cooking type primarily grown for food in the Southern

Nations, Nationalities, and Peoples' Region (Alemu and Bekele, 2005). The average white and red common bean productivity is 1.41 t ha^{-1} and 1.56 t ha^{-1} respectively (CSA, 2017).

2.4 Water Resource for Irrigation in Ethiopia and Central Rift Valley

The “abundance” of water resources in some regions has led to the country being called the “Water Tower of Eastern Africa.” This water resource from the excess runoff basins could, in principle, provide supplementary irrigation to overcome the effects of rainfall variability and drought during the major rain and secondary production seasons, as well as full irrigation during the dry season to intensify production and maximize the return on available land and water resources (Awulachew *et al.*, 2005). The 12 river basins covered by Ethiopia have an annual runoff volume of 122 billion m^3 of water. There is also an estimated 2.6 billion m^3 of ground water potential (MoWR, 2002). This amounts to an estimated 2,620 m^3 of water per person per year in 1990 for a population of 47 million. By 2005, this has reduced to 1707 m^3 due to population growth to about 73 million and the per capita availability continues to fall. Ethiopia will become a physically water scarce country by the year 2020 (Awulachew *et al.*, 2005). Furthermore, due to lack of water storage capacity and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year. Crop failures due to dry spells and droughts are frequent (Awulachew *et al.*, 2005).

The “irrigation water” resources of the country are found in lakes, rivers, streams and ground water, and are obviously dependent on the rainfall (Awulachew *et al.*, 2005). The main source of water to the Rift valley lakes and rivers is the rainfall in the eastern and western highlands. The most important rivers are the Meki–Katar, Bilate and Awash which feed Lakes Ziway, Abaya and Abhe, respectively (Ayenew, 2007). The Central Ethiopian Rift valley is characterized by a chain of lakes and wetlands with unique hydrological and ecological characteristics (Hengsdijk and Jansen, 2006) and increasing population pressure and economic developments put an increasing claim on the precious fresh water resources (Ayenew, 2007).

Lake levels in the Ethiopian Rift valley are reducing or lowering. Lake Abiyata showed the most drastic reduction; slight decline is evident in Lake Ziway (Legesse and Ayenew, 2006). Lake Abiyata is a relatively shallow small alkaline terminal lake fed by Horakelo and Bulbula Rivers originating from the near-by lakes Langano and Ziway, respectively (Legesse and Ayenew, 2006). The lake level reduction is believed to have been amplified by the large amount of water being pumped from Lake Ziway for irrigation, which is the major supplier of water to Lake Abiyata through the Bulbula River (Ayenew, 2007). There are a number of irrigation fields that pump water from the Bulbula River using gravitational canals (Legesse and Ayenew, 2006).

2.5 Irrigation in Ethiopia

Irrigation is practiced in Ethiopia since ancient times producing subsistence food crops, however modern irrigation systems were started in the 1960s with the objective of producing industrial crops in Awash Valley (Awulachew *et al.*, 2007). In the Ethiopian context, farmers use full irrigation to grow crops during the dry season when crop production from rainfall is not possible. This means that households get income from irrigated crops, which is in addition to what farmers get during the main cropping season (Fitsum *et al.*, 2009). Physical and economic scarcity of water is very common, and a growing problem in Ethiopia (Awulachew *et al.*, 2005). Currently, the government is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture (Awulachew *et al.*, 2007).

2.6 Crop Water Requirements

Crop water requirement is defined as the depth of water needed to meet the water lost through evapotranspiration (ETcrop) of a disease-free crop, growing in large fields under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (FAO, 1992). Allen (2006) also stated that the amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that is needed to be supplied to the crop, whereas crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Mahdi and Al-Kaisi, 1992). Crop water use, also known as evapotranspiration, is the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system, which represents transpiration and is no longer available as stored water in the soil.

Weather parameters, crop characteristics, management and environmental aspects are factors affecting evaporation and transpiration (Allen *et al.*, 1998). The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application (Allen, 2006). There are four methods to calculate ETo; the Blaney-Criddle, Radiation, Penman and Pan Evaporation using the mean daily climatic data (FAO, 1992). Among them the FAO Penman-Monteith method gives satisfactory prediction of the effect of climate on ET_o (Reddy, 2007) and it is determined with equation below (Allen *et al.*, 1998).

$$ETo = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma\left(\frac{900}{T + 273}\right)U2(es - ea)}{\Delta + \gamma[1 + 0.34U2]}$$

Where: ETo = reference evapotranspiration (mm/day), Rn = net radiation at the crop surface (MJ m^{-2}/day), G = soil heat flux density (MJ m^{-2} /day), T = mean daily air temperature at 2 m height (^{o}C), U_2 = wind speed at 2 m height (m s^{-1}), es = 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 curve (kPa $^{o}C^{-1}$) and γ= psychrometric constant (kPa $^{o}C^{-1}$)

2.7 Role of Deficit and Alternate Irrigation on Water Use Efficiency

Bourgault (2010) stated that as water for irrigation purposes becomes increasingly scarce because of climate change and population growth, there is growing interest in deficit irrigation as a way to improve efficiency of water usage and farm productivity in arid and semi-arid areas. Alternate irrigation, also called partial root-zone drying (PRD) in other literature, is a new irrigation technique that may improve the water use efficiency of crop production without significant yield reduction (Kang and Zhang, 2004). The irrigation system is developed on the basis of two theoretical backgrounds. (i) Fully irrigated plants usually have widely opened stomata. A small narrowing of the stomatal opening may reduce water loss substantially with little effect on photosynthesis. (ii) Part of the root system in drying soil can respond to the drying by sending a root-sourced signal to the shoots where stomata may be inhibited so that water loss is reduced (Kang and Zhang, 2004). With increasing amount of water supply, the water use efficiency decreases (Mekonen, 2011).

In the literature the term WUE is interchangeably used with water productivity (WP) for crop yield per unit evapotranspiration (Sepaskhah and Ahmadi, 2010). Kirda *et al.* (1999) indicated that among the techniques of increasing effective use of water, deficit evapotranspiration should also be used. Deficit evapotranspiration can be used either through agronomic practices or through changing management schemes to decrease crop evapotranspiration. The main approach in deficit irrigation practice is to increase crop water use efficiency by eliminating those irrigations with the least impact on crop yield (Kirda *et al.*, 1999). In the areas where water supplies are limited and unit water costs are expensive, the best irrigation practice is not necessarily that giving the highest yields. Fereres and Rabanales (2007) also reviewed that WP increases under DI, relative to its value under full irrigation, as shown experimentally for many crops. At that point the marginal water use efficiency is zero, since the application of additional water will produce no additional yield (English and Raja, 1996). The benefits of deficit irrigation are low production costs, increasing of irrigation efficiency, and acceptable cost-benefit ratio of irrigation water. Although crop yields are somewhat decreased under deficit irrigation, benefits from the saved water may be high (Kirda, 1994). According to Calvache *et al.* (1997) water use of common bean is markedly influenced by irrigation. There is a decline in ET with decreasing water content in the soil. This could be due to a combination of both, reduced surface soil evaporation with lower irrigation frequency and greater plant water deficits with low soil matric potentials. Water use efficiency, maximized with deficit irrigation at the vegetative stage and declined with irrigation frequency (Calvache *et al.*, 1997). Alternate wetting and drying reduced irrigation water use without a significant impact on grain yields and increased the mean water productivity by 16.9% compared with continuously flood irrigation (Tan *et al.,* 2013). Lower yield due to less water application may have higher water use efficiency (Mekonen, 2011).

2.8 Common bean Response to Deficit Irrigation

The potential benefits of deficit irrigation derive from three factors: increased irrigation efficiency, reduced costs of irrigation and the opportunity costs of water (English and Raja, 1996). According to Ghassemi-Golezani and Mazloomi-Oskooyi (2008) maximum seed weight, percentages of viable seeds and normal seedlings, seedling dry weight and minimum electrical conductivity of seeds were not significantly different among seeds produced under different irrigation conditions. Bourgault *et al.* (2013) also reported that yields of common bean in the moderate water stress were not different from the crop grown using the recommended schedule. Fereres and Rabanales (2007) in their review indicated that water deficits, by affecting growth, development, and carbon assimilation, reduce the yield of most annual crops. The reduction in yield by water deficits is caused by a decrease in biomass production and/or by a decrease in the fraction of biomass that is harvested, termed as the HI (Hsiao and Bradford, 1983). Calvache *et al.* (1997) reported that the flowering stage was the most sensitive growth stage to water stress and the treatment of stress at flowering stage had the same result as the one which had water stress during the whole growing cycle. According to Mart (2007), however, the yield component that was more affected by the water stress treatments is the number of pods per plant. Seed filling rate of common bean increased, but seed filling duration decreased, as water deficit severity increased (Ghassemi and Mazloomi, 2008). Calvache *et al.* (1997) on his experiment reported that a highly significant difference in seed yield of common bean as an effect of water deficit. Webber (2006) also reported that reduced seed yield, however, the highest reduction is found when the stress imposed at the beginning of grain formation. DI at the moderate depletion level produced the same seed yields of common bean as the recommended irrigation schedule while seed yields decreased with the large depletion factor. This reduction in yield is mainly due to the reduction in the number of pods per plant (Calvache *et al.,* 1997). On related crops like chickpea and field pea, Benjamin and Nielsen (2006) reported that water deficit stress resulted in a greater proportion of their roots to grow deeper in the soil. Under irrigated conditions, about 80% of the chickpea and field pea roots were in the surface 0.23 m. Under dry conditions, about 66% of the total chickpea and field pea roots were in the surface 0.23m and the remainder of the roots was deeper in the soil profile. In soybean, yield with delayed irrigation until the flowering stage or mid-pod elongation stage was not significantly different when compared with normally irrigated treatments where available soil water content was maintained between 50 to 80% of the total plant available soil Water content (Kirda *et al.,* 1994).

2.9 Common bean Response to Alternate Furrow Irrigation

The alternate furrow irrigation is a novel improvement of deficit irrigation in which half of the root zone is irrigated alternatively in scheduled irrigation events. Under limited water resources where water is precious, alternate furrow irrigation is a viable irrigation option to increase water productivity while maintaining the yield, rather than only increasing the economic yield without concern to the value of water in limited water environments (Sepaskhah and Ahmadi, 2010). Mintesinot (2004) reported that alternate furrow irrigation generates the highest WP values followed by every furrow-scientific scheduling.

Sepaskhah and Ahmadi (2010) on their review mentioned that shoot and pod biomass was significantly decreased in both alternate furrow irrigation and DI as compared with full irrigation. Comparison of alternate furrow irrigation with every-furrow irrigation at podding stage showed that grain yields were statistically equal (about 9% reductions) to those obtained in every-furrow irrigation although the amount of water used was 29% smaller (Sepaskhah and Ahmadi, 2010). Alternate furrow irrigation can improve WUE, and may or may not reduce yield, improve fruit quality, and control vegetative growth in the relatively short term (Kang and Zhang, 2004). Common bean yielded slightly less when alternate furrow irrigation was implemented compared to conventional furrow irrigation. Because the bean partitions less of its resources to seed production and more to root production. The strategy to extract more water by developing more root biomass comes at the expense of seed production (Webber *et al.*, 2006).

2.10 Combined Effect of Deficit and Alternate Irrigation on Common bean

Bourgault *et al.* (2013) reported that the combination of AFI and DI can allow legume production with reduced water inputs. AFI, which saves 25% of the water applied by not watering every second furrow, did not reduce yields, for most of the yield components measured, and did not affect crops negatively when combined with DI treatments. Although soil water productivity was reduced in the AFI treatment after irrigation events, this was not translated into yield differences. Therefore, AFI appears to be a simple yet effective way to increase WUE while maintaining yields (Bourgault *et al.,* 2013). Webber *et al.* (2006) stated that implementing DI and irrigating in alternate furrows produced the highest WUE, yield and the greatest seasonal water savings.

3. MATERIAL AND METHODS

3.1 Description of the Study Area

The study was conducted at Alage Agricultural Technical and Vocational Educational and Training College (7° 65’ N latitude and 38° 56’ E longitude with an altitude of 1600 meters above sea level) in the agroecology of dry plateau of the southern part of the Ethiopian rift valley from January to April 2019. The college is located 217 km south of Addis Ababa city and 32 km west of Bulbula town in the vicinity of Abidjata and Shalla lakes (Figure 1). The area is characterized by a bimodal rainfall pattern where short rainy season occurs during the months of March and April and the main rain starts in June and extends to September. High amount of rainfall is in the month of July and August. While the mean annual rainfall is 800 mm, the annual mean minimum and maximum temperatures are 11 ^{o}C and 29 ^{o}C, respectively. The soil textures of the area range from sandy loam to sandy clay loam with some clay loam and few clay soils (Eylachew, 2004). The soil analysis result of the experimental site showed that the soil textural class is silt clay loam (Table 6). The major crops grown in the area are Maize and Common bean.

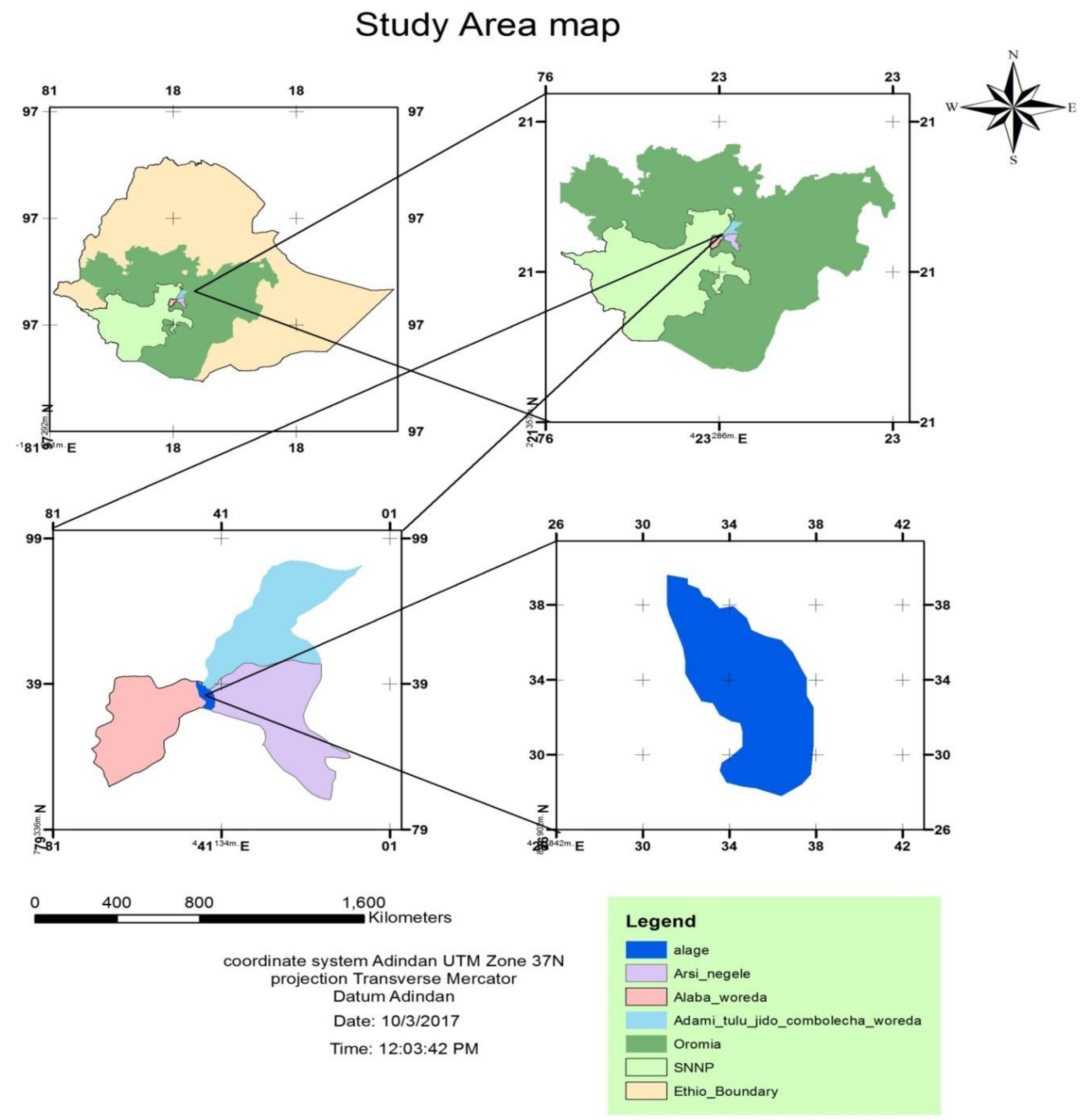

Figure 1: Map showing the study area Alage, Centeral Rift valley of Ethiopia

3.2 Treatments and Experimental Design

The study comprised 12 treatments of four irrigation levels (100% ETc (I_0), 80% ETc (I_1), 60% ETc (I_2) and 40% ETc (I_3) and three irrigation methods (fixed alternate furrow irrigation (**FAFI**), variable alternate furrow irrigation (**VAFI**) and conventional furrow irrigation (**CFI**)). The Irrigation levels (***I_0***, ***I_1***, ***I_2***, and ***I_3*****; 100%**, **80%**, **60%**, **and 40%**, of crop water requirement, respectively) were applied throughout the growing season except flowering stage, at flowering stage 100% of ETc was applied to all plots. The alternate furrow irrigation methods were applied throughout the growing season. The experiment was laid out in RCBD design on split-plot arrangement using irrigation levels as a main plot and alternate furrow irrigation method as a sub-plot, which was replicated three times. Each treatment combination was assigned randomly to the experimental units within a block. The plot size was 4 m x 2 m consisting of 10 rows. The rows width and depth was 20 cm x 10 cm, respectively. The spacing between rows and plants was 40 cm x 10 cm, respectively. The path between subplots, main plots and blocks were 1 m, 2 m and 2 m respectively. The experimental plots were covered with mobile waterproof shed at a time of drizzle for sudden rain protection (Appendix Figures 2 and 3).

Table 1: Description of combination of irrigation treatments

Alternate Irrigation	Irrigation Level			
	I_0	I_1	I_2	I_3
FAFI	FAFI+ I_0	FAFI+ I_1	FAFI+ I_2	FAFI+ I_3
VAFI	VAFI+ I_0	VAFI+ I_1	VAFI+ I_2	VAFI+ I_3
CFI	CFI+ I_0	CFI+ I_1	CFI+ I_2	CFI+ I_3

3.3 Soil Sampling, Preparation and Analysis

Three undisturbed core samples from the depth of 0-20 cm, 20-40 cm and 40-60 cm were taken before planting and analyzed for bulk density, soil moisture at field capacity and permanent wilting point in Debrezeit Agricultural Research Center. Soil moisture content at field capacity and permanent wilting point were measured using pressure plate apparatus by applying a suction of 0.33 and 15 bars, respectively to a saturated soil sample. When water no longer leaves the soil samples, the soil moisture were taken as field capacity and permanent wilting point (Stakman *et al.*, 1969) in that order. Total available soil water (TAW) was calculated as the amount of water retained between FC and PWP (Allen *et al.*, 1998).

$$\boldsymbol{TAW = 1000 * (\theta_{FC} - \theta_{WP}) * Zr} \qquad \textbf{(1)}$$

Where; TAW = total available soil water in the root zone (mm)

θ_{FC} = soil water content at field capacity ($m^3 m^{-3}$)

θ_{WP} = soil water content at wilting point ($m^3 m^{-3}$)

Zr = root depth (m)

1000 = constant to convert meter (m) to millimeter (mm)

Then the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume (Hillel, 2004).

$$\textbf{Soil bulk density g/cm3} = \frac{\boldsymbol{mass\ of\ soil\ after\ oven\ dry\ (g)}}{\boldsymbol{total\ volume\ of\ soil\ in\ the\ core}\ (\textbf{cm3})} \qquad \textbf{(2)}$$

Gravimetric method was used to determine the initial moisture content of the soil before the experiment was started. Soil samples taken from each depth (0-20 cm, 20-40 cm and 40-60 cm) of the soil profile depending on the rooting depth of the crop were weighted, then after it was placed in an oven at 105 °C until constant weight is obtained. After drying, the soil sample was weighed again. The gravimetric water content in fraction (θm) was computed using equation 3 (Hillel, 2004).

$$\theta m = \frac{(Mw - Ms)}{Ms} \quad \textbf{(3)}$$

Where; Mw is weight of wet soil sample (g) and Ms is weight of dry sample soil (g).

The initial volumetric water content of the soil was determined from the gravimetric water content by multiplying with the apparent specific gravity of the soil.

For determination of soil texture, pH, OC, CEC, EC, total Nitrogen and available Phosphorus in laboratory, composite soil sample were collected using auger at a depth of 0-20 cm. The soil texture was determined by the modified Bouyoucos hydrometer method (Boyoucous, 1962) in Debreziet Agricultural Research Center. The textural class was designated based on the mass ratio of the three particles (clay, silt and sand) with the help of soil textural triangle (Hillel, 2004).

The soil pH was determined by diluting the soil in a 0.01 M $CaCl_2$ solution in the ratio of 1 soil volume to 2.5 volume of the $CaCl_2$ solution. Thus, twenty-five ml of the 0.01 M $CaCl_2$ solution was added into soil sub samples each weighing 10 g. After equilibrating for 2-3 hours, the suspensions was filtered and the pH measured by a glass electrode. Organic carbon content of the soil was determined by wet combustion procedure of Walkley and Black (1954). Cation exchange capacity (CEC) was also determined after saturation of samples with 1M ammonium acetate solution by using the modified Kjeldhal 16 method as described by Okalebo *et al.* (2002). Total nitrogen was determined by treating the sample with a mixture of concentrated sulfuric acid and digestion catalysis following the Kjeldhal method (Okalebo *et al*., 2002). Available phosphorus content of the soils was determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) according to the procedure of Olsen method (Olsen *et al* 1982).

3.4 Method of Planting and Cultural Practices

The experiment field was ploughed and leveled manually to be ready for planting. Awash-2, a white color and canning Common bean variety was used. The seed was sown on January 28, 2019 on the prepared plot. Two days before planting, at planting and two days after planting the irrigation water was applied to every furrow in each plot, with 100% ETc. The purpose of this irrigation was to bring the soil to field capacity and encourage seed germination and good plant seedlings. Then after, the respective irrigation treatments were applied to individual plots according to the treatments designed using watering hose. In fixed alternate furrow irrigation, water application was fixed to one of the two adjacent furrows. In variable alternate furrow irrigation, water was applied to one of two adjacent furrows and change the irrigated furrow, alternatively. In conventional furrow irrigation, water was applied to every furrow during every irrigation time. All the recommended amount of NPS at the rate of 100 kg ha^{-1} (80 gm plot^{-1}) was applied in band just before planting. Furthermore, all necessary cultural practices (weeding and disease monitoring) were carried out uniformly for all plots at plant emergence and at mid stage of vegetative growth.

3.5 Amount of Irrigation Water Applied

For the calculations of irrigation requirements; climatic, crop and soil data were used as an input. Eleven year (2007-2017) climatic data (maximum and minimum temperature, humidity, wind speed (from 2 m height) and sunshine hours) on monthly basis were collected from National Meteorological Service of the study area (Appendix Table 1). The soil data i.e. total available soil moisture, maximum rain infiltration rate, initial soil moisture depletion and initial soil moisture was used based on the soil type as input data for CROPWAT (Table 2). Crop growth stage, crop coefficient (Kc), root depth, critical depletion coefficient, yield response factor and maximum crop height (Table 3) was taken from FAO irrigation and drainage paper 56 (FAO, 2006). The reference evapotranspiration (ETo) (Appendix Table 2) was calculated by FAO Penman Monteith method, using CROPWAT version 8.0 software developed by FAO to determine the irrigation water requirements. The irrigation scheduling of common bean for control treatment was determined based on irrigation with user defined intervals (two days interval) (Appendix Tables 4 and 5) and the control used as a reference to apply irrigation water in deficit treatments (Appendix Tables 6, 7 and 8). The gross water requirement was computed by adopting field application efficiency of 70%, which is recommended for well-managed furrow irrigation by FAO (FAO, 2006). The volume of water applied to each treatment was calculated by multiplying the depth of water with the plot area of the plot (Yenus, 2013) as:

$$\boldsymbol{V = A * D * 1000} \tag{4}$$

Where; V = Volume of water to be applied (liter)

A = Area of the plot (m^2)

D = Depth of application (m)

1000 = Constant to convert m^3 to liter

Table 2: Soil data used for CROPWAT model

Soil name	Silt clay loam
Total available soil moisture (FC-PWP)	211.83 mm/meter
Max. rain infiltration rate	40 mm/day
Maximum root depth	90 centimeter
Initial soil moisture depletion (as % TAM)	50%
Initial available soil moisture	105.92 mm/meter

Table 3: Common bean crop data used for CROPWAT program

Crop characteristics	Growth stage				
	Initial	Development	Mid-season	Late	Total
Rooting depth (m)	0.30	>>	>>	0.9	
Critical depletion coefficient	0.45	>>	0.45	0.6	
Crop coefficient (kc)	0.4	>>	1.15	0.35	
Number of days	15	25	35	20	95
Yield response factor (ky)	0.2	1.1	0.75	0.4	1.15
Max. crop height (optional)			0.4		

Source: FAO 2006

Note “>>” indicates the value is found between the right and the left column.

3.6 Water Measuring Method

The experimental field was prepared to create suitable condition for crop growth and furrow irrigation application as per the recommendation of the agronomic requirement of common bean. The irrigation water source was from water tap and brought to the experimental field through watering hose. Water Meter was connected to the tip of the water delivering hose in order to measure and control irrigation water application (discharge) for each row (Figure 2).

Figure 2: Water source (tanker) and measuring material (water gauge)

3.7 Data Collection and Measurement

Days to flowering and maturity when 50% of the plants were at respective phenological stages and stand count when the plants in the plot were at vegetative stage were recorded from net plot area. The following parameters were measured from 5 randomly selected plants at physiological maturity from net plot area of each plot: number of branches per plant, stem thickness (using digital Caliper) and plant height. Number of pods plant^{-1}, pod length and number of seeds pod^{-1} were recorded from 5 randomly selected pods of each 5 randomly selected plants from net plot area. Shoot dry weight and nodule dry weight were recorded from five randomly selected plants in each plot from destructive rows at flowering stage and inserted in to oven drying for 72 hours at 70 ^{o}C. Number of nodules was recorded from five randomly selected plants in each plot from destructive rows at flowering stage. For determination of grain yield and biological yield, the samples were taken from net plot area (2 m x 1.6 m = 3.2 m^2) at harvest maturity and converted in to tone per hectare. Grain yield was adjusted to 10% moisture content as equation 5:

$$\textbf{Adjusted grain yield } (\textbf{kg ha}^{-1}) = \textbf{Actual yield } (\textbf{kg ha}^{-1})\left(\frac{\textbf{100}-\textbf{M}}{\textbf{100}-\textbf{D}}\right) \qquad \textbf{(5)}$$

Where; M is the measured moisture content and D is the designated moisture content

Harvest index was calculated as the ratio of grain yield to total biomass (equation 6), and 100-seed weight was determined using sensitive electronic balance.

$$HI = \frac{Y}{Ys} \qquad \textbf{(6)}$$

Where: HI is harvest index, Y is grain yield (kg ha^{-1}) and Ys is total biomass (kg ha^{-1})

3.8 Water Use Efficiency

Water use efficiency was calculated as units of dry grain yield (kg) divided by units of water consumed by the crop (mm) to produce that yield. WUE is a measure of a crop's capacity to convert water into plant biomass or grain.

Crop water use efficiency (CWUE) of all twelve treatments was calculated as equation 7as described by Ibragimov *et al*. (2007)

$$CWUE = \frac{Crop\ Yield}{Actual\ Evapotranspiration} \qquad \textbf{(7)}$$

For each treatment, the irrigation water use efficiency (IWUE) was calculated using equation 8 as described by Ibragimov *et al*. (2007)

$$IWUE = \frac{Crop\ Yield}{\textbf{Total amount of irrigation water applied}} \qquad \textbf{(8)}$$

3.9 Economic Analysis

The economic evaluations comprising a partial budget with dominance and marginal analysis was carried out as described in CIMMYT (1988). The average yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could obtain from the same practices as described by CIMMYT (1988). Some of the concepts used in the partial budget analysis are grain yield ha^{-1}, gross field benefit (GFB), and total variable cost (TVC) and the net benefit (NB). The GFB ha^{-1} is obtained as a product of real price and common bean yields for each irrigation level (GFB= Adjusted yield x Unit price). The TVC in the partial budget analysis refers to the sum of cost of all variable inputs and managements practices, whereas the NB ha^{-1}is the differences between the GFB and the TVC (NB= GFB - TVC). The dominance analysis procedure, which was used to select potentially profitable treatments, comprised ranking of treatments in ascending order from lowest to highest cost to eliminate those treatments costing more but producing a lower NB than the next lowest cost treatment. The selected and rejected treatments by using this technique were referred to as undominated and dominated treatments, respectively. For each pair of ranked undominated treatments, percentage marginal rate of return (%MRR) was calculated. The percent MRR between any pairs of undominated treatments denotes the return per unit of investment in crop management practice expressed as percentage.

$$\mathbf{MRR}\,(\%) = \frac{\Delta \mathbf{NB}}{\Delta \mathbf{TCV}}\, \boldsymbol{x}\, \mathbf{100} \qquad \mathbf{(9)}$$

The minimum acceptable rate of return was set at 100%

3.10 Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using *Gen Stat*. Treatment means were separated using Fisher's protected least significant difference (LSD) at $p<0.05$ probability level. Correlation coefficient was determined for parameters using the same software.

4. RESULT AND DISCUSSION

4.1 Physico-Chemical Properties of Soil of Experimental Site

The soil physical properties determined before sowing is presented in Tables 5 and 6. The soil textural class was silty clay loam based on USDA soil textural classification triangle, having particle size distribution of 19%, 52% and 29% of sand, silt and clay, respectively. The soil moisture content of the study area at field capacity were obtained 43.55 mm, 45.58 mm and 42.81 mm at soil depth of 0-20 cm, 20-40 cm and 40-60 cm, respectively. The permanent wilting point values that were obtained from three distinct soil depths were 20.8%, 22.45% and 25.14% on volume basis, in that order. The laboratory analysis for total available water content at the depth of 0-20 cm, 20-40 cm and 40-60 cm was shown to be 227.5 mm m^{-1}, 231.3 mm $m^{-1}$and 176.7 mm m^{-1}, respectively. This indicated, the total available water that is the amount of water that the crop can extract from its root zone was found higher in the middle layer of the soil than the upper and the lower layers. The bulk density values were 1.35 g cm^{-3}, 1.39 g $cm^{-3}$and 1.41 g cm^{-3} at 0-20 cm, 20-40 cm and 40-60 cm soil depths, respectively, with a cumulative average of 1.38g cm^{-3}. Bulk density reflects the soils ability to function for structural support, water and solute movement, and soil aeration.

The chemical properties of the study area are presented in Table 4. The soil pH of the experimental site was slightly alkaline (7.78) based on USDA classification. The organic matter of the soils of study area was moderate (3.16). According to Landon (1991), ranking 1-2% organic matter (OM) is categorized as low; 2-4% is categorized as moderate and 4-6% as high. The organic carbon content and the C:N ratio of the experimental site were 1.84 and 10.2%, in that order. Soils are classified depending on their % of total nitrogen content, as very low (<0.1), low (0.1-0.15), medium (0.15-0.25), and high (>0.25) (Havlin *et al*., 1999). Thus, the soils of the study area have moderate rating with a nitrogen content of 0.16%. Olsen P rating shows very low (<3 mg kg^{-1}), low (4-7 mg kg^{-1}), medium (8-11.5 mg kg^{-1}), and high (>12mg kg^{-1}) classes as described by Havalin *et al*. (1999). The availability of P content of the soil was low in the study area, which was 6.64 mg kg^{-1}. According to the ratings of Landon (1991), soils having CEC of >25, 15-25 cmol (+) kg^{-1}, 5-15 cmol (+) kg^{-1} and < 5 cmol (+) kg^{-1} are classified as high, medium, low and very low, respectively. The CEC of the soils in study area is categorized as high (26.15 cmol(+) kg^{-1}). The electrical conductivity of the soil sample was non-saline (1.24 ds/m) based on USDA rating. This soil analysis result showed that the experimental site is suitable for common bean production though it requires managing the P availability.

Table 4: Chemical properties of the soil of experimental sites before planting

Soil properties	Value	Rate	Reference
pH	7.78	Slightly-alkaline	NRCS-USDA
Organic carbon content (%)	1.84	High	(Landon, 1991)
Organic matter content (%)	3.16	Medium	(Landon, 1991)
Total nitrogen (%)	0.16	Medium	(Havlin *et al*., 1999)
Carbon: nitrogen	10.2	--	--
Available Phosphorus (mg kg^{-1} of soil)	6.64	Low	(Havlin *et al*., 1999)
Cat-ion exchange capacity (cmol(+) kg^{-1})	26.15	High	(Landon, 1991)
Electric conductivity (ds/m)	1.24	Low salinity	NRCS-USDA

Table 5: Physical properties of the soil at three distinct soil depths of the experimental site before planting

Soil depth (cm)	Bulk density g cm^{-3}	Field capacity (%) v/v	Permanent wilting point (%) v/v	Total available moisture mm m^{-1}
0-20	1.35	43.55	20.80	227.5
20-40	1.39	45.58	22.45	231.3
40-60	1.41	42.81	25.14	176.7
Average	**1.38**	**43.98**	**22.80**	**211.83**

Table 6: Particle size distribution of the soil at the depth of 0-20 cm

Particle size distribution	In (%)
Sand	19
Silt	52
Clay	29
Textural class	Silt clay loam

4.2 Crop and Irrigation Water Requirement of Common bean

Monthly reference evapotranspiration (ETo) calculated from historical records of 11 years (2007-2017) data from National Meteorological Service of the study area using CROPWAT is presented in Appendix Table 2. The result showed that the minimum (3.25 mm/day) and maximum (4.41 mm/day) ETo value occurred in the months of July and March respectively. Generally the evaporative power of the atmosphere was under moderate range (3-5 mm/day) (Allen *et al.*, 1998). As the cycle of most common bean varieties is around 100-120 days, in the order of 350-400 mm of water would be required in adequate growing conditions

(Carvalho *et al.*, 2013). In this study, the accumulated crop water applied in the control was 341.9 mm (Table 7). The reduction of 8.1 mm from the above mentioned range might be due to the common bean variety (Awash-2), which is early maturing (85-90 days). The control treatment plot was monitored and used as a reference to apply irrigation water in other treatments. Adopting irrigation efficiency to be 70%, the gross water requirement was 450.5 mm (Appendix Table 3). The irrigation efficiency of 70 % is recommended for normal well-managed gravity irrigation (FAO, 2006).

Table 7: Crop water requirement of the control treatment (100% ETc) (mm/decade)

Month	Decade	Kc coefficient	Eff rain mm	ETc mm/decade	Irr. Req. mm/decade
Jan	1	0.4	0	1.5	1.5
Jan	2	0.4	0	15	15
Jan	3	0.48	0	20.4	20.4
Feb	1	0.78	0	31.3	31.3
Feb	2	1.07	0	44.5	44.5
Feb	3	1.15	0	39.3	39.3
Mar	1	1.15	0	49.8	49.8
Mar	2	1.15	0	50.7	50.7
Mar	3	1.07	0	51.8	51.8
Apr	1	0.69	0	30.5	30.5
Apr	2	0.41	0	7.1	7.1
				341.9	**341.9**

K_c = crop coefficient, Eff rain = effective rain fall, Et_c = crop evapotranspiration, Irr. Req. = irrigation requirement.

4.3 Phenological Parameters

4.3.1 Days to 50% Flowering

Analysis of variance for the number of days to flowering showed that common bean was significantly ($P<0.001$) affected by the main effect of DI but not significantly affected by AFI and interaction of DI and AFI (Appendix Table 9). Common bean which were treated under optimum irrigation (I_0) had longer flowering days (39.44) than I_1 (39.11 days), I_2 (37.56 days) and I_3 (35 days) (Table 8). The earliest flowering level was observed on I_3 (35 days) while the late flowering was observed on I_0 (39.44 days). The result obtained is in line with that obtained by Ahmed *et al*. (2008), regarding number of days to 50% flowering and maturity, for faba bean. 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. Similarly this is in agreement with Sisay *et al.* (2014) who showed that the number of days to flowering decreased under deficit irrigation and increases under optimal irrigation. This study demonstrated that imposing water deficit had hastened the time of flower induction of common bean than optimum irrigation. The lowest irrigation level (I_3) was advanced by 4 days, followed by I_2 (2 days) than the optimum irrigation (I_0) to attain 50% flowering.

The output of statistical analysis revealed that there was no significant ($P<0.05$) difference among treatments by the sub factor; FAFI, VAFI and CFI in terms of days to 50% flowering. The current study is in line with the earlier field work by Sepaskhah and Ahmadi (2010) who reported that alternate furrow irrigation had statistically equal days to 50% flowering with those obtained in conventional irrigation. Similarly, Bouman and Toung (2001) reported that the transition from the vegetative to reproductive stages, where the ‘time to initiation of flowering' had no significant difference between alternate wetting and drying, and conventional irrigation.

Table 8: Phenological parameters and Stand count of common bean as influenced by DI and AFI

Irrigation Level	Days to 50% flowering	Days to physiological maturity	Stand count plot^{-1}
I_0	39.44 ^{a}	85^{a}	186.61^{a}
I_1	39.11 ^{a}	82^{b}	183.43^{a}
I_2	37.56 ^{b}	77.11^{c}	181.70 ^{a}
I_3	35.00 ^{c}	74.56 ^{d}	156.38 ^{b}
LSD $_{0.05}$	1.148	1.779	5.568
CV%	**1.5**	**1.1**	**1.6**
Alternate Irrigation			
FAFI	38.08^{a}	80.92^{a}	177.37^{a}
VAFI	38.00^{a}	79.67^{a}	176.73^{a}
CFI	37.25^{a}	79.08 ^{b}	177.00^{a}
LSD $_{0.05}$	0.935	1.435	4.050
CV%	**2.9**	**2.1**	**2.6**

4.3.2 Days to Physiological Maturity

Highly significant variations were observed (P<0.001) on common bean for days to maturity under DI and (P<0.05) for AFI, and the interaction of DI x AFI was non-significant (Appendix

Table 9). Irrigation level I_3 was the earliest (75 days) followed by I_2 (77 days), whereas the I_0 required relatively more days (85 days) followed by I_1 (83 days) to reach maturity (Table 8). There was significant difference between each irrigation level (DI) I_0, I_1, I_2, and I_3. Similar result has been reported by Uddin *et al.* (2013) who showed that moisture stress causes early flowering, poding and maturity. This result is also in agreement with Al Suhaibani (2009) who indicated that soil water stress leads to significant decrease in number of days to maturity. The most deficited treatment took the least number of days to attain 50% flowering and also the least number of days to harvesting indicating that common bean rapidly completes its life cycle, hence, can escape periods of drought and grow during periods of favorable soil moisture. This study showed that a linear relationship between amounts of water applied and physiological maturity (Figure 4 (A)), indicating that moisture stress could enhance early senescence.

There was also significant variation ($P<0.05$) among AFI in influencing the days required to reach physiological maturity (Table 6). Common bean had longer days to reach maturity under FAFI (81days) than VAFI (80) and CFI (79). The reason for the prolonged maturity on FAFI might be due to that all the total irrigation water of the plot was applied only to the fixed furrows (via half of the total row). Out of ten rows only five rows had been received all the total irrigation water of the plot, which mean that some rows had been received additional water at each irrigation time. This may promote a prolonged days to FAFI than CFI. Alike FAFI, rows under VAFI had been received all the total irrigation water of the plot alternatively, but with an irrigation interval longer than FAFI. This may have resulted that the FAFI to have an extended one days to 50% physiological maturity over VAFI and CFI. This study is in agreement with Bevit (1984) who observed that wheat grown under fixed furrow irrigation had elongated flowering days than every-furrow irrigation.

4.4 Stand Count

Analysis of variance for the stand count showed that the parameter was significantly ($P<0.001$) affected by the main effect of DI but not significantly affected by AFI and interaction of DI and AFI (Appendix Table 9). This study showed that the number of plant plot^{-1} decreased with increasing deficit level (Table 8). Common bean which was treated under optimum irrigation (I_0) had large number of plant stand (187 plants plot^{-1}) followed by I_1 (183 plants plot^{-1}), I_2 (182 plants plot^{-1}) and common bean grown under I_3 had very small number of plant stand (157 plant plot^{-1}) as compared to the others. According to this study, the number of plants plot^{-1} that succeeded to establish under I_0, I_1, I_2 and I_3 were 93.3%, 91.7%, 90.9% and 78.2%, respectively. In the present study, similarities and differences have been recorded in the effects that DI and AFI have on common bean plant. There was numerical mean difference among I_0, I_1, and I_2, though, no significant difference was observed. Under water stress condition, plant growth and survival is adversely affected due to limited water availability (McDowell *et al.,* 2008). This study demonstrated that under treatment I_3, 21.8% of the expected plants plot^{-1} was died before flowering. This might be due to intensive water stress at early growth stage of the plant, which can cause plant desiccation and failure, or might be due to the fact that seedlings are more sensitive to intensive water stress than adult plants, due to the small volume of soil explored by the incipient root system (McDowell *et al*., 2008). Moreover, their small size limits water storage to a smaller volume with which to buffer water stress (Goldstein *et al*., 1998). This experiment is in line with Karlen and Camp (1985) who stated that optimum plant population is related to soil moisture availability. Similarly, Vasei

Kashani *et al.* (2010) reported that soybean seedling grown under water stress treatment had reduced seedling number, height and vigor. In addition, Bourgault *et al*. (2010) reported that in the severe water stress treatment, the population density of green gram was below optimal, reaching only 50% ground cover.

4.5 Growth Parameters

4.5.1 Plant Height

The average measured plant height of common bean is presented in Table 9. The analysis of variance on irrigation levels showed that the main effect of DI on plant height was highly significant ($P<0.001$) but was not significantly affected by AFI and by interaction (Appendix Table 10). I_0 which received the optimal amount of irrigation water had resulted in the longest plant height (63 cm) whereas the most stressed plots that were I_3 had resulted in the shortest plant height (26 cm). Similarly, Yang, (2008) reported that water stress usually decreases plant height and leaf numbers per plant to reduce transportation distance and transpiration loss. However although there was mean difference, there was no significant difference observed between I_0 and I_1, as well as I_1 and I_2. Generally, plants under water stress are commonly shorter than those supplied with optimal amount of irrigation water (Al Suhaibani, 2009). Similarly, Simsek *et al*. (2011) also reported that on common bean water stress resulted in stunted plant growth form. The total resistance in the soil-plant system increases with decreasing soil water potential, which leads to reduced photosynthesis and growth (Leach, 1980). It is well known that leaf growth and shoot elongation are inhibited when shoot water deficit develops and turgor is reduced as a result (Hsiao and Bradford, 1983).

4.5.2 Number of Branch

The analysis of variance for branch number (Table 9) revealed that the DI significantly ($P<0.05$) influenced the parameter but it was not significantly affected by AFI and by the interaction of DI and AFI (Appendix Table 10). However, there was no statistical difference on number of branch Plant^{-1} among I_0, I_1 and I_2. The highest number of primary branch was recorded at I_0 (3) whereas the minimum number of branch plant^{-1} (2) under I_3. This might be the reason that, plants respond to water deficit by decreasing stem number/branches (Hall *et al.*, 1988). An experiment conducted by Uddin *et al.* (2013) on mung bean showed that plant branching decreased when the water stress increased. Gallegos and Adams (1991) and Ramirez Vallejo and Kelly (1998), as cited by Habibi (2011), stated that drought stress can reduce biomass in bean. Furthermore, this study is in agreement with Liu *et al.* (2004) who reported that water stress reduces the number of branch of soybean because of reduced photosynthetic activity. The current experiment is in disagreement with Frederick *et al.* (2001) who reported that drought stress treatment had no effect on number of branch. There was no significant difference among AFI treatments, though there was mean variation among them.

4.5.3 Shoot dry Weight

The analysis of variance for shoot dry weight revealed that the DI significantly ($P<0.001$) influenced the parameter but it was not significantly affected by AFI and interaction (Appendix Table 10). The maximum result was recorded at I_0, which produced 28 g plant^{-1} dry biomass, followed by 26 g plant^{-1}, 22 g plant^{-1} and 9 g plant^{-1} at I_1, I_2, and I_3, respectively (Table 9). Plants at high water deficit showed a weak growth, leading to a lower accumulation of dry matter. According to Korir *et al.* (2006), biomass production plant^{-1} of common bean is significantly reduced due to soil moisture stress. Similarly, Timsina *et al.* (1993) indicated that total dry matter accumulation of cowpea significantly decreased due to moisture stress. Wakrim *et al.* (2005) also studied the effects of AFI, DI and conventional (full) irrigation on growth and water relation of pot-grown beans. Accordingly, the leaf water potential for DI decreased significantly compared with full irrigation. Furthermore, shoot and pod biomass was significantly decreased in DI, confirming the results of the present study. Rahman *et al*. (2000) had earlier observed decreases in dry weight of common bean under water stress conditions, which is similar to the results of this study. In addition, De Costa and Shanmugathasan (2002) reported that maximum dry matter increased significantly with the number of stages irrigated, with irrigation during the vegetative stages having the highest positive effect and found that water stress significantly decreased the shoot dry matter production.

Table 9: Growth parameters of common bean as influenced by DI and AFI

Irrigation Level	Plant height (cm)	Number of branch Plant^{-1}	Shoot fresh weight (g Plant^{-1})	Shoot dry weight (g Plant^{-1})
I_0	62.82^{a}	2.922^{a}	102.31^{a}	27.55^{a}
I_1	57.64^{ab}	2.711^{a}	95.82^{ab}	25.58^{a}
I_2	50.82^{b}	2.633^{a}	91.29^{b}	21.55^{b}
I_3	25.78^{c}	2.156^{b}	45.33^{c}	8.66^{c}
LSD $_{0.05}$	9.65	0.4588	8.127	2.239
CV%	**9.8**	**8.8**	**4.9**	**5.4**
Alternate Irrigation				
FAFI	52.18^{a}	2.658^{a}	83.31^{a}	21.61^{a}
VAFI	48.48^{a}	2.500^{a}	84.46^{a}	21.09^{a}
CFI	47.13^{a}	2.658^{a}	83.30^{a}	19.81^{a}
LSD $_{0.05}$	4.18	0.31	5.105	1.946
CV%	**9.8**	**13.7**	**7**	**10.8**

4.6 Nodulation

4.6.1 Number of Nodule

Analysis of variance for the number of nodule showed that common bean was significantly ($P<0.001$) affected by the main effect levels of irrigation water application and also alternate furrow irrigation had a significant ($P<0.05$) effect, but there was no significant effect of interaction (Appendix Table 11). The irrigation regime I_0 and I_1 were non significantly varied but I_1 and I_2 and I_3 had significant difference among each other (Table 10). The maximum number of nodule plant^{-1} was recorded at I_0 (42) and the minimum was at I_3 (12). This is because that an adequate plant water status is the most limiting factor to nodule function in legumes (Ramos *et al.*, 1999). The current study is in agreement with Serraj *et al.* (1998) who reported that soybean grown under water stress condition had reduced number of root nodules. This study is also in line with Rupela and Kumar Rao (1987) who found a substantial increase in chickpea nodulation and acetylene reduction activity due to irrigation. According to Pareek and Chandra (1995), low soil moisture results in maximum cell death of Rhizobium in chickpea, which significantly decrease the number of nodule plant^{-1}. Similarly, Kirda *et al.* (1989) indicated that nodulation and N_2 fixation drastically decreased on plants that were exposed to intensive water stress.

The analysis of variance for the number of nodule showed that common bean was also significantly ($P<0.05$) affected by alternate furrow irrigation. The number of nodule under FAFI was the maximum (36) and the lowest was recorded at VAFI (26). This might be due to that the privileged fixed furrows had received total water of the plot, which enabled them to produce more number of nodules. The importance of adequate soil moisture for efficient interaction of *Rhizobium* and host was also pointed out by Gallacher and Sprent (1995). This study is in agreement with previous work by komes *et al.* (1992), who indicated that AFI has a significant effect on the growth and biological nitrogen fixation of crops. According to komes *et al.* (1992), plants grown under FAFI can markedly enhance root hair and promote nodule growth and nitrogen fixation.

4.6.2 Nodule Dry Weight

The analysis of variance for nodule dry weight revealed that the DI significantly ($P<0.001$) influenced the parameter but it was not significantly affected by AFI and by the interaction of DI and AFI (Appendix Table 11). There was no significant difference between I_0 and I_1 whereas there was a significant difference among I_1 and I_2, and I_2 and I_3 (Table 10). The maximum nodule dry weight was recorded at the irrigation level of I_0 (0.28 g Plant^{-1}) and the lowermost was at I_3 (0.08 g Plant^{-1}). This variation seem to result from the difference on number of nodules per plant at different irrigation level. This might be due to the fact that adequate amount of water enhance phosphorus uptake and photosynthesis, which leads to more dry matter accumulations of nodule and result in more dry weight of nodule. The study is in agreement with Jardin (1984) who reported that soil moisture stress adversely affect nodule formation and dry matter accumulation. This study is also in line with Kumar and Pareek (1984) who reported that chickpea nodule dry weight significantly decreased when it is exposed to high water stress. According to this study, low soil moisture status considerably affects the number and dry weight of nodules, and this agrees with Bihari *et al*. (1992) who indicated that nodule dry weight decreased under low soil water potential condition. The increasing in root nodules dry weight at optimum irrigation may be due to enhanced physiological functions and production of adequate photosynthates for use by rhizobia in the process of root nodule formation (Zablotowicz *et al.*, 1981).

Table 10: Nodulation of common bean as influenced by DI and AFI

Irrigation Level	Number of nodule plant^{-1}	Nodule dry weight (g Plant^{-1})
I_0	42^{a}	0.284a
I_1	38.8^{a}	0.2583^{a}
I_2	27.8^{b}	0.1698^{b}
I_3	11.5^{c}	0.0780^{c}
LSD $_{0.05}$	5.98	0.0364
CV%	**10.0**	**9.2**
Alternate irrigation		
FAFI	35.8 ^{a}	0.2106 ^{a}
VAFI	26.4 ^{b}	0.1952 ^{a}
CFI	27.9 ^{b}	0.1868 ^{a}
LSD $_{0.05}$	7.23	0.03966
CV%	**27.8**	**23.2**

4.7 Yield and Yield Component Parameters

4.7.1 Number of Pod plant^{-1}

The analysis of variance for number of pods plant^{-1} showed significant ($P<0.001$) response to irrigation level whereas the AFI and the interaction were non significant (Appendix Table 12). However, the water regimes I_1 and I_2 did not vary significantly (Table 11). The highest number of pods plant^{-1} (15) was obtained at optimal irrigation application level I_0, whereas the lowest number of pods plant^{-1} (6) was recorded at I_3. The decrease in number of pods plant^{-1}

might be due to the limitation of moisture in the soil. An experiment conducted by Simsek *et al*. (2011) reported that water stress during reproductive stage in common bean increased the number of aborted flowers and reduced the number of pods plant^{-1}. Similarly Naresh *et al.* (2013) stated that reduction in number of pods plant^{-1} in mung bean is due to a shortage of water. Furthermore, Oliaca *et al.* (2000) reported that the number of pod plant^{-1} increases with increasing irrigation level. This is in line with other findings which reported that moisture stress at flowering and pod formation stage resulted in a reduction in the number of pods plant^{-1}, number of seeds pod^{-1} and 1000 seed weight in mung bean (Sadeghipour, 2008).

4.7.2 Pod Length

The analysis of variance for pod length showed significant ($P<0.05$) response to irrigation level whereas the AFI and the interaction were not significant (Appendix Table 12). The maximum pod length was recorded at the optimum irrigation level I_0 (7 cm) even though there was no significant difference among irrigation levels I_0, I_1 and I_2 on the parameter (Table 11). The current experiment demonstrated that the final length of pods was reduced mainly as a function of total amount of water applied. The longest (7.4 cm) pods were observed in plants receiving full irrigation, intermediate sizes (7.0 cm) and (7.1 cm) were observed in plants of both treatments receiving irrigation level of I_1 and I_2, in that order. The smallest pods (4.7 cm) were produced by plants of the most water deficit treatments (I_3). The reduction in pod length under intensive water stress may associate with the role of water on photosynthesis and translocation of carbohydrate. This study is in line with Chaves *et al. (*2002) who stated that the reduced soil water results in decline of photosynthesis and translocation of carbohydrate to the pod which causes in shortening of pod length or poding. Similar result with the current experiment is obtained by Onder *et al.* (2006) who reported that pod length increased when optimum irrigation imposed. The work of Boutraa and Sanders (2001) also showed that the bean pod length under optimum irrigation was higher than the water stressed treatments.

Number of Seed Pod^{-1}

Highly significant ($P<0.001$) variations were observed on number of seed pod^{-1} of common bean under irrigation level but was not significant due to alternate furrow irrigation and interaction of DI x AFI (Appendix Table 12). There was no significant difference among irrigation levels of I_0, I_1 and I_2 on the parameter though they had statistically mean difference among them (Table 11). This study showed that seed pod^{-1} of common bean was not significantly decreased until a certain threshold irrigation level is reached, which is I_2 in the current experiment. The maximum seed pod^{-1} was recorded at the optimum irrigation level I_0 (5) and the lowermost (3) was at I_3. The seed pod^{-1} of common bean at I_3 was significantly ($P<0.001$) varied from all the remaining levels. This finding agrees with results obtained by Markabu (2014), who reported that an adverse relationship was found between the amount of applied irrigation water and seed pod^{-1} on soybean. Similarly Sepaskhah and Ahmadi (2010) mentioned that seed pod^{-1} was significantly decreased when water stress increase.

Table 11: Yield component parameters of common bean as influenced by DI and AFI

Irrigation Level	Number of pod plant^{-1}	Pod length (cm)	Number of Seed pod^{-1}	100-Seed weight (g)
I_0	14.46^a	7.39^a	5.2^a	20.48^a
I_1	11.26^b	7.0^a	5.11^a	20.29^a
I_2	9.79^b	7.06^a	4.87^a	20.07^a
I_3	5.89^c	4.73^b	2.93^b	17.59^b
LSD $_{0.05}$	1.752	1.387	0.765	0.821
CV%	**8.5**	**10.6**	**8.5**	**2.1**
Alternate irrigation				
FAFI	10.71^a	6.79^a	4.79^a	20.26^a
VAFI	10.14^a	6.21^a	4.32^a	19.13^a
CFI	10.19^a	6.63^a	4.47^a	19.42^a
LSD $_{0.05}$	0.969	0.585	0.648	1.265
CV%	**10.8**	**10.3**	**16.5**	**7.5**

4.7.3 Seed Weigh

The 100-seed weigh was significantly ($P<0.01$) influenced by DI but AFI and interaction of DI x AFI did not significantly influence the parameter (Appendix Table 12). The maximum 100-seed weigh was recorded at irrigation level of I_0 (21 g) though statistically at par with those of I_1 (20 g) and I_2 (20 g) (Table 11). The smallest seed weight was obtained at I_3 (18 g). This study showed that 100-seed weigh of common bean was not significantly decreased until a certain threshold irrigation level of I_2. Shortening of grain–filling period due to water stress and decrease of transferring assimilates into grains due to water stress could be the two major reasons for reduction of common bean grain weight under water stress (Afsana *et al.*, 2016). Similar result was obtained by Habibi (2011) who reported that an increase in 100-seed weight is due to the increase in moisture level. Moreover, this study is in line with Meckel *et al.* (1984) who stated that water deficit stress decreases the seed size in soybean due to a shortening in the length of the seed filling period, rather than reduced seed growth rate. This study result is dissimilar to that of Heidari Zolleh *et al.* (2009) who reported that seed weight is more dependent on genetic factor than environmental factors, so water stress cannot reduce seed weight a lot because the plant provides the required nutrients for each seed by reducing the number of seed.

4.7.4 Biological Yield

The biological yield of common bean with different levels of irrigation water is presented in Table 12. The analysis of variance revealed that biological yield production was significantly ($p<0.001$) influenced by DI and AFI (Appendix Table 12). And also the interaction of DI and AFI significantly ($P<0.05$) affected the parameter. The maximum biological yield (5.16 t ha^{-1}) was obtained at optimum irrigation level I_0 with the combination of FAFI and the lowermost was at I_3 (3.38 t ha^{-1}) with combination of CFI (Table 12). The result also showed that while FAFI is superior under any DI regime, the difference VAFI and CFI levels of as the deficit level increased. This finding is in line with Shaozhong *et al.* (1991) who reported that low irrigation levels significantly reduced the total dry matter accumulation in the shoots of CFI treatments, but not so with AFI and FFI treatments. Moreover, the current result is related to Timsina *et al.* (1993) who indicated that total dry matter accumulation of cowpea significantly decreased due to moisture stress. Similarly, Sadeghipour (2008) showed that total biomass of mung bean is responsive to the amount of irrigation water applied. Additionally, Robel and Zelalem (2019) reported that plant biological yield was decreased significantly by increasing water stress. The decline of biological yield of common bean might be related with the decline with growth parameters.

Abo El-khier *et al.* (1994) found that water stress decreased significantly plant height, number of leaves and branches, total leaf area and dry weight of shoots per plant of soybean. According to Dong *et al.* (2011), there is a high correlation between the above ground biomass and the irrigation water. This experiment also showed that there is a linear correlation between irrigation and biological yield (Figure 4 (B)).

Table 12**:** Biological yield (t ha^{-1}) parameter of common bean as influenced by interaction of DI and AFI

Treatment	FAFI	VAFI	CFI
I_0	5.164^a	4.739^d	4.365^d
I_1	4.458^b	3.994^e	4.137^e
I_2	4.456^b	4.053^e	3.822^e
I_3	3.681^c	3.415^f	3.377^f
LSD $_{0.05}$	0.4082		
CV% of irrigation level	**3.5**		
CV% of AFI	**5.7**		

4.7.5 Grain Yield

The grain yield of common bean with different levels of irrigation water is presented in Table 13. The analysis of variance revealed that grain yield production was significantly ($p<0.001$) influenced by DI and AFI, but not significantly affected by interaction of DI x AFI (Appendix Table 13). The highest grain yield (2.45 t ha^{-1}) was recorded at optimum irrigation level I_0 and the lowermost was at I_3 (1.34 t ha^{-1}). This study showed that grain yield of common bean had no significant difference between irrigation levels of I_1 (2.12 t ha^{-1}) and I_2 (1.83 t ha^{-1}). Water stress causes a series of physiological, biochemical and morphological responses of crops, which finally results in low yield of green gram (Malik *et al.*, 2006). Reduction in yield by water deficits is caused by a decrease in biomass production and/or by a decrease in the number of pods per plant, the number of seeds per pod and the fraction of biomass that is harvested, termed the harvest index (HI). Harvestable yield of annual crops is normally a fraction of the biomass produced (Evans, 1993). Water deficits, by affecting growth, development, and carbon assimilation, reduce the yield of most annual crops (Hsiao and Bradford, 1983). The current study is in agreement with Bourgault *et al.* (2010) who reported that common bean yields were reduced by water stress. Similarly, Rosales-Serna *et al.* (2004) mentioned that grain yield of common bean was significantly decreased when water stress increase. Moreover, Habibi (2011) in his findings indicated that water stress significantly affect grain yield of white common bean. In the previous study, it was also reported that deficit irrigation reduced soybean yield as compared with full irrigation (Karam *et al.*, 2005). Similarly, Afsana *et al.* (2016) also reported that water deficit significantly reduced grain yield of soybean. Additionally, Robel and Zelalem (2019) studied the effects of deficit irrigation on common bean and stated that water deficit significantly affect grain yield. A similar result on maize was mentioned by Mansouri-Far *et al.* (2010) who reported that deficit irrigation of maize during the vegetative and reproductive stage has resulted in high yield reduction.

The analysis of variance revealed that grain yield production was significantly ($p<0.01$) influenced by AFI. The maximum grain yield (2.11 t ha^{-1}) was recorded under FAFI and the lowest was under CFI (1.78 t ha^{-1}). However there was no significant difference between VAFI and CFI, though they had mean difference. The reason for the superiority of FAFI over CFI might be due to the fact that water deficit at the seedling stage stimulates root development, so that the plants are better equipped for soil water deficit at the later stages (Xue *et al.*, 2006). This study is in line with Genocoglan *et al.* (2006) who reported that common bean grown under FAFI had higher yield than that of CFI. Similar result has been stated by Kang *et al.* (1999) who reported that AFI had the smallest grain yield reduction than CFI. Under FAFI, common bean root development is high (Liang *et al.*, 1996), this may promote a greater nutrient uptake and caused a higher photosynthesis rate and yield than CFI (Shahnazari *et al*., 2007). Moreover, AFI reduces the growth redundancy of stem and leaves and promotes the translocation of photosynthetic assimilates to the final products (Du *et al.*, 2008). This finding is also in agreement with Liu *et al.*, (2003) who concluded that soybean yielded better under FAFI than CFI. Furthermore, this experiment is in line with previous studies (Mintesinot, 2002) and conversely with an experiment conducted by Cabangon *et al.* (2011) who reported that an alternate wetting and severe soil drying may lead to a heavy yield loss.

4.7.6 Harvest Index

The mean harvest index of common bean is presented in Table 13. The analysis of variance revealed that harvest index was significantly ($p<0.05$) influenced by DI but AFI and interaction of DI x AFI did not significantly influence the parameter (Appendix Table 13). The all-out harvest index (0. 52) was obtained from the treatment that received optimal irrigation water application (I_0) and the lowest was obtained from I_3 (0.39). However, there was no significant difference among the three irrigation levels (I_0, I_1 and I_2) though there were mean difference. This study also showed that HI of common bean hadn't significantly decreased until a certain threshold irrigation level of I_2. In general, decreasing HI values were observed in this study with increasing water-deficit levels. Xue *et al.* (2006) earlier reported similar results on wheat. Similarly, Hossain *et al.* (2010) reported that soil moisture stress on mung bean had resulted in reduced grain yield, yield components and then ultimately reduced harvest index. The current study also agreed with earlier experiment conducted by Fischer (1979) who stated that as the water stress increases in severity, there would be direct effects on the HI in many determinate crops, particularly when the post-anthesis fraction of total transpiration is too low. According to Kobraei *et al.* (2011), the relationship between grain yield and components of yield (number of pod, number of grain pod^{-1} and plant^{-1}) is positive and significant, therefore, decreasing these components may be reason for reducing grain yield and biological yield.

The analysis of variance revealed that harvest index was not significantly ($p<0.05$) influenced by AFI. The result of this study agree with findings of Mulugeta Mohammed and Kannan Narayanan (2015) who reported that harvest index was not significantly affected by AFI. Moreover, Redwanur Rahman and Sheikh Helena (2014) found that non significant effect of alternate irrigation on harvest index. Similarly, Yushi *et al.* (2013) studied the effects of alternate irrigation and reported that AFI did not significantly affect harvest index. This study is also in agreement with Bourgault *et al.* (2013) who reported that AFI had no significant effect on harvest index of common bean.

Table 13: Grain yield, CWUE and IWUE of common bean as influenced by DI and AFI

Irrigation Level	Grain yield (t ha$^{-1)}$	Harvest index	CWUE (kg m^{-3})	IWUE (kg m^{-3})
I_0	2.452^{a}	0.519^{a}	0.702^{b}	0.4911^{b}
I_1	2.123^{b}	0.506^{a}	0.774^{b}	0.5306^{b}
I_2	1.833^{b}	0.447^{ab}	0.923^{a}	0.6102^{a}
I_3	1.343^{c}	0.385^{b}	1.027^{a}	0.6347^{a}
LSD $_{0.05}$	0.3068	0.0905	0.1146	0.07896
CV%	**7.9**	**9.3**	**6.2**	**6.4**
Alternate irrigation				
FAFI	2.113^{a}	0.479^{a}	0.919^{a}	0.6093^{a}
VAFI	1.924^{b}	0.465^{a}	0.860^{a}	0.5681^{a}
CFI	1.777^{b}	0.449^{a}	0.790^{b}	0.5226^{b}
LSD $_{0.05}$	0.1677	0.0526	0.0663	0.04482
CV%	**10.0**	**13.1**	**8.9**	**8.6**

4.8 Crop Water Use Efficiency

The analysis of variance among irrigation water levels showed that the variability among irrigation level (DI) treatments were statistically significant (P<0.001) on the mean CWUE values (Appendix Table 13). The crop water use efficiency of common bean varied from 1.03 kg m^{-3} to 0.70 kg m^{-3} (Table 13). The minimum and the maximum mean CWUE was obtained when the highest and the lowest amount of crop water requirement was applied, in that order. Findings show that the more plants are water stressed the more plant have used water efficiency (Onder *et al.*, 2009). The current study also confirmed that the highest irrigation level (I_0) had the lowest CWUE (0.70 kg m^{-3}) followed by I_1 and I_2 with 0.77 kg m^{-3} and 0.92 kg m^{-3}, respectively. Similarly, Howell (2003) stated that IWUE and CWUE can be increased by practicing deficit irrigation, improving irrigation technology, and irrigation scheduling and improving agronomic practices that lead to yield increase. According to Fereres and Soriano (2007) deficit irrigation almost always increases water-use efficiency as the applied water is less than the depletion by ET, and most or all of the applied water remains in the root zone.

The analysis of variance revealed that CWUE was significantly ($P<0.01$) influenced by AFI. Maximum mean CWUE was obtained under FAFI (0.92 kg m^{-3}) followed by VAFI (0.86 kg m^{-3}) and CFI (0.79 kg m^{-3}). The current study showed that FAFI and VAFI significantly saved water than that of the conventional method of irrigation (CFI). This might be due to the great reduction of wetted surface in AFI; almost half of the soil surface is wetted in AFI as compared with CFI. This result supports the result obtained by Graterol *et al.* (1993), who found that AFI methods can supply water in a way that greatly reduces the amount of wetted surface, which leads to less evapotranspiration and less deep percolation. This is in conformity with the previous study where AFI has proved to be an effective water-saving irrigation model (Kang and Zhang, 2004), which increases the WUE of soybean without much reduction in yield (Liang *et al*., 2013). Another reason for FAFI's high WUE is the partial stomatal closure and reduced leaf area occurred due to increased ABA. These are the main physiological responses to decrease transpiration in plants under FAFI and enhance WUE (Davies *et al.*, 2002). Lateral movement of water is higher than that of the conventional one due to skipping of every other furrow by which water loss by evaporation could be minimized (Kifle *et al.*, 2008).

4.9 Irrigation Water Use Efficiency

The analysis of variance on irrigation water levels showed that the variability among irrigation level (DI) treatments were statistically significant ($P<0.01$) on the mean IWUE values (Appendix Table 13). The irrigation water use efficiency of common bean varied from 0.64 kg m^{-3} to 0.49 kg m^{-3} (Table 13). Maximum mean IWUE was obtained when 40% of the crop water requirement was applied. According to the current study irrigation water of optimum level (I_0) has low IWUE. An experiment conducted by Geerts and Raes (2009) confirm that deficit irrigation increase water productivity for various crops. As shown in Table11, the present study has demonstrated that there was mean variation between treatment I_0 (0.49 kg m^{-3}) and I_1 (0.53 kg m^{-3}), and also I_2 (0.61 kg m^{-3}) and I_3 (0.64 kg m^{-3}), however there was no significant difference between them. This study showed that the irrigation water use efficiency of common bean increase when the amount of irrigation water decreased. Similarly, Zwart and Bastiaanssen (2004) showed that measured IWUE for several crops around the world, including corn, and concluded that the IWUE could be significantly increased if irrigation was reduced and crop water deficit was intentionally induced.

The analysis of variance revealed that IWUE was significantly ($P<0.01$) influenced by AFI. Maximum mean IWUE was obtained at FAFI (0.61 kg m^{-3}) followed by VAFI (0.57 kg m^{-3}) and CFI (0.52 kg m^{-3}) without significant difference between them. The current study showed that both FAFI and VAFI saved water significantly than that of the conventional method of irrigation (CFI). This result confirmed that the result found by Abdel-Maksoud *et al*. (2002) who reported that wheat which was treated under alternate irrigation showed high IWUE than CFI. Similarly Webber *et al*. (2006) reported on green gram production. This might be due to the fact that when roots are in drying soil, even in a situation where only part of the root system is dried, substantial amounts of ABA can be produced in the roots and transported through the xylem to the shoots where stomatal opening can be regulated by which unwanted water loss is eliminated (Zhang *et al*., 1987; Davies and Zhang, 1987). Many researches showed that the foremost benefit of using AFI is to reduce the amount of irrigation and increase IWUE. Likewise, Fereres and Rabanales (2007) indicated that IWUE increased when the irrigation water decreased. Furthermore, Li *et al*. (2013) found that a decreased IWUE under optimum irrigation on maize. This study result also ratified by Hu *et al*. (2009) who stated that the FAFI and VAFI methods led to save 33% and 29.5% of irrigation water use efficiency, respectively, compared to the CFI method. The increase in water use efficiency might be due to the root absorbed water only from some parts of the soil.

4.10 Yield and Water Relationship

The relationship between applied water and yield is presented in Figure 3 (B). It was observed that increase in irrigation water application resulted in increase in the grain yield. The relationship can be expressed by linear equation as:

Grain yield (kg ha^{-1}) = 0.0003(applied water (m^{-3})) + 0.9255, $R^2 = 0.9989$

The coefficient of determination (R^2) indicates that more than 99.9% of the yield variation is coming from the variability in applied irrigation water. Similar result was reported by Yeo *et* *al.* (1996) who observed that water deficit reduced yield. In the same way Sadeghipour (2008) reported that water stress reduced mung bean yield when the water stress had imposed.

4.11 Correlation Analysis

An appendix Table 14 presents results of simple linear correlation (r) analysis carried out to study the nature and degree of relationship between various growth and yield components. The findings showed that the grain yield was significant and positively correlated with plant height (r = 0.7652***), number of branches per plant (r = 0.8110**), shoot fresh weight per plant (r = 0.7537***), shoot dry weight per plant (r = 0.8207***), number of pods per plant (r = 0.8083***) and number of seeds per pod (r = 0.7509***), 100-seed weight (r = 0.6601**), number of nodule per plant (r = 0.7967***), Nodule dry weight per plant (r = 0.7693***), biological yield (r = 0.7633***) and HI (r = 0.8741***).

CWUE showed significant and negatively correlated with days to flowering (r = -0.6055***), days to physiological maturity (r = -0.6676***), plant height (r = -0.6663***), number of branches per plant (r = -0.5682***), biological yield (r = -0.5160**), shoot fresh weight (r= -0.6691***), number of pod per plant (r = -0.7182***), number of nodule per plant (r = -0.5270***), number of seed per pod (r = -0.5557***), and grain yield (r = -0.4625**). CWUI also had a positive and significant correlation with IWUE (r = 0.9754***). Results showed that yield and yield components of common bean are highly associated with the performance of other growth parameters.

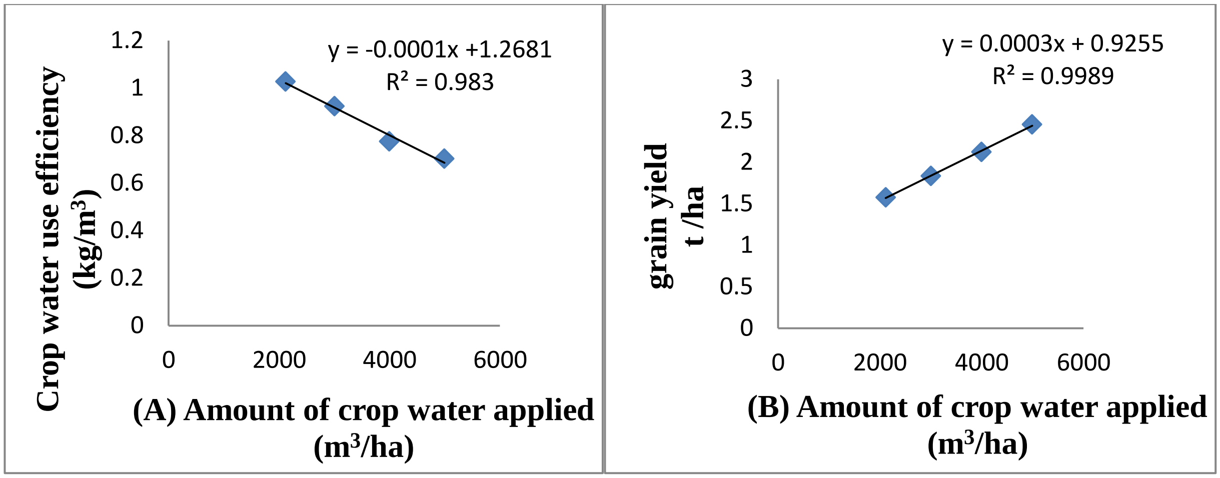

Figure 3: Correlation between (A) amount of crop water applied and crop water use efficiency, and (B) amount of crop water applied and grain yield

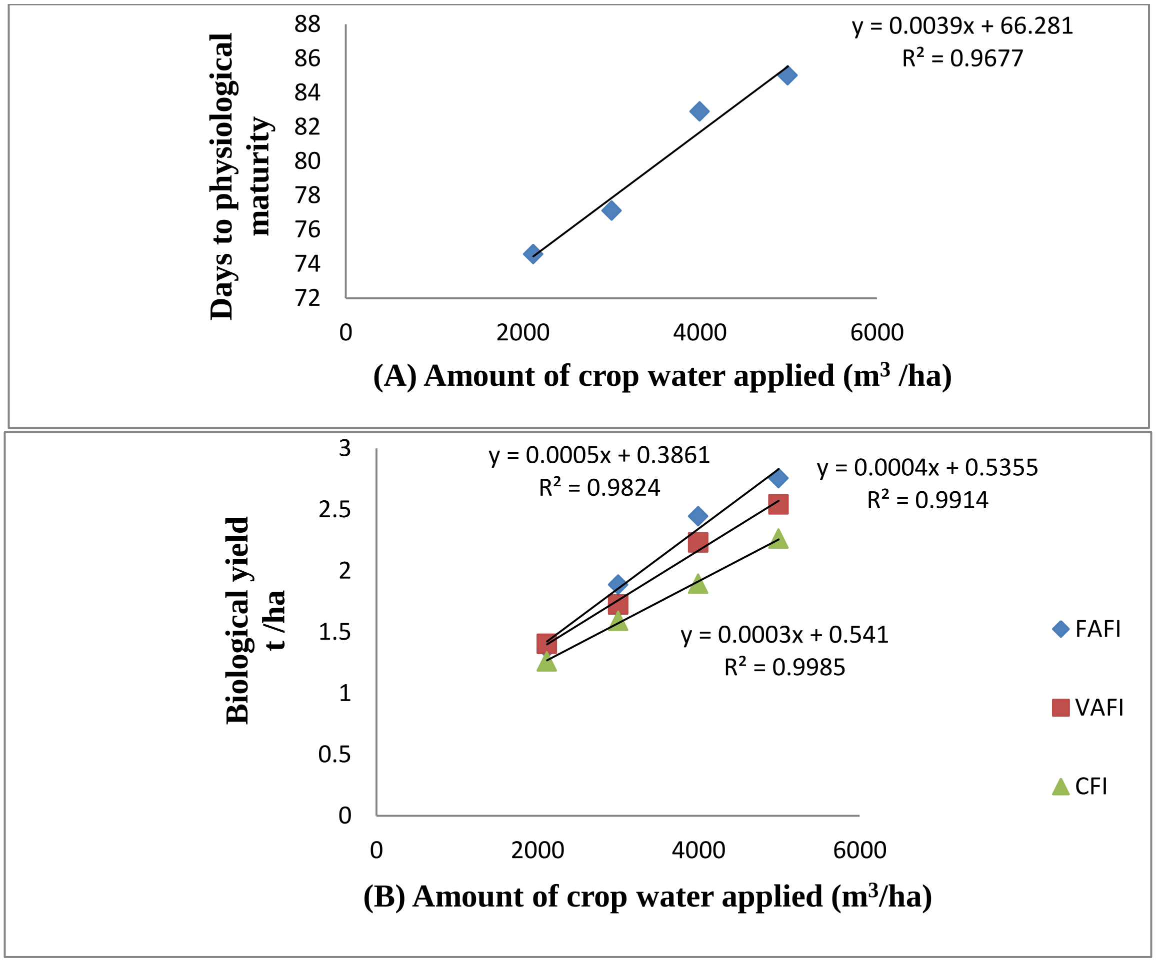

Figure 4: Correlation between (A) amount of crop water applied and days to physiological maturity, and (B) amount of crop water applied and biological yield

4.12 Partial Budget Analysis

The average yield was adjusted down ward by 10%. This is for the reasons that, researchers have assumed that using the same treatments they yields from experimental plots and farmers field vary, thus average yield should be adjusted down ward. The second factor (AFI) had no cost difference among them. The highest gross field benefit (55170 ETB/ha) and net benefit (52920 ETB/ha) at study area was obtained from I_0 irrigation level while the lowest gross field benefit (30217 ETB/ha) and net benefit (29567 ETB/ha) was obtained from I_3. The dominance analysis (Table 14) at study area indicated that the irrigation levels I_0, I_1 and I_2 were undominated treatments. The analysis of marginal rate of return (MRR) revealed that I_0, I_1 and I_2 had given marginal rate of return above the minimum acceptable rate (100%). Partial budget analysis revealed that the highest net benefit of birr of 52920 was recorded from I_0 with marginal rate of 1874%. This was followed by net benefit of birr 45892 and 40017 from I_1 and I_2 with marginal rate of 903.9% and 1817.4%, respectively. This means that for every 1.00 Birr invested in I_0, I_1 and I_2 and Awash-2 producers can expect recovery of the birr and additional benefit of 18, 9 and 18 birr in that order. This analysis indicates that farmers at study area need to use 100% ETc in order to maximize their profitability. If there is lack of adequate irrigation water they can use I_1 (80% ETc) in order to save and use irrigation water more economically. In case of alternate irrigation, the partial budget analysis revealed that the highest net benefit of birr of 46192.5 was recorded from FAFI with marginal rate of 1790%. This was followed by net benefit of birr 42165 with marginal rate of 1295%. This means that for every 1.00 Birr invested in FAFI and VAFI, and Awash-2 producers can expect recovery of the birr and additional benefit of 17.9, and 12.9 birr in that order.

Table 14: Partial budget and marginal rate of return analysis of different irrigation level

Irri. Level	Average yield t ha^{-1}	Adjusted yield t ha^{-1}	GFB ETB ha^{-1}	TVC ETB ha^{-1}	NB ETB ha^{-1}	MNB ETB ha^{-1}	MC ETB ha^{-1}	MRR %
I_3	1.343	1.2087	30217.5	650	29567.5			
I_2	1.833	1.6497	41242.5	1225	40017.5	10450	575	1817.4
I_1	2.123	1.9107	47767.5	1875	45892.5	5875	650	903.85
I_0	2.452	2.2068	55170	2250	52920	7027.5	375	1874

Table 15: Partial budget and marginal rate of return analysis of alternate irrigation

	Average yield t ha^{-1}	Adjusted yield t ha^{-1}	GFB ETB ha^{-1}	TVC ETB ha^{-1}	NB ETB ha^{-1}	MNB ETB ha^{-1}	MC ETB ha^{-1}	MRR %
CFI	1.777	1.5223	38057.5	750	37307.5			
VAFI	1.924	1.7316	43290	1125	42165	4857.5	375	1295
FAFI	2.113	1.9017	47542.5	1350	46192.5	4027.5	225	1790

GFB= gross field benefit, TVC= total variable cost, NB= net benefit, MNB= marginal net benefit, MC= marginal cost, MRR= marginal rate of return, and price of common bean 25 ETB. 1 *ETB = 0.0347 USD (May 1, 2019).*

5. SUMMARY AND CONCLUSION

Common bean is a major grain legume grown and produced in sub Saharan Africa, including Ethiopia. Currently, it forms the greatest part of the Ethiopia's pulses export; the world demand for common bean is ever increasing. To meet this demand using improved agricultural practice and inputs by which increase productivity is important. Among many limiting factors of common been production water is the most prominent. Therefore, improving the efficiency of the irrigation water is a key strategy for water savings in agriculture. Currently, many techniques are implemented to enhance water productivity; research effort has focused on developing new techniques to receive high returns from restricted supply of water. Among these technologies deficit irrigation and alternate furrow irrigation are relatively the most prominent, inexpensive and easy to implement. The study was proposed to determine the water use efficiency of common bean under deficit and alternate irrigation practices**.** The experiment was laid out in factorial randomized complete block design in split plot arrangement using irrigation level as a main plot and alternate furrow irrigation as a sub-plot with three replications. The Irrigation treatments **(**I_0, I_1, I_2, I_3; 100%, 80%, 60%, and 40%, of crop water requirement, respectively) were applied throughout the growing season except flowering stage. The alternate furrow irrigation treatments were Fixed Alternate Furrow Irrigation (FAFI), Variable Alternate Furrow Irrigation (VAFI) and Conventional Furrow Irrigation (CFI).

The result of this study showed that the minimum (3.25 mm/day) and maximum (4.41 mm/day) ETo value was in the months of July and March respectively. The accumulated crop water applied and gross irrigation water requirement in the control was 341.9 mm and 450.5

mm, in that order. The phenological parameters (days to 50% flowering and maturity), stand count, growth parameters (plant height, shoot dry weight and number of branch), nodulation (number of nodule and nodule dry weight), yield component (number of pod, pod length, seed pod^{-1}, 100-seed weight, biological yield and HI), grain yield, CWUE and IWUE were significantly influenced by DI. Days to 50% physiological maturity, number of nodules, grain yield, CWUE and IWUE were significantly affect by DI and AFI. The biological yield of the common bean was influenced by the interaction of DI and AFI**.** The higher biological yield (5.16 t ha^{-1}) was obtained at optimum irrigation level I_0 with the combination of FAFI and the lowermost was at I_3 (3.38 t ha^{-1}) with combination of CFI. The maximum grain yield (2.45 t ha^{-1}) was recorded at optimum irrigation level (I_0) and the lowest yield was at the lowest irrigation level I_3 (1.34 t ha^{-1}). There was no significant difference between irrigation levels of I_1 (2.12 t ha^{-1}) and I_2 (1.83 t ha^{-1}). This study also showed that grain yield of common bean at FAFI was higher than VAFI and CFI. The maximum grain yield (2.11 t ha^{-1}) was recorded at FAFI and the lowest was at CFI (1.78 t ha^{-1}). There was no significant difference between VAFI and CFI rather they had mean difference between them. The interaction effect of DI and AFI was not Significant on grain yield. The crop water use efficiency of common bean varied from 1.0 kg m^{-3} to 0.70 kg m^{-3}. Maximum mean CWUE was obtained when 40% of the crop water requirement was applied. The current study also confirm that the highest irrigation level (I_0) had the lowest CWUE (0.70 kg m^{-3}) followed by I_1 (0.77 kg m^{-3}), I_2 (0.92 kg m^{-3}) and I_3 (1.03 kg m^{-3}). Under AFI maximum mean CWUE was obtained at FAFI (0.92 kg m^{-3}) followed by VAFI (0.86 kg m^{-3}) and CFI (0.79 kg m^{-3}).

Generally, DI and AFI on common bean could have considerable positive effects on the water use efficiency by reducing irrigation water requirements. The results indicated that CWUE and

IWUE values decreased with increasing irrigation level. However although common bean had better water use efficiency at I_2 than I_0 and I_1, its yield was lowered by 0.62 t ha^{-1} and 0.33 t ha^{-1}, in that order. FAFI was better water saving method of irrigation followed by VAFI than conventional method. The marginal rate of return analysis showed that the irrigation level I_0 (100% ETc) and FAFI has the highest net benefit with MRR greater than the threshold needed for acceptance (100%) and, thus, can be used by farmers in the study area to maximize their income from increased investment. If there is lack of adequate irrigation water they can use I_1 (80% ETc) in order to save and use irrigation water more economically.

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7. APPENDICES

7.1 Appendix Table

Appendix Table 1: Eleven year (2007-2017) mean monthly meteorological data of the study area

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours
January	9.4	27.8	57	78	8.1
February	11.1	29.1	55	78	8.2
March	12.7	28	59	78	8.5
April	13.3	27.7	63	78	8.1
May	12.4	27.7	74	78	7.6
June	12.9	25.7	75	95	6.5
July	12.2	25.6	78	52	5.3
August	12.4	24.6	77	37	5.4
September	12	25.9	77	69	5.2
October	10.6	27.9	71	69	8.2
November	9.2	27.1	58	86	8.8
December	7.9	27.8	53	86	8.3
Average	**11.3**	**27.1**	**66**	**74**	**7.3**

Source: National Meteorology Agency, Alage Branch

Appendix Table 2: Average monthly reference evapotranspiration (ETo) of the study area

Month	Min Temp (°C)	Max Temp (°C)	Relative Humidity (%)	Wind speed (km/day)	Sun hour (Hrs)	Radiation MJ/m²/day	ETo mm/day
January	9.4	27.8	57	78	8.1	19.8	3.76
February	11.1	29.1	55	78	8.2	21.1	4.17
March	12.7	28	59	78	8.5	22.5	4.41
April	13.3	27.7	63	78	8.1	22	4.34
May	12.4	27.7	74	78	7.6	20.6	4.04
June	12.9	25.7	75	95	6.5	18.5	3.64
July	12.2	25.6	78	52	5.3	16.9	3.25
August	12.4	24.6	77	37	5.4	17.5	3.26
September	12	25.9	77	69	5.2	17.3	3.37
October	10.6	27.9	71	69	8.2	21.2	4.02
November	9.2	27.1	58	86	8.8	21	3.98
Average	**11.3**	**27.1**	**66**	**74**	**7.3**	**19.8**	**3.84**

Appendix Table 3: Irrigation water requirement of common bean in decade in mm

Month	Decade	Stage	Kc coefficient	ETc mm/day	ETc mm/decade	Eff rain mm	Irr. Req. mm/decade
Jan	1	Init	0.4	1.51	1.5	0	1.5
Jan	2	Init	0.4	1.5	15	0	15
Jan	3	Deve	0.48	1.86	20.4	0	20.4
Feb	1	Deve	0.78	3.13	31.3	0	31.3
Feb	2	Mid	1.07	4.45	44.5	0	44.5
Feb	3	Mid	1.15	4.89	39.3	0	39.3
Mar	1	Mid	1.15	4.98	49.8	0	49.8
Mar	2	Mid	1.15	5.07	50.7	0	50.7
Mar	3	Late	1.07	4.71	51.8	0	51.8
Apr	1	Late	0.69	3.01	30.5	0	30.5
Apr	2	Late	0.41	1.78	7.1	0	7.1
					341.9	0	**341.9**

Appendix Table 4: Irrigation scheduling of common bean at study area

Date	Day	Stage	Rain mm	Ks frac.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/S/ha
26-Jan	1	Init	0	0.91	91	52	34.5	0	0	49.3	5.71
28-Jan	3	Init	0	1	100	8	5.9	0	0	8.4	0.49
31-Jan	6	Init	0	1	100	11	8.9	0	0	12.7	0.49
3-Feb	9	Init	12.7	1	100	3	2.8	0	0	4	0.15
6-Feb	12	Init	0	1	100	8	8.4	0	0	12	0.46
9-Feb	15	Init	0	1	100	6	7	0	0	10	0.39
12-Feb	18	Dev	0	1	100	7	8.7	0	0	12.4	0.48
15-Feb	21	Dev	0	1	100	6	7.4	0	0	10.6	0.41
18-Feb	24	Dev	0	1	100	4	4.9	0	0	7.1	0.27
21-Feb	27	Dev	0	1	100	6	8.6	0	0	12.3	0.47
24-Feb	30	Dev	0	1	100	5	7.3	0	0	10.4	0.4
27-Feb	33	Dev	16.2	1	100	2	3.6	0	0	5.2	0.2
2-Mar	36	Dev	0	1	100	7	13.1	0	0	18.7	0.72
4-Mar	38	Dev	0	1	100	5	9.5	0	0	13.5	0.78
6-Mar	40	Dev	0	1	100	5	9.5	0	0	13.5	0.78
8-Mar	42	Mid	0	1	100	5	9.5	0	0	13.5	0.78
10-Mar	44	Mid	0	1	100	5	9.5	0	0	13.5	0.78
12-Mar	46	Mid	0	1	100	5	10	0	0	14.3	0.83
14-Mar	48	Mid	0	1	100	5	10	0	0	14.3	0.83
17-Mar	51	Mid	15.9	1	100	3	5	0	0	7.2	0.28
20-Mar	54	Mid	0	1	100	8	15.1	0	0	21.5	0.83
23-Mar	57	Mid	17.6	1	100	3	5	0	0	7.1	0.28
26-Mar	60	Mid	0	1	100	8	15	0	0	21.4	0.83
29-Mar	63	Mid	0	1	100	8	15	0	0	21.4	0.83
1-Apr	66	Mid	0	1	100	8	15	0	0	21.4	0.82
4-Apr	69	Mid	0	1	100	5	9.9	0	0	14.2	0.55
7-Apr	72	Mid	20.2	1	100	3	5	0	0	7.1	0.27
10-Apr	75	Mid	0	1	100	8	14.9	0	0	21.3	0.82
13-Apr	78	End	22.1	1	100	2	4	0	0	5.7	0.22
16-Apr	81	End	0	1	100	6	12	0	0	17.2	0.66
19-Apr	84	End	0	1	100	6	12	0	0	17.2	0.66
22-Apr	87	End	0	1	100	4	8.5	0	0	12.1	0.47
30-Apr	--	End	0	1	0	4					
										450.5	

Ks frac. = water stress coefficient, Eta = actual evapotranspiration, Depl = water depletion, Net Irr = net irrigation, Gr. Irr = gross irrigation.

Appendix Table 5: Irrigation scheduling of common bean for I_0 (100% ETc)

Date	Day	Stage	Net Irr	Gr. Irr
26-Jan	1	BP	34.5[BP]	49.3[BP]
28-Jan	3	Init	5.9	8.4
31-Jan	6	Init	8.9	12.7
3-Feb	9	Init	2.8	4
6-Feb	12	Init	8.4	12
9-Feb	15	Init	7	10
12-Feb	18	Dev	8.7	12.4
15-Feb	21	Dev	7.4	10.6
18-Feb	24	Dev	4.9	7.1
21-Feb	27	Dev	8.6	12.3
24-Feb	30	Dev	7.3	10.4
27-Feb	33	Dev	3.6	5.2
2-Mar	36	Dev	13.1	18.7
4-Mar	38	Dev	9.5	13.5
6-Mar	40	Dev	9.5	13.5
8-Mar	42	Mid	9.5	13.5
10-Mar	44	Mid	9.5	13.5
12-Mar	46	Mid	10	14.3
14-Mar	48	Mid	10	14.3
17-Mar	51	Mid	5	7.2
20-Mar	54	Mid	15.1	21.5
23-Mar	57	Mid	5	7.1
26-Mar	60	Mid	15	21.4
29-Mar	63	Mid	15	21.4
1-Apr	66	Mid	15	21.4
4-Apr	69	Mid	9.9	14.2
7-Apr	72	Mid	5	7.1
10-Apr	75	Mid	14.9	21.3
13-Apr	78	End	4	5.7
16-Apr	81	End	12	17.2
19-Apr	84	End	12	17.2
22-Apr	87	End	8.5	12.1
30-Apr	End	End		
				450.5

BP = before planting

Appendix Table 6: Irrigation scheduling of common bean for I_1 (80% ETc)

Date	Day	Stage	Net Irr	Gr. Irr
26-Jan	1	BP	34.5^{BP}	49.3^{BP}
28-Jan	3	Init	5.9^{FI}	8.4^{FI}
31-Jan	6	Init	8.9^{FI}	12.7^{FI}
3-Feb	9	Init	2.24	3.2
6-Feb	12	Init	6.72	9.6
9-Feb	15	Init	5.6	8
12-Feb	18	Dev	6.96	9.92
15-Feb	21	Dev	5.92	8.48
18-Feb	24	Dev	3.92	5.68
21-Feb	27	Dev	6.88	9.84
24-Feb	30	Dev	5.84	8.32
27-Feb	33	Dev	2.88	4.16
2-Mar	36	Dev	10.48	14.96
4-Mar	38	Dev	7.6	10.8
6-Mar	40	Dev	7.6	10.8
8-Mar	42	Mid	7.6	10.8
10-Mar	44	Mid	7.6	10.8
12-Mar	46	Mid	8	11.44
14-Mar	48	Mid	8	11.44
17-Mar	51	Mid	4	5.76
20-Mar	54	Mid	12.08	17.2
23-Mar	57	Mid	4	5.68
26-Mar	60	Mid	12	17.12
29-Mar	63	Mid	12	17.12
1-Apr	66	Mid	12	17.12
4-Apr	69	Mid	7.92	11.36
7-Apr	72	Mid	4	5.68
10-Apr	75	Mid	11.92	17.04
13-Apr	78	End	3.2	4.56
16-Apr	81	End	9.6	13.76
19-Apr	84	End	9.6	13.76
22-Apr	87	End	6.8	9.68
30-Apr	End	End	0	0
				374. 48

BP = before planting, FI = full irrigation (100% Etc)

Appendix Table 7: Irrigation scheduling of common bean for I_2 (60% ETc)

Date	Day	Stage	Net Irr	Gr. Irr
26-Jan	1	BP	34.5^{BP}	49.3^{BP}
28-Jan	3	Init	5.9^{FI}	8.4^{FI}
31-Jan	6	Init	8.9^{FI}	12.7^{FI}
3-Feb	9	Init	1.68	2.4
6-Feb	12	Init	5.04	7.2
9-Feb	15	Init	4.2	6
12-Feb	18	Dev	5.22	7.44
15-Feb	21	Dev	4.44	6.36
18-Feb	24	Dev	2.94	4.26
21-Feb	27	Dev	5.16	7.38
24-Feb	30	Dev	4.38	6.24
27-Feb	33	Dev	2.16	3.12
2-Mar	36	Dev	7.86	11.22
4-Mar	38	Dev	5.7	8.1
6-Mar	40	Dev	5.7	8.1
8-Mar	42	Mid	5.7	8.1
10-Mar	44	Mid	5.7	8.1
12-Mar	46	Mid	6	8.58
14-Mar	48	Mid	6	8.58
17-Mar	51	Mid	3	4.32
20-Mar	54	Mid	9.06	12.9
23-Mar	57	Mid	3	4.26
26-Mar	60	Mid	9	12.84
29-Mar	63	Mid	9	12.84
1-Apr	66	Mid	9	12.84
4-Apr	69	Mid	5.94	8.52
7-Apr	72	Mid	3	4.26
10-Apr	75	Mid	8.94	12.78
13-Apr	78	End	2.4	3.42
16-Apr	81	End	7.2	10.32
19-Apr	84	End	7.2	10.32
22-Apr	87	End	5.1	7.26
30-Apr	End	End	0	0
				298.46

BP = before planting, FI = full irrigation (100% Etc)

Appendix Table 8: Irrigation scheduling of common bean for I_3 (40%ETc)

Date	Day	Stage	Net Irr	Gr. Irr
26-Jan	1	BP	34.5^{BP}	49.3^{BP}
28-Jan	3	Init	5.9^{FI}	8.4^{FI}
31-Jan	6	Init	8.9^{FI}	12.7^{FI}
3-Feb	9	Init	1.12	1.6
6-Feb	12	Init	3.36	4.8
9-Feb	15	Init	2.8	4
12-Feb	18	Dev	3.48	4.96
15-Feb	21	Dev	2.96	4.24
18-Feb	24	Dev	1.96	2.84
21-Feb	27	Dev	3.44	4.92
24-Feb	30	Dev	2.92	4.16
27-Feb	33	Dev	1.44	2.08
2-Mar	36	Dev	5.24	7.48
4-Mar	38	Dev	3.8	5.4
6-Mar	40	Dev	3.8	5.4
8-Mar	42	Mid	3.8	5.4
10-Mar	44	Mid	3.8	5.4
12-Mar	46	Mid	4	5.72
14-Mar	48	Mid	4	5.72
17-Mar	51	Mid	2	2.88
20-Mar	54	Mid	6.04	8.6
23-Mar	57	Mid	2	2.84
26-Mar	60	Mid	6	8.56
29-Mar	63	Mid	6	8.56
1-Apr	66	Mid	6	8.56
4-Apr	69	Mid	3.96	5.68
7-Apr	72	Mid	2	2.84
10-Apr	75	Mid	5.96	8.52
13-Apr	78	End	1.6	2.28
16-Apr	81	End	4.8	6.88
19-Apr	84	End	4.8	6.88
22-Apr	87	End	3.4	4.84
30-Apr	End	End	0	0
				222.44

BP = before planting, FI = full irrigation (100% Etc)

Appendix Table 9: Mean squares of days to flowering, maturity, and stand count at Alage

Source of Variation	DF	DTF	DPM	SC
Replication	2	0.36	7.53	334.24
Irrigation level (A)	3	36.96***	213.85***	1743.37***
Error	6	0.99	2.38	23.30
Alternate irrigation (B)	2	2.53 ^{ns}	10.53*	1.24 ^{ns}
Interaction (AxB)	6	0.82 ^{ns}	2.60 ^{ns}	46.41 ^{ns}
Error	16	1.17	2.75	21.90

*DF= degree of freedom, DTF= days to flowering, DPM= days to physiological maturity, SC= stand count, * =significant at 0.05, *** = significant at 0.001 and ns= non-significant.*

Appendix Table 10: Mean squares of plant height, number of branch, shoot fresh and dry weight plant^{-1} at Alage

Source of Variation	DF	PH	NB	SFW	SDW
Replication	2	103.63	0.042	265.72	13.15
Irrigation level (A)	3	2424.26***	0.944*	6068.74***	649.21***
Error	6	70.00	0.158	49.64	3.767
Alternate irrigation (B)	2	82.03 ^{ns}	0.1003 ^{ns}	5.33 ^{ns}	10.26 ^{ns}
Interaction (AxB)	6	9.97 ^{ns}	0.077 ^{ns}	27.73 ^{ns}	10.93 ^{ns}
Error	16	23.33	0.128	34.80	5.058

*DF= degree of freedom, PH= plant height, NB= number of branch, SFW= shoot fresh weight, SDW= shoot dry weight, *= significant at 0.05, ***= significant at 0.001 and ns= non-significant.*

Appendix Table 11: Mean squares of stem diameter, number of nodule, nodule dry weight, number of pod plant^{-1} at Alage

Source of Variation	DF	SD	NN	NDW	NPPP
Replication	2	0.00214	28.24	0.0010	1.10
Irrigation level (A)	3	0.00123 ^{ns}	1706.75***	0.0706***	113.68***
Error	6	0.00065	26.89	0.0013	2.31
Alternate irrigation (B)	2	0.00034 ^{ns}	304.17*	0.0027 ^{ns}	1.18 ^{ns}
Interaction (AxB)	6	0.00020 ^{ns}	41.04 ^{ns}	0.0011 ^{ns}	0.45 ^{ns}
Error	16	0.00022	69.82	0.0525	1.25

*DF= degree freedom, SD= stem diameter, NN= number of nodule, NDW= nodule dry weight, NPPP= number of pod plant^{-1}, *= significant at 0.05, ***= significant at 0.001and ns= non-significant*

Appendix Table 12: Mean squares of pod length, number of seed per pod, 100-seed weight, biological yield at Alage

Source of Variation	DF	PL	NSP	100-SW	BY
Replication	2	1.01	0.33	2.68	0.12685
Irrigation level (A)	3	13.41*	10.35***	16.46**	2.41354***
Error	6	1.45	0.44	0.51	0.06331
Alternate irrigation (B)	2	1.07 ^{ns}	0.69 ^{ns}	4.17 ^{ns}	0.55762***
Interaction (AxB)	6	0.20 ^{ns}	0.027 ^{ns}	1.96 ^{ns}	0.16132*
Error	16	0.46	0.56	2.14	0.05508

*DF= degree freedom, PL= pod length, NSP= number of seed per pod, 100-SW= 100-seed weight, BY= biological yield, *= significant at 0.05, **= significant at 0.01, ***= significant at 0.001 and ns= non-significant.*

Appendix Table 13: Mean squares of grain yield, harvesting index, crop and irrigation water use efficiency at Alage

Source of Variation	DF	GY	HI	CWUE	IWUE
Replication	2	0.07315	0.000909	0.014175	0.07315
Irrigation level (A)	3	1.99027***	0.033982*	0.192561***	1.99027**
Error	6	0.07074	0.006156	0.008443	0.07074
Alternate irrigation (B)	2	0.34067**	0.002649 **ns**	0.050485**	0.34067**
Interaction (AxB)	6	0.05960 **ns**	0.002887 **ns**	0.006555 **ns**	0.05960 **ns**
Error	16	0.03753	0.003697	0.005186	0.03753

*DF= degree freedom, GY= grain yield, HI= harvesting index, CWUE= crop water use efficiency, IWUE= irrigation water use efficiency, *= significant at 0.05, **= significant at 0.01, ***= significant at 0.001 and ns= non-significant.*

Appendix Table 14: Linear correlation among phenological, growth, yield and yield components

	DF	DPM	NNPP	NDW	PH	NBPP	SD	SC	SDW
DF	-								
DPM	0.8570	-							
NN	0.7517	0.8060	-						
NDW	0.8345	0.8387	0.8678	-					
PH	0.7880	0.7778	0.7896	0.8213	-				
NB	0.5528	0.6189	0.6064	0.5677	0.6079	-			
SD	0.3310	0.3319	0.4543	0.3994	0.4797	0.3374	-		
SC	0.7090	0.6600	0.7830	0.7371	0.8200	0.5853	0.5345	-	
SDW	0.8183	0.7885	0.8106	0.7947	0.8983	0.6458	0.4047	0.8227	-
SFW	0.8215	0.7209	0.7381	0.8084	0.8621	0.6055	0.3130	0.7884	0.9341
BY	0.7290	0.7825	0.7780	0.7661	0.7876	0.6367	0.5659	0.7429	0.7193
SW	0.4494	0.4787	0.5637	0.5246	0.7013	0.5879	0.4299	0.6955	0.6325
NP	0.7610	0.8339	0.8036	0.8465	0.9126	0.7038	0.4357	0.7325	0.8753
PL	0.6448	0.6015	0.6344	0.6221	0.7910	0.6874	0.4072	0.7486	0.7891
NSPP	0.6683	0.6384	0.7335	0.6887	0.8615	0.5783	0.3988	0.7671	0.8380
CWUI	-0.6055	-0.6676	-0.5270	-0.6865	-0.6663	-0.5682	-0.1131	-0.5747	-0.6577
HI	0.6131	0.6156	0.5775	0.5652	0.5492	0.2763	0.2870	0.4864	0.6714
IWUI	-0.4504	-0.5305	-0.3680	-0.5490	-0.5127	-0.4745	-0.0083	-0.4199	-0.4887
GY	0.7869	0.8266	0.7967	0.7693	0.7652	0.8110	0.4866	0.7032	0.8207

Correlation Table continued

	SFW	BY	SW	NPPP	PL	NSPP	CWUI	HI	IWUI
	-								
BY	0.6640	-							
BW	0.5559	0.5867	-						
NP	0.8516	0.8137	0.5964	-					
PL	0.7636	0.6200	0.7727	0.7802	-				
NSPP	0.8173	0.6321	0.6865	0.7943	0.8538	-			
CWUI	0.6691	-0.5160	-0.5114	-0.7182	-0.5745	-0.5557	-		
HI	0.6333	0.3594	0.2428	0.5823	0.4204	0.4947	-0.1643	-	
IWUI	-0.5076	-0.3767	-0.4129	-0.5785	-0.4445	-0.4114	0.9754	0.0227	-
GY	0.7537	0.7633	0.6601	0.8083	0.5936	0.7509	-0.3625	0.8741	-0.1629

DF= days to flowering, DPM= days to physiological maturity, NNPP= number of nodule per plant, NDW= nodule dry weight, PH= plant height, NBPP= number of branch per plant, SD= stem diameter, SC= stand count, SDW= shoot dry weight, BY= biological yield, SW= 100-seed weight, NPPP= number of pod per plant, PL= pod length, NSPP= number of seed per pod, CWUI= crop water use efficiency, HI= harvesting index, IWUI= irrigation water use efficiency, GY= grain yield and

7.2 Appendix Figure

Appendix Figure 1: Furrow preparation and watering method of the experiment

Appendix Figure 2: Covered plots at a time sudden drizzle

Appendix Figure 3: Immediate removing of the shed after the drizzle had stop

Appendix Figure 4: Data collections in the experimental fields

8. BIOGRAPHICAL SKETCH

The author, Hunde Hayile Tolosa was born in 1991, in Merti Metehara, East Shewa Zone of Oromia, Ethiopia. He attended his elementary at Merti and Awash melkasa Elementary School then his secondary school and preparatory education at Adama secondary school and Hawas preparatory school respectively. He then, joined the then Mizan-Tepi University, College of Agriculture, in 2009 and graduated in June 2012 with B.Sc. Degree in plant science. Then in 2014, he was employed in private farm, where he served as Crop Production Expert. Until he joined the School of Graduate Studies, Hawasa University, in 2017 in pursuit of Master of Science in Agronomy, he has been working in Alage ATVET College as Instructor, since 2015.