COMPARISON OF FURROW AND DRIP IRRIGATION SYSTEMS UNDER DEFICIT IRRIGATION LEVELS ON GROWTH, YIELD AND WATER USE EFFICIENCY OF GREEN BEANS (PHASEOLUS VULGARIS L.)

Mihiret Hailu

A Thesis Submitted To the Department Of Water Resources Engineering,

School Of Civil Engineering and Architecture

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resource Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

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Comparison of Furrow and Drip Irrigation Systems under Deficit Irrigation Levels on Growth, Yield and Water Use Efficiency of Green Beans (Phaseolus vulgaris L.)

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Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Mihiret Hailu have read and evaluated her thesis entitled "Comparison Of Furrow And Drip Irrigation Systems Under Deficit Irrigation Levels On Growth, Yield And Water Use Efficiency Of Green Bean(Phaseolus Vulgaris L.)" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master science in Water Resource Engineering (Specialization in irrigation Engineering).

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Declaration

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

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Supervisor's/Advisor's approval sheet

To: Water Resources Engineering Department

Subject: Thesis Submission

This is to certify that the thesis/dissertation entitled "Comparison Of Furrow And Drip Irrigation Systems Under Deficit Irrigation Levels On Growth, Yield And Water Use Efficiency Of Green Bean (Phaseolus vulgaris L.)" submitted in partial fulfillment of the requirements for the degree of Master science in Water Resource Engineering (Specialization in irrigation Engineering), the Graduate program of the department of Water Resources Engineering, and has been carried out by Mihiret Hailu Id. No GSR/0013/09, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby she can submit the thesis/dissertation to the department.

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ACRONYMS AND ABBREVIATION

AFI	Alternate Furrow Irrigation
CFI	Conventional Furrow Irrigation
CV	Coefficient of Variation
DI	Deficit irrigation
Dp	Drip irrigation
ECe	Electrical Conductivity
ETa	Actual Evapotranspiration
ETc	Crop Evapotranspiration
ETm	Maximum Evapotranspiration
FC	Field Capacity
IWMI	International Water Management Institute
Ky	Yield Response Factor
LSD	Least Significance Difference
MARC	Melkassa Agricultural Research Center
MoA	Ministry of Agriculture
masl	Meter above sea level
PWP	Permanent Wilting Point
RAW	Readily Available Water
RCBD	Randomized Complete Block Design
UN	United Nations
SAS	Statistical Analysis System
WP	Water Productivity
Ya	Actual Yield
Ym	Maximum Yield

Comparison of Furrow and Drip Irrigation Systems under Deficit Irrigation Levels on Growth, Yield and Water Use Efficiency of Green Beans (Phaseolus vulgaris L.)

ABSTRACT

Efficient use of water for irrigated agriculture is fundamental for agricultural production. In arid and semi-arid areas of Ethiopia, water is the most limiting factor for crop production. A field experiment was conducted at Melkassa Agricultural Research Center to compare furrow and drip irrigation systems under deficit irrigation to evaluate the growth, yield and water use efficiency of green bean. The experiment was carried out in split plot design with three replications. The treatments were set as three systems of irrigation, viz., conventional furrow irrigation, alternate furrow irrigation and drip irrigation as main plot and three deficit irrigation levels, viz., 80%ETc, 60%ETc and 40%ETc and a control irrigation level of 100%ETc as sub plot. Daily crop water requirement was estimated using CROPWAT 8.0 model. The deficit irrigation levels applied in this study affected green bean yield and yield parameters. The treatment under Drip irrigation gave the highest yield (16.18 ton/ha) and Alternate Furrow irrigation gave lower yield (13.75ton/ha). The quality parameters such as pod length show significant difference but pod diameter does not show any significant difference to deficit irrigation. The highest Crop Water Use Efficiency was obtained from treatment that received 40% ETc application under drip Irrigation (9.61kg/ha). With Drip irrigation 55.58% of water saved and 37.08 of water saved by alternate furrow irrigation compare to conventional furrow irrigation. Drip irrigation increases green bean yield and save water, so it is recommended to use drip irrigation under deficit for sustainable production of green bean.

Key words: Deficit Irrigation; Green Beans; WUE, Alternate Furrow Irrigation; Drip irrigation

1. INTRODUCTION

1.1 Background

Water is a limiting factor for crop production. The distribution of water on the Earth's surface is extremely uneven. Only three percent of water on the earth surface is fresh and irrigated agriculture uses more than 70 percent of the fresh water; in developing countries the proportion exceeds 80 percent (FAO, 2002).

Efficient use of water for irrigated agriculture is fundamental for agricultural production, particularly in arid and semi-arid areas. In Ethiopia greater than 50% of the area is categorized under semi-arid climatic zone and less than 10% as arid (NRMRD, 1998). In the semi-arid areas of Ethiopia, water is the most limiting factor for crop production.

Irrigation is widely carried out through surface and pressurized irrigation systems. Surface irrigation methods having relatively lower water use efficiency compared to the pressurized systems. From surface irrigation methods, furrow irrigation system is the most widely practice to irrigate many row crops including horticultural crops. Furrow irrigation, a method of applying irrigation water by small, parallel channels to irrigate entire crop field.

Furrow irrigation is widely used irrigation system in Ethiopia and practiced via many farmers and state farms. According to FAO (2001), 97.8% of the irrigated farm in Ethiopia practice surface methods of irrigation, especially small holder and commercial farmers using furrow system which is characterized as less efficient and high water loss during application. Water use efficiency can be improved in furrow irrigation using deficit irrigation and watering alternate furrows (Jemal and Mukerem, 2017 and Yemane et al, 2018).

Drip irrigation is the most advanced irrigation method with the highest application efficiency. The drip irrigation method is rapidly gaining importance in areas where water is scarce or expensive and whenever high valued crops are grown. Because of high initial cost drip irrigation is not well adapted in developing countries like Ethiopia and hence the idea of low cost drip irrigation is introduced. Low cost drip irrigation system which operates under gravity is suitable and economical also give high yield for vegetable crops.

Deficit irrigation is water management strategy that improves water and crop productivity. Deficit irrigation (DI) can be applied by different types of irrigation application methods. By applying deficit irrigation water productivity is improved in arid and semi-arid areas.

Green beans are a legume that has been used as food for centuries. In Ethiopia, green bean is economically one of the most important vegetable crops grown for both export and local markets. It is mostly grown in Rift Valley region, especially for export.

1.2 Statement of the Problem

Applying full requirement of crop water requirement in arid and semi-arid areas limits the crop production. By reducing irrigation depth water can be saved with minimum yield reduction. Applying full irrigation in arid and semi-arid areas do not reduce crop evapotranspiration but applying deficit irrigation reduce crop evapotranspiration to increase water use efficiency and maintain yield comparable to that of a fully irrigated crop.

Water management for green bean production is extremely important at all stages of plant development due to its influence on stand establishment, pod set and quality. In the study area, green beans are mostly produced under irrigation rather than rain fed because of unpredictability and low amount of rain fall. The source of water for irrigation is from Awash River which has high computation from up to downstream side of irrigated farm.

Sustainable production of green beans in a water limiting areas requires an approach that uses water very efficiently and saves certain amount of water or the shortage in irrigation water compensated through water deficit application during irrigation. Alternate furrow irrigation offers opportunities for reducing size of irrigation and permits irrigating a field in shorter time period with a given water application. The reduced size of irrigation may not reduce yield appreciably and thus increase irrigation water use efficiency. Application of deficit irrigation and the use of efficient irrigation system such as drip also permit the reduction of applied irrigation water. To identify deficit irrigation level that maximizes water use efficiency without significant yield penalties requires a study for particular crop. The response of green beans to deficit irrigation under different irrigation systems was not studied in the study area. Considering green bean as an important cash crop and adaptability of the crop in the area, there is an urgent need to study irrigation water management practices for increased production and productivity under present and future water limitation conditions.

1.3 Objective of the Study

The general objective of this study was to enhance green beans production and productivity using furrow and drip irrigation system under limited water source condition.

The specific objectives were:

- To determine the effects of deficit irrigation on growth, yield and yield components of green beans under furrow irrigation.
- To determine the effects of deficit irrigation on growth, yield and yield components of green beans under drip irrigation.
- To compare furrow and drip irrigation methods on crop water use efficiency of green beans under deficit irrigation.

1.4 Significance of the Study

Considering the importance of green beans for the study area, the productivity and production should be increased without limitation of water availability. This study is important by showing the way to produce green beans in water limiting condition of the area. The study is also beneficial for a better understanding of how to increase the yield of green beans under different irrigation methods in case of water stress, increase water productivity and help to identify the deficit irrigation level where water stress does not significantly reduce yield. On the other hand, it is not only helpful for the study area but also helpful to other places with similar agro-climatic and soil condition.

This study can be considered as a model to farmers who afraid and not sure about changing backward irrigation systems (conventional furrow irrigation) to drip irrigation system because of not having information about drip and the benefit for production of green beans.

2 LITERATURE REVIEW

2.1 Water Resource Potential

Water is an increasingly scarce resource with many competing uses. As FAO (2016) estimated two-thirds of the global population over four billion people live with severe water shortages for at least one month each year. Also UN (2006) report, by 2025, 1800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions.

Water shortages are shaping the future of irrigated agriculture over the entire world (English et al., 2014). Agricultural production is the major user of the Earth's water resources and the water demand for this sector is increasing steadily with its root on population growth. These days about 70% of the available water we have on Earth is used for agriculture and by 2020 additional 17% more water is needed than is available now if we are to feed the world (Sleper et al., 2007).

Changing climate patterns will have important implications for water availability in Africa. According to the IPCC (2014), by 2030 an additional of 75 to 250 million people in Africa are projected to be exposed to an increased water stress due to climate change. The most important pressure on renewable water resources is linked to the agricultural sector in which irrigation represents the maximum demands (Valipour, 2014). Ethiopia, one of Africans country and has plenty physical available water resource but economic water scare and repeatedly drought affected country. Ethiopia has 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6 - 6.5 billion m^3 of ground water potential, which makes an average of 1575 m3 of physically available water per person per year, a relatively large volume. In Ethiopia, water scarcity is majorly associates with economic considerations. Hence, despite abundance in some parts the country is highly water-scarce due to lack of water control infrastructure (Seleshi et. al., 2007).

Rainfall in Ethiopia is highly erratic, resulting in a very high risk of intra-seasonal dry spells and annual droughts, of which the 1973-74, 1983-84, 1987-88, 1990-91, 1993-94 and 2015-16 are the major ones in the last decades. The drought in 2015-16 is even considered to be the worst drought for over 30 years. Frequent dry spells and droughts exacerbate the incidence of crop failure and hence food insecurity and poverty (FAO, 2017).A rapid increasing population (based on United Nations estimation in September 23, 2018 the number of population in Ethiopia is 108,089,847) plus climate change which cause drought and erratic rainfall affects water availability.

2.2 Irrigated Agriculture

Available water resources for agriculture have been decreasing in recent years with the increased demands for irrigation and other non-agricultural water uses (de Fraiture and Wichelns, 2009). Irrigated agriculture uses more than 70 percent of the water withdrawn from the earth's rivers; in developing countries the proportion exceeds 80 percent (FAO, 2002).The increase in water demand from other users coupled with water scarcity is leading to the reduction in the amount of water diverted for agriculture.

Irrigation has an important role to play in contributing to food security and poverty alleviation. Of the 1,500 million hectares of global cropland, only about 250 million hectares (17 percent) are irrigated, despite this 17 percent irrigated agriculture provides about 40% of world food production (FAO, 2002). The food production principally depends on availability of water and an increase in production necessarily requires more water to be set aside for the agriculture sector. As the global population heads for more than 9 billion people by 2050, demand for food is expected to surge by more than 50 percent. Agriculture must adapt to the impacts of climate change and improve the resilience of food production systems in order to feed a growing population with less water (FAO, 2016).

Although irrigation has an important role to play in contributing to food security and poverty alleviation, it covers only 17% of the world cultivated area and provides 40 to45% of the world food and fiber supply (Evans and Sadler, 2008). The volume of water withdrawn for irrigation, globally, will increase from 2.6 billion km^3 in 2005 - 2007 to an estimated 2.9 billion km^3 in 2050 with most of the net increase occurring in lower income countries (Bruinsma, 2011). In Ethiopia, irrigation contributed approximately 5.7% to agricultural Gross Domestic Product (GDP) and 2.5% to the overall GDP during the 2005/2006 cropping season (Hagos et al., 2009).

The efficiency of water use in most agricultural productions is low with poor management and improper designs of water application systems. Only part of agricultural water withdrawals is effectively used in the production of food or other agricultural commodities. According to FAO (1996), the crop effectively uses only 40 to 60% of the total applied water. The remainder of the water is lost in the system, and in the field, either through evaporation, runoff to the drainage system or by percolation into the groundwater. Perhaps that part of water lost can be recovered, but additional costs are needed to be incurred. As a step towards achieving the objective of more crops per drop of water, there is a need for irrigators to begin to adopt the use of techniques and practices that save irrigation water and minimize needless waste.

The use of efficient irrigated farming practices with the most economical exploitation of the water resources is an issue as far as irrigation water saving is concerned. Based on the actual crop need, the irrigation management has to be improved so that the water supply to the crop can be reduced while still achieving a high yield (Pereira et al., 2002).

2.3 Alternative and Conventional Furrow Irrigation Systems

Furrow irrigation water application system is most popular form of surface irrigation, as it requires a smaller initial investment compared to other types of irrigation water application systems (Brouwer et al., 1985). This type of irrigation method is the most widely used in our country in almost all-large and small irrigation schemes (FAO, 2001). It has been reported by FAO (2001) that 97.8% of irrigation in Ethiopia is done by surface methods of irrigation especially by furrow system in farmers' fields and majority of the commercial farms. Apart from the conventional method the use of furrow irrigation can be modified to alternate or fixed furrows so that it can maintain relatively drier soil condition.

2.3.1 Alternate furrow irrigation (AFI) method

Alternate furrow irrigation (AFI) meant one of the two neighboring furrows alternately irrigated during consecutive watering. It offers opportunity for reducing size of irrigation and permits irrigating a field in a shorter time with a given water supply. The reduced size of irrigation may not reduce yields appreciably and thus increase irrigation- water use efficiency (Ashinie Bogale et al., 2016, Yemane et al., 2018). Besides this, AFI save quite a good amount of water and is very useful and crucial in areas of water scarcity (Jemal and Mukerem, 2017).

According to Zhang *et al*. (2000), alternate furrow irrigation method uses less irrigation water but can maintain the same grain yield production as that of conventional furrow irrigation with high irrigation amounts. This is believed to be because of continuous regulation by root drying signal on stomatal inhibition and reduced leaf transpiration. When roots are in drying soil, even in a situation where only part of the root system is dry, substantial ABA is produced in the roots and transported through the xylem to the shoots where stomatal opening is regulated. AFI takes advantage of this physiological response and exposes part of the root system alternatively to the drying soil. This method of watering can lead to continuous stomatal inhibition and reduced leaf transpiration. Photosynthesis and dry matter accumulation are less affected by such partial stomatal closure because photosynthesis and stomatal opening have a saturation relationship. Maximum stomatal opening does not necessarily lead to maximum photosynthesis, and transpiration and stomatal opening, however, have a linear relationship (Zhang and Davies, 1991).

Alternative drying of part of the root system is better than the drying of fixed part of the root zone. This is because alternative drying substantially stimulates more roots growth. In addition, alternate drying favors an even distribution of the root system in the soil, while drying of the fixed root zone resulted in more roots in the wet and less in the dried zone (Kang *et al*., 1998). Plant water uptake rate is enhanced after re-watering in water stress condition compared to full irrigation. This is obtained due to improvement of hydraulic conductivity of root systems that is subjected to water stress. This compensation in root hydraulic conductivity might be explained by new secondary roots and changes in the old roots when exposed to rewetting (Kang and Zhang, 2004).

AFI is beneficial in minimizing nutrient leaching from the plant root zone. This is due to, on one hand, less water application that can favor nutrient movement within the plant root zone. The significant lateral water movement, on the other hand, helps in keeping nutrient in the root zone rather than leaching it down (Skinner *et al.*, 1999).

AFI can avert severe leaf water deficit, which develops in the shoots when irrigation is drastically reduced. Evidence for this conclusion is that the AFI treatments show no significant reduction in terms of shoot height and dry matter accumulation when irrigation was reduced. 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, 2000).

2.3.2 Conventional furrow irrigation

Conventional furrow irrigation (CFI) or traditional irrigation means irrigating all furrows during consecutive watering. Frequent irrigation under CFI may result in higher evaporation from the soil surface, especially during the early growing season with incomplete ground cover (Sepaskhah and Kamgar-Haghighi, 1997). This irrigation system has speed up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, brought to soil fertility losses (Karajeh et al., 2000).

2.4 Drip Irrigation

Drip irrigation involves supplying water to the soil very close to the plants at very low flow rates (0.2 – 8 lt/hr) from a plastic pipe fitted with outlets (drip emitters). The basic concept underlying the drip irrigation method is to maintain a wet bulb of soil in which plant roots suck water. Only the part of the soil immediately surrounding the plant is wetted. The volume and shape of the wet bulb irrigated by each drip emitter are a function of the characteristics of the soil (texture and hydraulic conductivity) and the discharge rate of the drip emitter. Applications are usually frequent (every 1- 3 days) to maintain soil water content in the bulb close to field capacity (Sileshi and Taffa, 2006). Compared to the sprinkler and furrow irrigation methods (with efficiencies of 60 – 70 % in high management systems), drip irrigation can achieve 90 – 95% efficiency (Isaya, 2001). Drip irrigation increases WUE compare to furrow irrigation (Fekadu And Teshome, 1998). Drip irrigation has the potential to be the most efficient irrigation technology when evaluated in terms of either crop production per unit of water consumed by ET or per unit of water applied. This is because the water can be uniformly delivered to each plant through a closed pipe system. Thus, converting from traditional surface irrigation to drip irrigation can significantly increase the area of land that can be fully irrigated with a given volume of water (Keller, 2002).

Drip irrigation is more suitable for horticultural crops for increase crop yield and efficient water use. Study conducted in India confirm that drip irrigation give higher yield and water use efficiency in vegetable production compare to furrow irrigation(Jha et al.,2017).

The main problem of drip irrigation is the susceptibility of the small emitter orifices, typically 0.5-1.5 mm in diameter, to become clogged by contaminants in the irrigation water. Causes of clogging are sand and silt particles, organic matter, bacterial slimes, iron, algae and chemical precipitates (magnesium and calcium salts in particular). Clogging affects the uniformity of distribution of water application and if left uncontrolled crop growth will suffer. Partial clogging is particularly difficult to see in the field. Prevention by filtration and control by chemical additives are necessary.

Because of high initial cost drip irrigation is only worthwhile for high value Crops (Squire, 1981). Because of high initial cost of drip irrigation is not well adapted in developing countries like Ethiopia and hence the idea of low cost drip irrigation is introduced. Low cost drip irrigation system which operates under gravity is suitable and economical also give high yield for vegetable crops.

2.4.1 Low pressure drip irrigation

A low pressure drip irrigation system is a cheap effective way to provide water for a smaller sized crop area. It would be especially cost effective if the climate of the area can provide enough precipitation to consistently keep a reservoir filled using rain water harvesting techniques. The basic system is very simple consisting of an elevated reservoir with a pipe coming out the bottom that feeds water into a basic drip irrigation system that is all controlled either by hand or with a very efficient battery powered timer that controls the rate at which the crop is watered. Main components are water container, a structure to support the water container, piping, valve, filter and drip lines (Phocaides, 2007).

2.4.2 Distribution uniformity of drip emitters

The uniformity of water application calculated in terms of distribution uniformity (DU). Distribution uniformity is measure of the uniformity of emission from all the emission points within an entire drip irrigation system, for field test. The most common measure of DU is the Low Quarter DU, which is a measure of the average of the lowest quarter of samples, divided by the average of all samples. The higher the DU, the better the performance of the system. The lower the DU, the less efficient the distribution, and thus the more water that must be applied to meet the minimum requirement. Distribution uniformity calculated using equation (Kruse, 1978) as follows;

$$DU = (q_{1q} / qa) \times 100 \qquad 2.1$$

where: qa is average emitter flow rate (l/h); and q_{lq} is The average lowest quarter emitter flow rate (l/h)

2.4.3 Percentage wetting area

The percentage wetted area (P_w) is the average horizontal area wetted within the top 30 cm of the crop root zone depth in relation to the total cropped area. The wetted area approaches 100% for closely spaced crops with rows and drip laterals spaced less than 1.8m apart. A figure of 50- 60% for low rainfall areas and 40% for high rainfall areas is proposed for widely spaced crops (Andreas and Karen, 2002).

2.5 Deficit Irrigation

Deficit irrigation (DI) is an optimization strategy in which irrigation is applied during drought sensitive growth stages of a crop (Geerts and Raes, 2009). Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phenological stages, often the vegetative stages and the late ripening period.

One of the objectives of using DI, from a farm management perspective, is to find the level of irrigation that maximizes WUE. This takes special knowledge of individual crop cycles and irrigation needs, and thus cannot be generalized across all crop types (FAO, 2002). Many researchers have evaluated the feasibility of deficit irrigation and whether significant savings in irrigation water are possible without significant yield penalties (Geerts and Raes, 2009). Deficit irrigation management involves under-irrigating most or all of a field at some times , rather than avoiding crop water stress irrigators control stress at levels that can increase profits, and the allowable margin for error must be minimized because that reduces the returns to water (English, 1990).

The concept of deficit irrigation is based on the assumption that in field crops, imposing water stress at specific growth stages may not cause significant yield reduction and irrigation in these stages can be ignored, which will save substantial amount of irrigation water.The main advantage of DI is that it maximizes the productivity of water. In areas where water is the limiting factor for crop production, maximizing WP by DI is often economically more profitable for the farmer than maximizing yield (Fereres and Soriano, 2007). In some species, a period of drought stress can enhance allocation of resources to reproduction, leading to early flowering (Kozlowski and Pallardy, 2002) and increased fruiting (Nora et al., 2012). Moreover, irrigated yields can be stabilized at a particular level, guaranteeing a stable income for the farmer and allowing economic planning.

The economic advantage from deficit irrigation is derive from three factors: increased irrigation efficiency, reduced costs of irrigation and the opportunity cost of water (English et al., 1990; English & Rajan, 1996).

2.6 Irrigation Scheduling

Irrigation scheduling involves determining both the timing of irrigation and the quantity of water to apply. Irrigation scheduling methods are based on two approaches, soil measurements and crop monitoring (Hoffman et al., 1990). The goal of irrigation scheduling is to make the most efficient use of water and energy by applying the right amount of water to cropland at the right time and in the right place. Proper irrigation scheduling requires a lot of information about the soil and the crop. The soil properties can be very important parameter to determine the water status in the root zone, which is related to the amount of water. Also the crop information is important when we determine the water requirement (Brouwer et al., 1989)

Establishing irrigation scheduling requires knowledge about availability of water supply, crop water use or evapotranspiration (ET), irrigation and effective rainfall, soil water-holding capacity and current available soil moisture content. This information is the main factor to decide when to apply water and how much water to apply. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. The most common irrigation criteria are soil moisture content and soil moisture tension. The critical soil water content can be found at different level. For many crops irrigation should start when soil water content drops below 50 % of the total available soil moisture (Allen *et al*., 1998).

The RAW is the amount of water that crops can extract from the root zone without experiencing any water stress. For maximum crop production, the irrigation schedule should be fixed based on RAW. Since green bean is sensitive to water deficit, for high yield, soil water depletion should not exceed 45% of the TAW (ρ=45%) (Allen *et al*., 1998).Thus, RAW will be computed from the expression:

$$RAW = \rho * TAW \tag{2.2}$$

where; RAW is the readily available soil water in the root zone (mm), ρ is in fraction for allowable permissible soil moisture depletion for no stress, and TAW is total available water (mm/m).

Determine the time of irrigation means decide when we should supply the water to the field. There are many techniques and technologies that can forecast the timing and amount of irrigation water to supply such as monitoring the soil, monitoring the crop and monitoring the weather conditions (Brouwer et al., 1989).

2.7 Crop Water Requirement

The term crop water requirement is defined as the amount of water required to compensate the evapotranspiration loss from the cropped field. For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo) and the effect of crop characteristics (Kc) are important (Doorenbos and Pruitt, 1977).

The growth and yield of any crop is related to the amount of water used. The variable amount of water contained in a soil and its energy state are important factors affecting growth of plants (Hillel, 2004). The accuracy of determination of crop water requirements will be largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Allen et al., 1998).

Based on the comparative studies of the reference evapotranspiration methods and recommendations of a panel of experts and researchers organized in FAO, Rome, in 1990, the Penman Monteith equation has been adopted as the globally best performing method of estimating evapotranspiration.

The calculation can be done using CROPWAT model. Reference evapotranspiration (ET_o) is calculated based on the FAO Penman-Monteith method (Allen et al., 1998) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34U_2)} \qquad 2.3$$

where, ET_o is reference evapotranspiration (mm/day), Rn is net radiation at the crop surface (MJ/m2/day), G is soil heat flux density (MJ/m^2/day), T is mean daily air temperature at 2 m height (°C), U_2 is wind speed at 2 m height (m/s), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), e_s - e_a is saturation vapor pressure deficit (kPa), Δ is slope of vapor pressure curve (kPa/°C), γ is psychrometric constant (kPa/ °C).

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

$$ETc = ET_o x Kc \qquad 2.4$$

where, ETc is crop evapotranspiration(mm/day); Kc is crop coefficient; ET_o is reference evapotranspiration(mm/day)

Reference evapotranspiration (ET_o) can be estimated using the Penman-Monteith equation. Various crop growth stages and their respective lengths are identified for the locations of interest, and then Kc for the various stages of the crop is determined. Kc values are then adjusted for frequency of wetting condition for rain or irrigation. Then crop coefficient curves are developed to determine Kc values for periods of any length. Crop ET is then calculated for well-watered conditions for each period of interest as the product of ET_o and Kc. Having ETc and all necessary meteorological data, crop water requirement can be computed with the aid of CROPWAT program (Allen et al., 1998).

2.8 Water Productivity

In crop production system, water productivity (WP) is used to define the relationship between crops produced and the amount of water involved in crop production, expressed as crop production per unit volume of water (Molden et al., 2009).The common measure that is emerging to measure water productivity is kilograms of yield produced per meter cube of water. The yield can be quantified in terms of wet or dry yield, nutritional value or economic return. When dealing with different crops, yield may be transformed into monetary units. Crop water productivity (CWP) with dimensions of kg/m^3 is defined by Kassam and Smith (2001) as the ratio of the mass of yield (Y) in kilograms to the volume of water consumed by the crop (ET) in m^3.

In the dry areas, water, not land, is the most limiting resource for improving agricultural production. Maximization of yield per unit of water (WP), and not yield per unit of land (land productivity), is, therefore, a better strategy for dry farming systems (Fereres and Soriano, 2007). It is widely believed that an increase in agricultural water productivity is the key approach to mitigate water shortage and to reduce environmental problems in arid and semiarid regions. So, enhancement of WP in irrigated agriculture is very important (FAO, 2003).

Deficit irrigation has been widely investigated as a valuable and sustainable production strategy in dry regions. Geerts and Raes (2009) confirm that deficit irrigation is successful in increasing water productivity for various crops without causing severe yield reductions. Study conducted in different areas of Ethiopia suggested that applying deficit irrigation improves water productivity (Mekonen, 2011, Nigus, 2013, Enchalew et al, 2016 and Gobena et al, 2017). Deficit irrigation increased the water use efficiency of beans. Mehmet (2011) indicated that applications of 75%ETc and 50 %ETc at reproductive stage of Common bean found to give the highest irrigation water use efficiency (IWUE) and water use efficiency (WUE).

2.9 Crop Yield Response Factors to Water

The yield response factor (Ky) captures the essence of the complex linkages between production and water use by a crop, where many biological, physical and chemical processes are involved. The relationship has shown a remarkable validity and allowed a workable procedure to quantify the effects of water deficits on yield.

A standard formulation relates four parameters actual yield (kg/ha), maximum yield, actual evapotranspiration (mm) and maximum evapotranspiration to a fifth: Ky (the yield response factor) which relates relative yield decrease to relative evapo-transpiration deficit. When water deficit occurs during a specific crop development period, the yield response can vary depending on crop sensitivity at that growth stage. Therefore, timing the water deficit appropriately is a tool for scheduling irrigation where a limited supply of water is available (FAO, 2002).

Doorenbos and Kassam (1979) formulated the relationship between the relative yield decreases produced by relative evapotranspiration deficit in a given irrigation scheduling protocol. The formulation relates four parameters (Ya, Ym, ETa and ETm) to a fifth: Ky, the yield response factor as:

$$[1 - \frac{Y_a}{Y_m}] = K_y \left[1 - \frac{ET_a}{ET_m}\right] \qquad 2.5$$

where: Ya is actual yield (kg/ha), Ym is maximum yield (kg/ha), ETa is actual evapotranspiration (mm), ETm= maximum evapotranspiration (mm), and Ky is yield response factor.

This equation means that for each deficit irrigation strategy corresponds a relative evapotranspiration (1 – ETa/ETm) that induces a relative yield loss expressed by (1 – Ya/Ym), where Maximum evapotranspiration (ETm) refers to conditions when water is adequate for unrestricted growth and development, ETa is Actual evapotranspiration and equals maximum evapo-transpiration (ETm) when available soil water to the crop is adequate. However, ETa < ETm when available soil water is limited and Ym and Ya are the grain yields corresponding to ETm and ETa, respectively. Maximum yield o f a crop (Ym) is defined as the harvested yield of a high-producing variety , well-adapted to the given growing environment, including the time available to reach maturity, under conditions where water, nutrients and pests and diseases do not limit yield.

Yield responses of major field crops to deficit irrigation, including cotton, maize, potato, sugar cane, soybean and wheat were studied by FAO and IAEA research coordinated group. Crop yields obtained under various levels of reduced evapotranspiration were fitted to the linear crop yield response function. Results showed that cotton, maize, wheat, sunflower, sugar beet and potato are well suited to deficit irrigation practices, with reduced evapotranspiration imposed throughout the growing season. This list may also include common bean, groundnut, soybean and sugar cane where reduced evapotranspiration is limited to a certain growth stage(s) (FAO, 2002).

Crop yield response factor varies depending on species, variety, irrigation method and management, and growth stage when deficit evapotranspiration is imposed. The crop yield response factor gives an indication of whether the crop is tolerant of water stress. A response factor greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration (Kirda *et al*., 1999).

2.10 Agronomy of Green Beans

Green bean are a legume that has been used as food for centuries, and is today still one of the most important foodstuffs utilized by mankind. The pods contribute vitamins such as vitamin C, and minerals such as calcium, iron, folic acid and riboflavin (vitamin B2) to the human diet. Green beans are a tropical crop and consequently sensitive to low temperatures (Shadrack, 2013). There are two types of green beans plants: bush and pole (also called vine). Bush bean varieties branch out and grow in a bushy shape, hence the name. They may grow upright and tall or semi-upright and compact, generally reaching a height of 24-30 inches. Most varieties of pole or vine beans grow to be 6-8 feet long, but they have been known to reach heights of 10-15 feet. As a result, pole beans need a cage, trellis or other supportive device next to the Tower so the plant has its own place to grow (Decoteau, 2000).

Green bean does not need water on the seed while germinating (5-7 days after sowing). After sowing water properly and wait for emergence. From the flowering stage, green beans are very sensitive to lack of moisture. The crop does not have specific soil requirements but friable, deep soils with PH of 5. 3 to 6.0 are preferred. Bean is capable of fixing nitrogen which can meet its requirements for high yields (Doorenbos and Kassam ,1979).

Water management in green bean production is extremely important at all stages of plant development due to its influence on stand establishment, pod set and quality. Crop coefficient (kc) relating reference evapotranspiration (ETo) to water requirements (ETm) for different development stages is for green beans: during the initial stage 0.3-0.4 (15 to 20 days); the development stage 0.65-0.75 (15 to 20 days) ; the mid-season stage 0,95-1.05 (20 to 3O days); the late-season stage 0.9-0.95 (5 to 20 days) and at harvest 0.85-0.9. When the crop is grown under full irrigation, the soil water depletion during the flowering and yield formation periods should not exceed 40 to 50 percent of the total available soil water (p= O.4-0.5) (Doorenbos and Kassam ,1979).

Green bean pods are normally ready for harvest 50 - 60 days after planting, some 14 - 28 days after the first flower appeared, even though variation occurs in different altitudes and cultivars (Kay, 1979). Repeated harvests when the pods are still young will induce the formation of new flower buds which will result in a higher yield of young pods. It is important to harvest at the right stage and the following method can be applied: When the pod is cut open lengthwise, the seed must be well developed, but be careful because the seed can harden very quickly. Beans ripen very quickly in warm weather and therefore it is necessary to harvest every day to get good quality pods. It is important to harvest early in the morning, and pods must not be left in the sun as they wilt quickly (within 2 to 4 hours) (Shadrack, 2013).

2.11 Green Bean Response to Deficit Irrigation

The effects of water stress vary depending on the frequency, duration and intensity of stress and stage of growth of the plant.Green bean response to deficit irrigation may be positive or negative depend on Varity, climate condition, soil type and stage of growth. Some yield parameters such as the pod number per plant, pod weight, and pod length of plant significantly increased with amount of water (Onder et.al, 2006). Green bean is most sensitive to moisture stress during flowering and pod sizing. Water deficit during this period will have the greatest negative impact on yield and pod quality (Doorenbos and Kassam, 1979).

Regulated deficit irrigation decreased yields of common beans, but the combination of alternate furrow and deficit irrigation can allow legume production with reduced water inputs (Bourgault M. et. al, 2007). Both irrigation levels and irrigation frequencies had significantly different effects on quality parameters such as fresh bean length and width (Metin et.al, 2008). By applying deficit irrigation water use efficiency of beans can be improve (Calvache et al., 1997).

3 MATERIALS AND METHODS

3.1 Description of the Study Area

This field experiment was conducted at Melkassa Agricultural Research Center (MARC). The center was located in the Central Rift Valley of Ethiopia, Oromia Regional State at 8°24′36” N - 8°26′24” N latitude, 39°19′12” E - 39°21′48” E longitude, and altitude of 1,550 m above sea level.

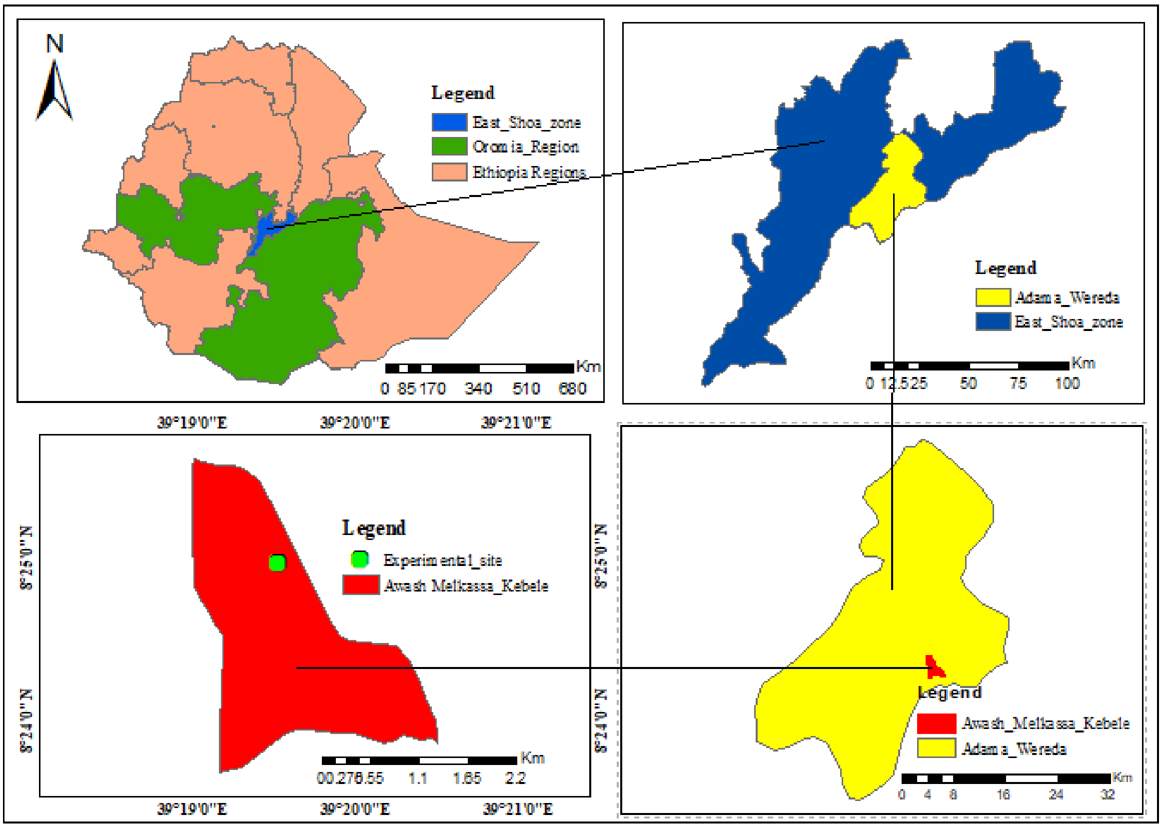

Figure 3.1 Map of the study area

The climate of the area is characterized as semi-arid with uni-modal low and erratic rainfall. Kiremt season has more rainfall and contribute about 67.4% of the total rainfall of the year occurring during June to September with peak on the months of July and August. From long-term (1977 – 2017) climatic record of Melkassa agro-meteorological observatory station indicted the average annual rainfall in the area was 824.9 mm and the mean maximum and minimum monthly rainfall were 204.2 mm and 9.6 mm occurs in the month of August and November, respectively. The mean maximum temperature varies from 26.3 ^{0}C to 31.0 ^{0}C while the mean minimum temperature varies from 10.4 ^{0}C to 16.4 ^{0}C, with the average of 21.3 ^{0}C.

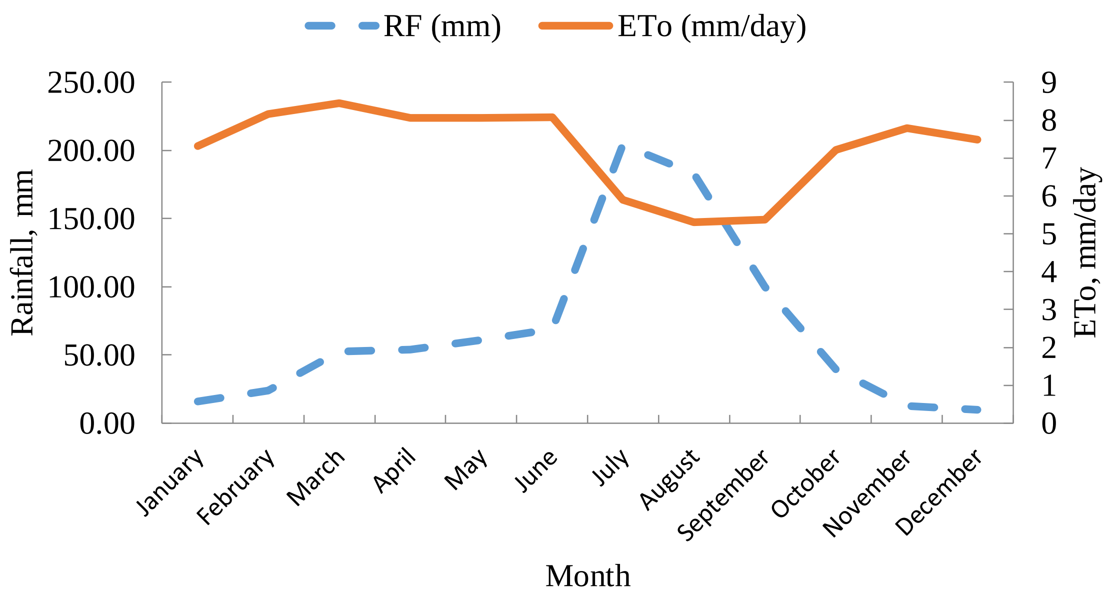

Figure 3.2: Long-term (1977 – 2017 years) monthly climatic data of the study area
Source: MARC

The source of irrigation water in the study area is Awash River that serves 27% of the total irrigated agriculture of the country (Zemede, 2011).The textural classification mainly varies from clay to clay loam.

3.2 Soil Physical and Chemical Properties of Experimental Site

Disturbed soil samples was collected from three depths 0-20 cm, 20-40 cm, and 40-60 cm by considering the effective root zone of green beans at five points along the diagonal of the experimental block for physical and chemical analysis.

Soil texture and bulk density

Hydrometer method was used for analysing particle size distribution and the textural class was assigned using USDA textural triangle.

The soil bulk density was determined from undisturbed soil samples using core sampler at different location and depth at 20 cm intervals up to 60cm along the diagonal. The samples were then dried in an oven at 105°C for 24 hours and the bulk density was then calculated using the following equation:

$$\rho_b = \frac{Ws}{Vc} \qquad 3.1$$

where, ρ_b is soil bulk-density (g/ cm^3), W_s is mass of dry soil (g) and V_c is volume of soil in the core (cm^3)

Field capacity and permanent wilting point

Soil samples was also collected for the determination of moisture content at field capacity (FC) and permanent wilting point (PWP) from three depths 0-20 cm, 20-40 cm and 40-60 cm. The Field capacity (FC) and permanent wilting point (PWP) were determined using pressure plate and pressure membrane apparatus, respectively. Soil samples were saturated for one day (24 hours) and a pressure of 1/3 bar and 15 bar were exerted, respectively for FC and PWP, until no water droplets detected. After getting soil moisture values corresponding to these constants, available water holding capacity of the soil was calculated using equation:

$$TAW=1000(\theta_{FC} - \theta_{PWP})*DZ \qquad 3.2$$

where, TAW the total available soil water in the root zone (mm), θ_{FC} the water content at field capacity (m3 m^{-3}),θ_{PWP} the water content at wilting point (m3 m^{-3}), and Dz is the maximum effective root zone depth(m).

Infiltration rate

The infiltration rate of the soil in the experimental field was determined using double ring infiltrometer. First by placing the inner ring with the cutting edge facing down on the ground and putting the driving plate (wooden plate) on the top of the inner ring then hammer was used to insert the inner ring about 5 cm vertically in to the soil. The same procedure was repeated for the outer ring. After finishing inserting the rings vertically in to the soil a ruler was attached to the inner ring then pour water first to the outer ring then in to the inner ring. A stop watch was used to record the time. Measuring the infiltration rate was continued by pouring water when the water depth is reduced in the rings until the infiltration rate has been reach a constant value.

Determination of soil chemical characteristics

Soil chemical characteristics of the experimental site such as soil pH, OM, EC and total nitrogen was subjected to laboratory analysis and determined following the standard procedures for determination of each chemical characteristics of the soil to know the suitability for growing green beans.

3.3 Experimental Design and Treatments

The field experiments consisted 12 treatments and include three irrigation system, viz., conventional furrow irrigation (CFI), Alternate furrow irrigation (AFI) and Drip irrigation (Dp) and four irrigation levels, 100%ETc (control treatment), 80%ETc, 60%ETc and 40%ETc .The design of the experiment was split plot design with three replications. The three irrigation systems were used as main plot and the four irrigation levels were used as sub plot treatment. The treatment combination is given in Tables 3.1 and layout in Figure 3.3.

Table 3.1 Experimental treatments combination

sub-plot	Main plot(MP)		
	CF	AF	Dp
100%ETc(I_1)	CFI_1	AFI_1	DpI_1
80%ETc(I_2)	CFI_2	AFI_2	DpI_2
60%ETc(I_3)	CFI_3	AFI_3	DpI_3
40%ETc(I_4)	CFI_4	AFI_4	DpI_4

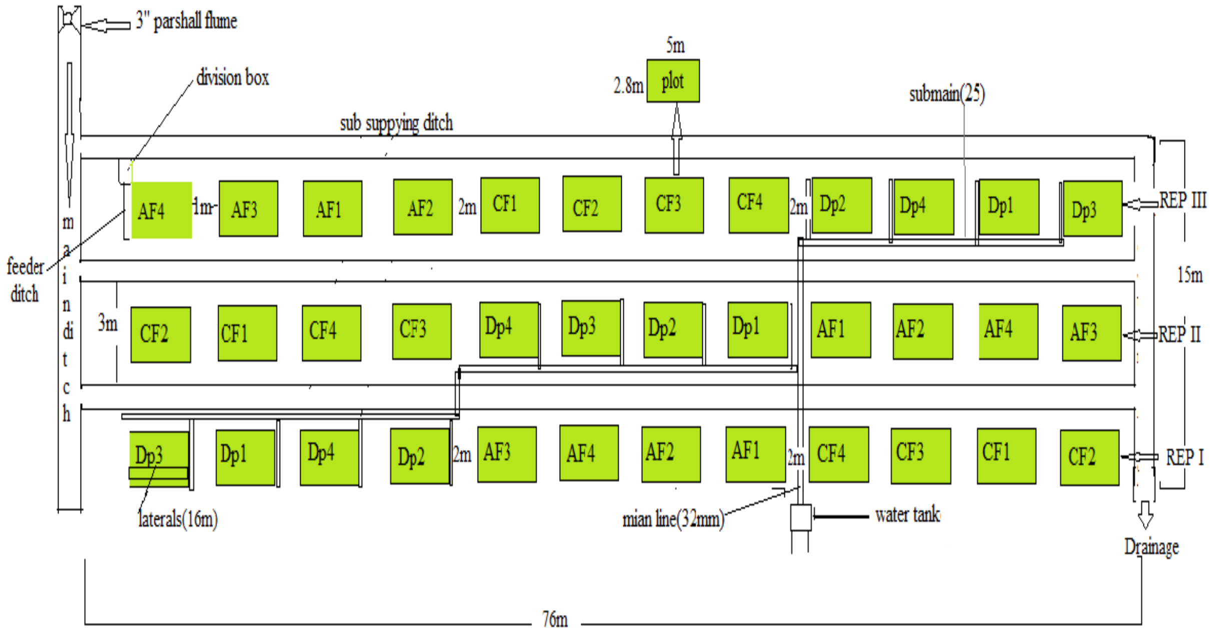

Figure 3.3 Experimental layout

3.3.1 Preparation of the experimental site

Land preparation was made using tractor driven dick plough and labor force to finish. The plots were leveled manually to create uniform plots within the given treatment. The experimental field was divided into 36 plots and each plot size having 5 m by 2.40 m dimension. The furrow had 6 ridges with 40 cm furrow spacing and 5 m furrow length. Each treatment plot consists of six rows with 10 cm plant spacing. The total net area was 504 m^2. Having three replication and 36 plots, the plots are separated by 1 m buffer strip and between replication 3 m buffer strip was provided.

3.3.2 Installation of drip irrigation sets and furrow preparation

The drip irrigation system was designed and installed in such a way to maintain the required pressure at the end of the plot so that uniform water distribution at each emitter was obtained. In drip irrigation system treatments, there were 12 plots laid out 5 m length by 2.40 m width, and six laterals per plot, 40 cm spacing between laterals and 20 cm interval between emitters with discharge rates of 2 lit/hr. Wooden platform to carry the water tank was constructed. The tank was placed 2m above the ground to get enough pressure. The water tank was fitted with gate valve and water filter on ¾ inch socket (connector) welded at 10 cm above the bottom of the water tank.

The water distribution system component (25 mm, sub main line) was laid and connected the water container to the individual drip lines. There was 12 valve attach to sub main line to control water flow to each drip irrigated plot. The drip lines (laterals) of 16 mm diameter was unrolled and laid along the crop rows and each lateral served one row of crop. In line emitter with 20 mm spacing is used. The end of the laterals and the sub main lines was closed with end cup in order to flush the entire lateral system periodically.

Furrow irrigated plot had 24 plots and were short closed ended dike furrow type. Conventional and alternate furrow irrigation had 12 plots each. For conventional furrow irrigated plot all furrows are watered during all irrigation events but in alternate furrow irrigated plot by numbering each furrows and watered the odd and even numbered furrows alternatively during each irrigation event.

3.4 Crop Management Practices

The experiment was started on 19 April 2018. The experimental plots were pre-irrigated before two days to planting to get favorable condition to the seed to germinate. Green bean variety plati was used for the experiment because it have short duration to mature, it is bush type and have high yield compare to the other varieties also suitable for the study area. Each treatment plot consists of six rows with 10 cm plant spacing and 40cm row spacing. All cultural practices other than variable factor are standard practices recommended for the area. The experimental plots received 142 kg ha^{-1} NPS and 79 kg ha^{-1} urea. On the ridges two seeds per hole were directly seeded in each hole at 10cm plant spacing in both furrow and drip irrigation and thinned after the germination of seedlings and establishment. Weeding was done manually in drip and furrow irrigated plots at the same time to eliminate variation between plots.

Irrigation management was based on daily crop evapotranspiration (ETc), estimated from using FAO Penman-Monteith method (Eq. 2.3) with the daily meteorological data (including maximum, minimum air temperature; precipitation; average wind speed; the average relative humidity; hours of sunshine) were provided by the Melkassa Agro-meteorological observatory near the experiment area and crop (kc) coefficients proposed by Allen et al. (1998) (Table 3.2). In every application, irrigation water amount of the control treatment (100% ETc) was estimated by subtracting the effective precipitation from the crop water use ETc. The water amount of the other treatments was calculated by using the corresponding percentages of deficit (80%, 60% and 40%) based on the amount of the control treatment. Irrigation was applied when the computed readily available soil moisture (Eq. 2.2) was nearly used by crops. Irrigation frequencies were the same for all treatments under furrow irrigation and drip irrigation.

Table 3.2 Date of green bean growth stage and crop coefficient (kc)

Growth stage	Initial	Dev't	Mid	Late
Dev't days	15	25	25	10
Root depth(m)	0.3	0.4	0.6	0.6
kc	0.5	1.05	1.05	0.9

Source: Allen et al., 1998

3.5 Irrigation Scheduling and Management

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

$$I_n = ET_c - P_e \qquad 3.3$$

where; I_n is the net irrigation depth in mm, ET_c is the crop water requirement in mm and P_e is the effective rainfall in mm.

The effective rainfall estimated using dependable rain (FAO/AGLW formula) method as given by (Allen *et al.*, 1998).

$$Pe = 0.6 * P - 10 \quad \text{for month} \leq 70 \text{ mm} \qquad 3.4$$

$$Pe = 0.8 * P - 24 \quad \text{for month} \geq 70 \text{ mm} \qquad 3.5$$

where; Pe is the effective rainfall in mm and P is the monthly total rainfall in mm.

The gross irrigation requirement was obtained from the following expression:

Furrow irrigation $$I_g = \frac{I_n}{E_a} \qquad 3.6$$

Drip irrigation $$Ig = \frac{In*wa}{Ea} \qquad 3.7$$

where; Ig is the gross irrigation depth in mm; In as obtained from Eq (3.3); Ea is the field application efficiency (%) and wa is the wetted area (%).

The determined depth of irrigation water was applied to the furrow irrigated plots using a 3 inch Parshall flume that was installed at the upper stream side near the experimental field. Field application efficiency of the furrows was taken as 60% which recommended to the study area and the time required to deliver the desired depth of water into each furrow plots was calculated using the equation:

$$t = \frac{Ig * w * l}{60 * q} \qquad 3.8$$

where, Ig is gross depth of water applied (mm), t is application time (min), l is plot furrow length (m), w is plot width (m), q is flow rate (l/s).

In the case of drip irrigation field application efficiency of 90% was taken and, knowing drip/emitter size, length of lateral and the number of laterals per plot, the time required to deliver the desired depth of water was calculated as follows:

$$T = \frac{Ig\ x\ A}{Nl\ x\ Ne\ x\ q} \qquad 3.9$$

where, T is time in hours, A is the plot area in m^2, Nl is the number of lateral, Ne is number of emitters per lateral and q is emitter discharge in l/hr.

The irrigation frequency was determined by dividing calculated RAW by crop evapotranspiration (ETc) (eq. 3.12).

$$f = \frac{RAW}{ETc} \qquad 3.10$$

where: f is irrigation frequency in day, RAW is in mm, and ETc is the mean daily crop water requirement (mm/day)

Soil moisture determination

Moisture status of the soil profile for each treatment was observed before starting the treatment by gravimetric moisture content determination method at three depths, which are 0-20 cm, 20-40 cm and 40-60 cm. The wet soil samples was put in an oven set at a temperature of 105°C and dried for 24 hours. Its gravimetric water content was determined using the following equation.

$$\theta_m = \frac{W_{ws-}W_s}{W_s} \times 100 \qquad 3.11$$

where: -θ_m is water content expressed on weight basis in (%), W_s is weight of dry soil (g), and W_{ws} is weight of wet soil (g).

The volumetric water content was calculated from the gravimetric water content using the following expression.

$$\theta_v = \frac{\rho_b}{\rho_w} \times \theta_m \qquad 3.12$$

where: θ_v is volumetric moisture content in (%); ρ_b is soil bulk density (g cm^{-3}), and ρ_w is water density (g cm^{-3})

3.6 Data Collection

3.6.1 Weather data

Data on daily weather of the site during crop growth period was collected from the Melkassa Agro-meteorological observatory. The reference evapotranspiration (ETo) was computed using Penman-Monteith method using CROPWAT ver. 8.0 window based computer model from the climatic data. The climatic data collected were maximum and minimum temperature (°C), humidity (%), wind speed at 2m (km/hr), sunshine hours (hr) and rainfall (mm).

3.6.2 Drip uniformity parameters

The performance of drip irrigation system was evaluated using commonly used performance indicators such as distribution uniformity and coefficient uniformity.

Distribution uniformity (Du)

The uniformity of drip emitters was measured and checked by taking one plot from each block and nine emitters from each plot at equal intervals of the laterals. Cans were placed beneath the drip emitter, the water coming out of the emitters was collected for 1.2 hours and the volume of water was measured using a graduated cylinder. Emitter discharge was determined by dividing the volume of water collected by the time taken to collect that volume of water. DU (%) was estimated as:

$$DU = \frac{\bar{q}\ lowest\ 25\%}{\bar{q}} \qquad 3.13$$

where, $\bar{q}_{\text{lowest 25\%}}$ is average of the lowest quarter discharge, $\bar{q}$ is average discharge

3.6.2.1 Coefficient of uniformity (CU)

It is also known as Christiansen's uniformity coefficient or emission uniformity (EU).

$$CU = \left(1 - \left(\frac{\sum|q_i - \bar{q}|}{n\bar{q}}\right)\right) \times 100 \qquad 3.14$$

where, q_i is dripper discharge, $\bar{q}$= average discharge and n = number of drippers

3.6.3 Crop data

The crop data was collected and recorded from middle rows of each plot and five randomly selected plants which represent much of the population from these rows. The net harvest area in each plot was 6.4 m^2 (four rows, each 4m long). Plants phenological stages such as days 50% to flowering and maturity was recorded in plot base. The following data was recorded from randomly selected plants of middle rows.

Plant height

Green bean height was taken by measuring the main stem height from the ground level up to the tip of the leaf with the help of ruler. This measurement was taken when the green bean pods were matured. All measurements made on five samples represent plants from the population then recorded.

Biomass

Biomass was recorded from five representative plant of the population at horticultural maturity from net area of each plot. Moisture content of the samples was estimated by drying the plants after taking fresh weight in an oven at temperature of 70ºC for 24 hours.

Quality parameters

Pod length and pod diameter was recorded form each selected five pod which represent much of the population in plot base for each treatments. Pod length is measured using ruler putting the pod straight to the ruler and record the number from the ruler. Pod diameter was measure using 6’’ digital caliper at the middle of the pod.

Yield

Yield was determined first by counting all plants in the net area in each plot separately. All of these plants were harvested when the pods were matured. To assess the effect of treatments the data collected include: marketable pod yield (kg ha^{-1}) and unmarketable yield. Weight was measured using automatic balance.

Number of pods per plant

Number of pods per plant is recorded in plot base from each treatment by counting each pod from five selected plants which represent the population.

3.7 Crop Water Use Efficiency

The crop water use efficiency was determined using the expression:

$$CWU = \frac{Y}{ET_c} \qquad 3.13$$

where, CWUE is crop water use efficiency (kg $ha^{-1}mm^{-1}$), Y is fresh green bean yield ($kgha^{-1}$) and ET_C is crop evapotranspiration (mm)

The water saving with AFI and Drip irrigation compared to CFI was calculated as:

$$\text{Water saving } \% = \frac{\text{WCFI}-\text{WAFI or WDp}}{\text{WCFI}} * 100 \qquad 3.14$$

where, WCFI is total water used (mm) with the CFI system and WAFI is total water used (mm) with the AFI system and WDp is total water used with the drip irrigation system.

The water saving with deficit irrigation at different irrigation depth application also calculated and the increase/decrease in yield (%) compared to the full irrigation was calculated.

The increase/decrease in yield (%) compared to the AFI and drip irrigation system was computed as:

$$Increase\ in\ yield\ (\%) = \frac{YAFI\ or\ YDp - YCFI}{YAFI\ or\ YDp} * 100 \qquad 3.15$$

where, YAFI is yield obtained with AFI (kg ha^{-1}), YDp is yield obtained with Drip irrigation (kg ha^{-1}) and YCFI is yield obtained with CFI (kg ha^{-1}).

3.8 Yield Response Factor

The yield response factor (Ky) of green bean which relates relative yield decrease to relative ET deficit under this study was estimated using the following formula;

$$[1 - \frac{Y_a}{Y_m}] = K_y \left[1 - \frac{ET_a}{ET_m}\right] \qquad 3.16$$

where: Ya = actual yield (kg/ha), Ym = maximum yield (kg/ha), ETa = actual evapotranspiration (mm), ETm= maximum evapotranspiration (mm), and Ky = yield response factor.

3.9 Statistical Analysis

The crop data collected were statistically analyzed following the standard procedures applicable to split plot design. The data was analyzed by using SAS software version 9.0 and whenever there is a significant difference among the treatments mean LSD test were carried out.

4 RESULTS AND DISCUSSION

4.1 Soil Physical and Chemical Properties

The results of soil physical and chemical properties as obtained from laboratory were presented and discussed below.

4.1.1 Soil texture and bulk density

Laboratory analysis of particle size distribution of the experimental site is presented in Table 4.1. Based on the USDA soil textural classification the dominant textural class of the experimental site was classified as Clay loam.

Table 4.1 Summarized soil particle size distribution

	% Particle size distribution			
Soil depth (cm)	Sand (%) (2-0.05)	Silt (%) (0.05-0.002)	Clay (%) (<0.002)	Textural class
0-20	33.6	32.1	34.3	Clay Loam
20-40	34.31	28.99	36.7	Clay Loam
40-60	34.3	30.7	35	Clay Loam
Average	34.07	30.6	35.33	Clay Loam

4.1.2 Bulk density, field capacity and permanent wilting point

The bulk density varies with depth and found in a narrow range of 1.09 to 1.2 gm/ cm^3 with an average bulk density of 1.14 gm/ cm^3. The top surface soil layer had slightly lower bulk density than the subsurface and this might be due to high organic matter contents in the top soil surface. In general, the average bulk density indicate a porous soil condition and suitable for root growth (Hunt and Gilkes, 1992).

Table 4.2 Soil moisture constants and bulk density of experimental site

Sampling depth (cm)	Bulk density (gm/cm^3)	FC (% wt.)	PWP (%wt.)	TAW (mm/m)
0-20	1.09	41.3	25.3	174.4
20-40	1.13	36.62	21.42	171.76
40-60	1.2	32.65	18.68	167.64
Mean	1.14	36.85	21.8	171.27

Moisture content at field capacity for the experimental site soil varies between 41.3 and 32.65% for the soil depths considered. Moisture content at permanent wilting point also showed variation with depth and ranged between 25.3 and 18.68% for the soil depths. The representative value of TAW was 171.27 mm/m.

4.1.3 Infiltration rate

The generated information on soil infiltration rate and cumulative infiltration from the field test data presented in figure 4.1. The basic infiltration rate was about 12 mm/hr, this means that a water layer of 12 mm on the soil surface will take one hour to infiltrate. At the beginning, water infiltrates rapidly. As more water replaces the air in the pores, the water infiltrates more slowly and eventually reaches a steady rate which is called the basic infiltration rate. This rate of infiltration is in the range of infiltration characteristics of clay loam soils (Andreas and Karen, 2002). The basic infiltration of the soil indicate that the soil is perfect for surface irrigation (Landon, 1991).

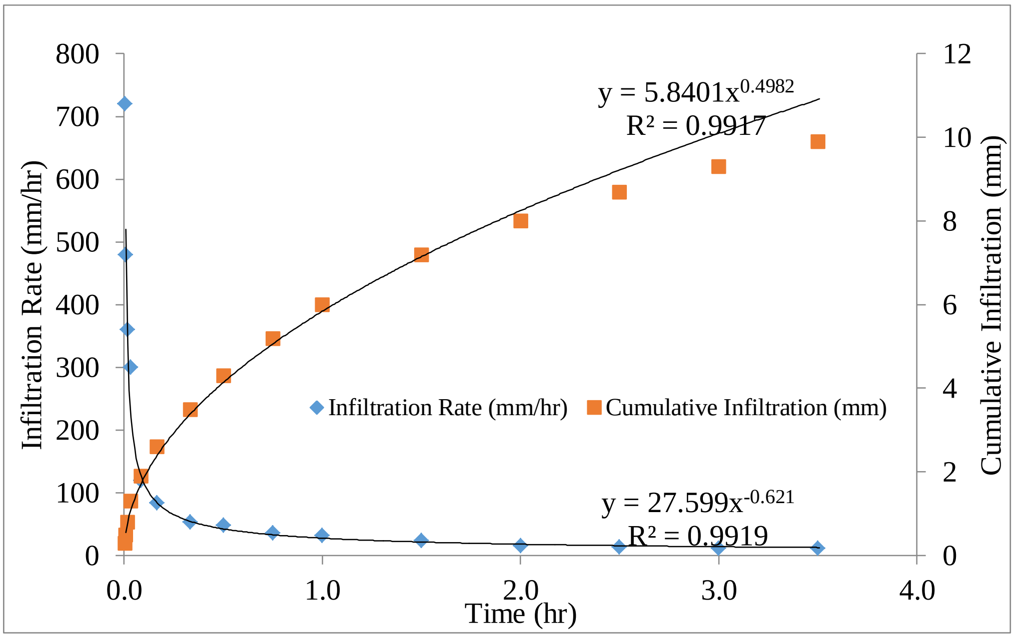

Figure 4.1 Soil infiltration rate of the experimental site

4.1.4 Chemical characteristics of the soil

As indicated in Table 4.3 the pH of the experimental site varied from 7.64 to 7.45 with an average pH-value of 7.53 that indicate the soil is slightly alkaline and suitable for most crops. The electrical conductivity (ECe) of soil varied between 0.27 and 0.33 dS m^{-1} which is classified as salt free and had negligible effect on most crop growth and yield (Hazelton and Murphy, 2007). Green bean is considered sensitive to salinity, the maximum soil ECe level for Green bean without a significant yield loss being 1 dS m^{-1} (Allen *et al.*, 1998).

Table 4.3 Selected soil chemical properties of the surface of the experimental field

Soil depth (cm)	PH	ECe (ds/m)	Nitrogen (%)	OM (%)
0-20	7.64	0.27	0.11	5.11
20-40	7.5	0.33	0.1	4.44
40-60	7.45	0.27	0.08	4.30
Average	7.53	0.29	0.09	4.62

The OM content of experimental field had highest content of 5.11% in the soil depth of 0-20 cm whereas lowest content of 4.30% was found in the bottom 40-60 cm soil depth. It indicated that the soil had high rating and described to have good structural condition with high structural stability. However, at a depth of 40-60 cm, the OM content was 4.30%, (Table4.1) which showed that moderate rating and average structural condition with average structural stability (Hazelton and Murphy, 2007). The nitrogen level varied within the narrow range of 0.11 to 0.08 with the average value of about 0.09%, which is low to very low (Landon, 1991).

4.2 Distribution Uniformity of Drip Emitters

The measured values of emitter discharge uniformity are presented in Table 4.4. Analysis of data on emitter discharge observation under all parameters has shown better performance. The values of distribution uniformities (Du) and uniformity coefficient (Cu) were 97.57% and 98.20%, respectively. The field distribution uniformity was excellent, emitter coefficient of variation was good and according to Bralts (1986) emitter flow variation was acceptable.

Table 4.4 Uniformity of drip irrigation

Parameters	Units	Average
Distribution uniformities (Du)	%	97.57
Emitter flow variation (q_V)	%	6.77
Coefficient of variation (Cv)	%	2.10
Uniformity coefficient (Cu)	%	98.20

4.3 Crop Water Requirement

Depth of water required during the growing season and depth of water applied in each treatment plots is presented in Tables 4.2 and 4.3, respectively. As indicated in Table 4.2 water requirement at initial stage is low and increase during development stage and mid stage, then decreasing at late growth stage. High water requirement was observed at mid stage. Total Seasonal water requirement of green been at MARC climatic condition was 304.7 while effective rainfall was 89.5. It is reported that the water requirement of green bean was between 300 and 500 mm depend on climate (Doorenbos and Kassam, 1979).The irrigation water requirement (IWR) was estimated 226.97 mm.

Table 4.5 Water requirement of green beans

Irrigation event	Growth stage	ETc(mm)	Peff(mm)	Net irrigation(ETc-Peff)mm
Frist	initial	19.95	2.7	17.25
Second	initial	17.67	0	17.67
Third	develop	21.17	1.5	19.67
Fourth	develop	25.44	2.6	22.84
Fifth	develop	26.36	0	26.39
Sixth	develop	30.86	42.6	0
Seventh	mid	32.54	10.5	22.04
Eighth	mid	35.94	0.3	35.64
Nineth	mid	34.01	18.4	15.61
Tenth	late	30.7	0	30.7
Eleventh	late	30.06	10.9	19.16
Total		304.7	89.5	226.97

The total water applied depending on deficit irrigation levels and irrigation systems and varied from the highest 346.5 mm (100%ETc) to the lowest 140.9 mm (40%ETc) including effective rainfall and common irrigation. The maximum total depth of water was applied to the control treatment, which received 100%ETc at all growth stages under conventional furrow irrigation, while the lowest was applied to the treatment which received 40%ETc under alternate furrow irrigation. Drip and AF irrigated plots received lower irrigation depth compare to CF irrigated plot. In case of drip irrigated plots water is applied directly in to the root zone and do not wet the entire field (considering the wetting area of 55%). AF irrigated plots also have reduced irrigation depth because, for every irrigation events furrows are watered alternatively.

Table 4.6 Amount of water supplied during the season (both irrigation and effective rainfall).

Treatment		Net irrigation (mm)	Peff(mm)	CWR(mm)	Gross irrigation(mm)
DPI	100%ETc	141.35	89.5	230.85	235.58
	80%ETc	113.08	89.5	202.58	125.64
	60%ETc	84.81	89.5	174.31	94.23
	40%ETc	56.54	89.5	146.04	62.82
CFI	100%ETc	257	89.5	346.5	428.33
	80%ETc	205.6	89.5	295.1	342.66
	60%ETc	154.2	89.5	243.7	257
	40%ETc	102.8	89.5	192.3	171.33
AFI	100%ETc	128.5	89.5	218	214.16
	80%ETc	102.8	89.5	192.3	171.33
	60%ETc	77.1	89.5	166.6	128.5
	40%ETc	51.4	89.5	140.9	85.66

4.4 Effects of Irrigation System and Irrigation Levels on Green Beans

The analysis of variance showed that the interaction effect of irrigation system and deficit levels had not significant effect on growth, yield and yield components of green beans.

Table 4.7 Mean values for interaction effect of irrigation system and deficit levels on growth, yield and yield components of green beans

Treatments		DF	DM	Height	Biomass	PL	PD	Yield
DPI	100%ETc	42	61	66	16	14.33	8.3	18.83
	80%ETc	41	59.67	62	15.5	13.67	7.4	16.76
	60%ETc	39	58	58	15	12.67	7.3	15.1
	40%ETc	38	57	57	14	11.56	6.5	14
CFI	100%ETc	44	63	64	16	13.67	7.4	17.33
	80%ETc	42	61	61	15	13.33	7	15
	60%ETc	40	59	56	15	13	6.8	14.2
	40%ETc	39	58	55.5	14.55	11	6.3	12
AFI	100%ETc	40.6	60	61	15	13.33	6.16	15
	80%ETc	40.67	60	57	14.7	13	6.8	14.75
	60%ETc	39	59	55	14.6	11	6.2	14
	40%ETc	39	58	51	14	10.66	6	11
LSD (5%)		NS	NS	NS	NS	NS	NS	NS
CV (%)		3.68	2.70	5.48	4.39	9.85	2.1	5.17

Note: DF is days to 50% flowering, DM is days to 50% maturity, PL is pod length, PD is pod maturity.

4.4.1 Days to 50% flowering

The analysis of variance showed that irrigation system and the interaction effect of irrigation system and deficit levels had not significant effect on days to 50% flowering. The effect of deficit irrigation level resulted a highly significance ($p \leq 0.01$) difference on 50% of flowering, but not irrigation system (Table 4.3). A 40%ETc deficit irrigation level able to flower after 39 days from planting and had no significant difference with 60%ETc deficit irrigation application. The days to 50% flowering took longest (42 days) for 100%ETc irrigation application and significantly different to all deficit irrigation applications. The result shows application of deficit irrigation shows early flowering this might be water stress enhance allocation of resources to reproduction and leading to early flowering. Similar result was obtained by Abdulaziz (2015), in which common bean shows early flowering under deficit irrigation.

Table 4.8 Effects of irrigation level and irrigation system on crop phenology

Treatment	Days to 50% flowering	Days to 50% maturity
100%ETc	42.22^{a}	61.33^{a}
80%ETc	40.56^{b}	59.89^{ab}
60%ETc	39.78^{bc}	58.88^{bc}
40%ETc	38.89^{c}	58^{c}
L.S.D (5%)	1.47	1.58
CV	3.68	2.70
CFI	41.08	60.08
DPI	40.08	59.08
AFI	39.92	59.41
L.S.D (5%)	NS	NS
CV	5.71	3.10

*Means followed by the same letter in a column are not significantly different from each other at 5% probability level

4.4.2 Days to 50% maturity

The analysis of variance showed that irrigation system and the interaction effect of irrigation system and deficit levels had not significant effect on days to 50% maturity. The analysis of variance for physiological maturity revealed that a highly significance ($P \leq 0.01$)

difference for 50% maturity for deficit irrigation levels but not irrigation systems. The longest days (63 days) to maturity was taken in treatment receiving 100%ETc and significantly different to all other treatments. The early maturity (58days) was recorded from 40%ETc application and had no significant difference with 60%ETc application ($P < 0.05$). The result indicates application of full requirement of irrigation water leads to late maturity and applying deficit irrigation fasten the maturity of green bean plant. Applying of full requirement of irrigation water may be contributes for vegetative growth but not for reproduction, this may be why deficit irrigation able to mature early, because water stress enhance allocation of resources to reproduction. Studies show that moisture stress from flowering to maturity tended to hasten maturity of snap bean (Salter and Goode, 1967).

4.4.3 Plant height

The analysis of variance showed that deficit levels had significant effect on plant height but not irrigation system and the interaction effect of irrigation system and deficit levels. Analysis of variance indicated that deficit irrigation application had shown a highly significant ($P<0.01$) difference on plant height measurement at physiological maturity.

Table 4.9 Effect of irrigation system and irrigation levels on plant height

Treatment	crop height(cm)
100%ETc	63.56a
80%ETc	59.87b
60%ETc	56.96bc
40%ETc	55.33c
L.S.D (5%)	3.19
CV (%)	5.48
CFI	59.56
DPI	60.50
AFI	56.72
L.S.D (5%)	NS
CV (%)	5.44

*Means followed by the same letter in a column are not significantly different from each other at 5% probability level

As depicted in Table 4.5 above, there was significant difference among all the deficit levels ($P < 0.05$). The tallest plant height (63.56 cm) was observed at 100%ETc and significantly different to all deficit irrigation applications. The shortest plant height (55.33cm) was observed at 40%ETc. Generally, the mean table showed increasing trend in plant height with increasing water application level indicating that direct relationship between vegetative growth and water use. As shown in Table 4.5, the tallest and shortest plants of 60.5 cm and 56.72 cm were observed for DPI and AFI systems, respectively.

4.4.4 Biomass

The analysis of variance showed that irrigation system and the interaction effect of irrigation system and deficit levels had not significant effect on biomass production. The biomass of green bean crop was significantly ($p \leq 0.05$) affected by deficit irrigation. Table 4.6 shows that the highest biomass was obtained from 100% ETc (15.89 ton/ha) application and had no significant difference with 80% ETc and 60%ETc deficit irrigation level. The 40% ETc had resulted in low total biomass (14.78 ton/ha) and inferior to all other irrigation levels. This result indicates the direct relationship between water applied and biomass production, increasing water application increases biomass production.

Table 4.10 The effect of irrigation system and irrigation levels on total biomass

Treatment	biomass(ton/ha)
100%ETc	15.89a
80%ETc	15.78a
60%ETc	15.56a
40%ETc	14.78b
L.S.D (5%)	0.67
CV (%)	4.39
CFI	15.91
DPI	15.75
AFI	14.83
L.S.D (5%)	NS
CV (%)	6.18

*Means followed by the same letter in a column are not significantly different from each other at 5% probability level

4.4.5 Quality parameters

Pod length

The analysis of variance showed that the interaction effect of irrigation system and deficit levels had not significant effect on pod length. Analysis of variance showed that pod length significantly ($P \leq 0.05$) affected by irrigation system and a highly significant ($p \leq 0.01$) difference in pod length was observed due deficit levels. Table 4.7 shows, the largest pod length was 13.44 cm observed at 100%ETc application level which was not significantly different to 80%ETc and 60%ETc irrigation level. Similarly, the smallest pod length was 11.33 cm recorded at 40%ETc irrigation application and inferior to all irrigation level.

The different irrigation application systems also had significant difference in pod length. The largest pod length was 13.8 cm observed under drip irrigation system and the smallest pod length was 12 cm recorded at alternate furrow irrigation application method. As the result indicates green bean quality affected by water deficit and irrigation system. Drip irrigation system gave good quality green bean and 100%ETc, 80%ETc and 60%ETc also gave good quality green bean.

Table 4.11 Effect of irrigation level and irrigation system on pod length and pod diameter

Treatment	pod length(cm)	pod diameter(mm)
100%ETc	13.44^{a}	7.11
80%ETc	13.33^{a}	6.95
60%ETc	12.67^{a}	6.82
40%ETc	11.33^{b}	6.73
L.S.D(5%)	1.23	NS
CV(%)	9.85	2.1
CFI	13^{a}	6.9
DPI	13.8^{a}	7.14
AFI	12^{b}	7
L.S.D(5%)	0.82	NS
CV(%)	5.72	2.77

*Means followed by the same letter in a column are not significantly different from each other at 5% probability level

Pod diameter

The analysis of variance showed that irrigation system and the interaction effect of irrigation system and deficit levels had not significant effect on pod diameter. The same analysis of variance also showed that there was no significant effect of deficit levels.

4.4.6 Pod yield

The analysis of variance showed that irrigation system and deficit levels had significant effect on pod yield but not the interaction effect of irrigation system and deficit levels. Analysis of variance showed that pod yield significantly ($P \leq 0.05$) affected by irrigation system and a highly significant ($p \leq 0.01$) difference in pod yield was observed due deficit levels.

Table 4.8 shows; the largest yield was 17.16 observed from 100%ETc application level which was significantly different to all deficit irrigation levels. Among deficit irrigation, 80%ETc application gave the highest pod yield and significantly different to all deficit irrigation. Minimum yield of 12.34 ton/ha was obtained from the 40%ETc application and inferior to all irrigation level. The result indicates applying of water without deficit (100%ETc) increase pod yield. The higher pod yield in 100% ETc might be attributed to the optimum availability of soil moisture as well as plant nutrients in the soil. Deficit irrigation reduces pod yield of grean bean. 80% ETc gave better yield compare to other deficit irrigtion levels. The reduced yield under 40% ETc might be due to moisture stress caused by deficit irrigation. This indicates green bean pod yield increases with increasing water application (Bourgault M. et. al, 2007, Doorenbos and Kassam, 1979).

The different irrigation systems also affect pod yield. The largest pod yield of 16.78 ton/ha was obtained from drip irrigation. The smallest yield of 13.75 ton/ha was obtained from alternate furrow irrigation application method. Drip irrigation give higher yield compare to furrow irrigation. The low yield under furrow irrigation might be cause of poor aeration and higher weed infestation problems (Kumari and Kaushal,2014). In drip irrigation weed infestation is less and water is applied directly into the root zone. Drip irrigtion is suitable for green bean production to get higher pod yield (Jha et al., 2017).

Unmarketable yield

The analysis of variance showed that deficit levels and the interaction effect of irrigation system and deficit levels had not significant effect on unmarketable yield but not the effect of irrigation system. The Analysis of variance showed that unmarketable yield significantly ($p<0.01$) affected by irrigation system. Drip irrigated plot gave lowest unmarketable yield compare to furrow irrigated plot (Table 4.8). This might be drip irrigated plots were less infested by weed.

Number of pod per plant

The analysis of variance showed that irrigation system and the interaction effect of irrigation system and deficit levels had not significant effect on number of pod per plant. The deficit levels had shown a highly significant ($p\leq 0.01$) effect on number of pod per plant. The greatest number of pods per plant was recorded from 100% ETc application and significantly different to all other irrigation levels.

Table 4.12 Mean value of fresh pod yield, un marketable yield and pod number per five plant

Treatment	Yield(ton/ha)	un marketable yield	pod no per five plant
100%ETc	17.16^{a}	2.67	32.16^{a}
80%ETc	15.48^{b}	2.26	26.08^{b}
60%ETc	14.44^{c}	2.2	23.82^{bc}
40%ETc	12.34^{d}	1.90	21.27^{c}
L.S.D (5%)	0.76	NS	3.82
CV (%)	5.17	15.03	14.95
CFI	14.64ab	3.12^{a}	25.98
DPI	16.18a	1.22^{c}	26.06
AFI	13.75b	2.43^{b}	25.45
L.S.D (5%)	1.81	0.64	NS
CV (%)	11.11	12.5	24.95

*Means followed by the same letter in a column are not significantly different from each other at 5% probability level

Among deficit irrigation, 80%ETc application gave the highest pod no per plant (26 pods per plant). The least number of pods per plant was produced from 40%ETc (21 pods per plant) and had no significant difference with 60%ETc application. As the result show number of pods per plant increases with increasing water application levels. These results are quite in line with the previous findings of Onder et.al. (2006), who recorded significantly highest number of pods per plant with water application depth is increases.

4.5 Crop water use efficiency

The analysis of variance showed that deficit levels, irrigation system and the interaction effect of irrigation system and deficit levels had significant effect on CWUE. The analysis of variance for CWUE revealed that a highly significance ($P \leq 0.01$) difference for deficit levels and irrigation systems. The interaction effect of deficit levels and irrigation systems have shown significant ($p<0.05$) difference on CWUE. As depicted in Table 4.9 the CWUE achieved at 40%ETc (9.61) deficit level under drip irrigation was the highest, and significantly different to all other treatments. CFI 100%ETc (5.00), is the lowest, and not significantly different to CFI 80%ETc. Drip irrigation and AFI combined with deficit irrigation attained the highest CWUE compare to CFI. This was because it interactively produced relatively similar pod yield to that of CFI system while reducing the total water use that used for producing the yield. From all treatment combinations 60%ETc and 80%ETc under drip irrigation and AFI had attained the highest CWUE next to 40%ETc under drip irrigation.

Table 4.13 Mean value of Crop Water Use Efficiency

Treatments		Yield(kg/ha)	CWU(mm)	CWUE(kg/m3)
DPI	100%ETc	18833	230.85	8.167[bc]
	80%ETc	16767	202.58	8.28b[c]
	60%ETc	15100	174.31	8.66[b]
	40%ETc	14033	146.04	9.61[a]
CFI	100%ETc	17330	346.5	5.00[f]
	80%ETc	15000	295.1	5.08[f]
	60%ETc	14233	243.7	5.84[e]
	40%ETc	12000	192.3	6.24[e]
AFI	100%ETc	15330	218	7.03[d]
	80%ETc	14667	192.3	7.63[c]
	60%ETc	14000	166.6	8.40[b]
	40%ETc	11000	140.9	7.81[bc]
LSD(5%)	0.53			
CV(%)	11.07			

The result indicated that the lower depth of water received with the higher the water use efficiency. The crop water use efficiency (CWUE) varied between 9.61-5.00 kg/m^{-3} depending on irrigation system and deficit irrigation level. Stansel and Smittle (1980), reported green bean WUE of 4-6 kgm^{-3} in USA. Sezen et al. (2008), found that green bean WUE of 4.33-6.08 kgm^{-3} under different irrigation intervals and plant-pan coefficient under Mediterranean condition. WUE values determined in this study were generally higher than the ones reported in the literature.

The water saving and increase/decrease in yield with AFI and Drip irrigation compared to CFI depicted in Table 4.10. There is 9.52 % yield increasement due to drip irrigation and in AFI there is 6.48% yield reduction recorded compare to CFI. A 55.58% of water is saved by drip irrigation and 37.08% water saved by AFI compare to CFI. This result in line with Sijali (2001), which found that 30%-60% water, is saved by drip irrigation compare to CFI.

Table 4.14 The water saving and increase/decrease in yield with AFI and Drip irrigation compared to CFI

			Compare to CFI system	
Treatments	Yield(kg/ha)	Water applied (lit/plot)	Increase/decrease in yield (%) with drip and AFI	Water saving with drip and AFI (%)
CFI	14642	6930	-	-
DPI	16183	3078	9.52	55.58
AFI	13750	4360	-6.48	37.08

Table 4.15 The water saving with deficit irrigation and the increase/decrease in yield (%) compared to the control irrigation

Treatment	Yield(kg/ha)	Yield decreased compare to 100%ETc	Water saved (%)
100%ETc	17167	-	-
80%ETc	15478	-10.91	20
60%ETc	14440	-18.89	40
40%ETc	12344	-39.05	60

As in Table 4.14 above shows there is a direct relationship between irrigation water application and yield. As water application depth decrease yield also decrease.

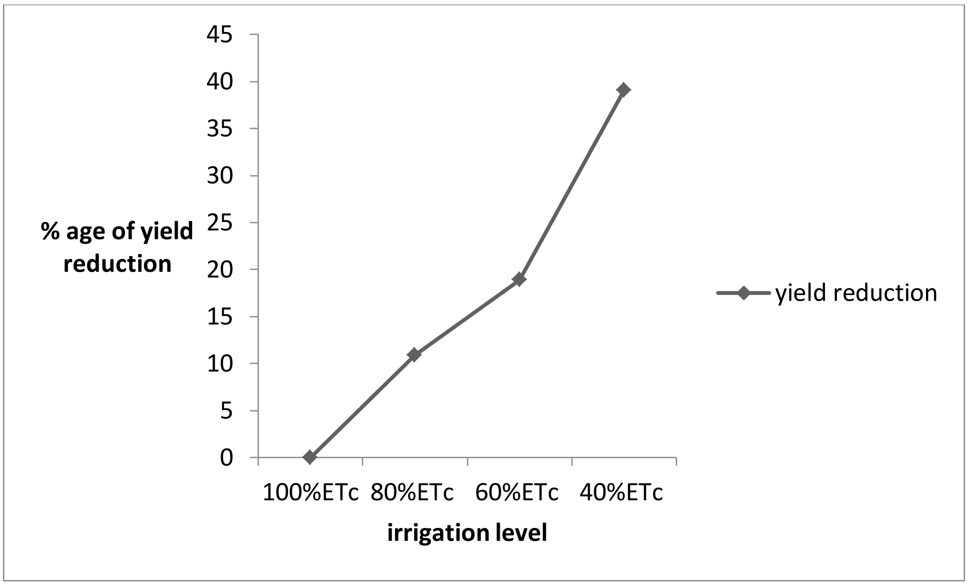

Figure 4.2 Graph of yield reduction

4.6 Yield Response Factor

Results of the analysis of yield shows that the highest ky was 0.91 attained at 80%ETc under CFI and the lowest was 0.31 observed at 100%ETc under AFI system. The ky values greater than unity indicates the relative yield decrease is higher than the water deficit (Pasquale et.al, 2012). According to Kirda et al. (1999), the ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result. The magnitude of ky value indicates the sensitivity of the irrigation protocol for water stress and subsequent yield decrease and the result shows that the treatment combination can resist the yield decrease associated with water deficit.

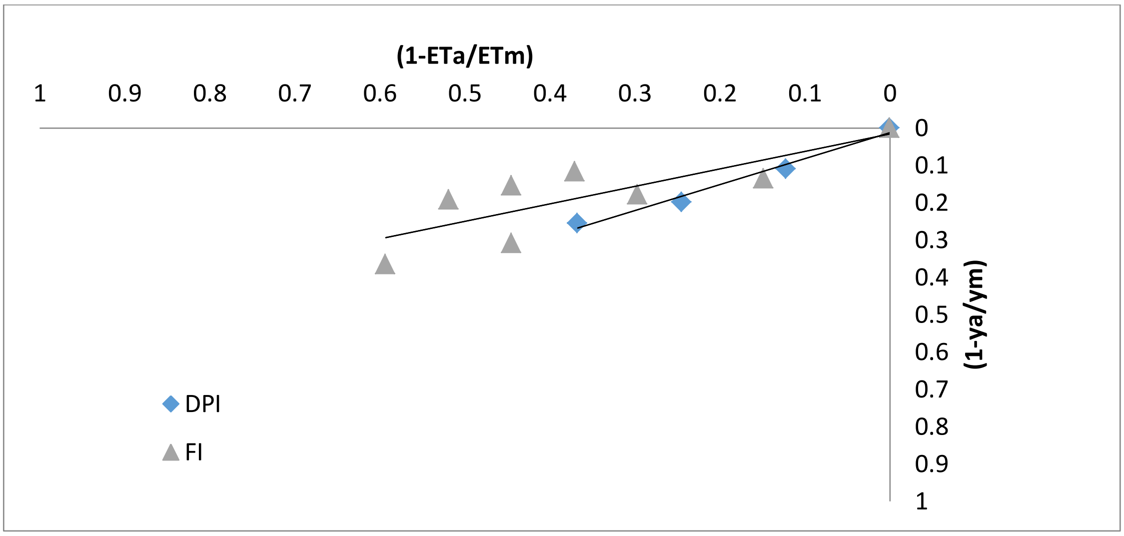

Figure 4.3 Relationship between relative pod yield decrease and relative ET deficit for drip irrigation and furrow irrigation method

5 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The study shows, the interaction effects of deficit irrigation and irrigation systems on green beans growth, yield and yield parameters are insignificant. Deficit irrigation have significant effect on yield, days to 50% flowering, days to 50% maturity, plant height, biomass and quality of green bean. The maximum yield of 17.16 ton/ha was obtained from 100% ETc and a minimum yield of 12.34 ton/ha from 40% ETc. Deficit irrigation shows early flowering and maturity compare to control irrigation (100% ETc). Also deficit irrigation shows highly significant ($p<0.01$) effect on plant height and 100% ETc gave the highest (63.56 cm) plant height and 40% ETc gave the shortest (55.33 cm) plant height. Pod diameter had not shown any significant difference among deficit irrigation but pod length had shown significance difference. Drip irrigation had shown greater yield and plant height compare to CFI and AFI. Drip irrigation gave less un marketable yield compare to CFI and AFI. 55.58% of water is saved by drip irrigation with 9.52% yield increase and 37.08% water saved by AFI with 6.48 yield reduction compare to CFI. The combined effect of irrigation system and deficit irrigation had shown significant difference ($p<0.05$) on CWUE. Drip 40% ETc had shown higher (9.61kg/m^3) CWUE and CFI 100% ETc had shown lower (5.00 kg/m^3) CWUE. In conclusion, deficit irrigation affects green bean yield and yield parameters. 80% ETc and 60% ETc compare to control irrigation shown minimum yield reduction, so it can be used for green bean production to save water. Drip irrigation gave better yield and water saving results compares to furrow irrigation system for green bean production.

5.2 Recommendations

From this study the following recommendation can be drawn.

- 80%ETc deficit irrigation application gives minimum yield reduction and water saving so recommended to use under water scarcity condition.

- Drip irrigation system under deficit irrigation gives better yield and more water saved compare to furrow irrigation so it is recommended to use drip irrigation for green bean production.

- Alternate furrow irrigation gives better WUE and minimum yield reduction compare to conventional furrow irrigation. It is recommended to use alternate furrow irrigation under water scarcity condition and when drip irrigation equipment is un available

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7 APPENDICES

Appendix A. Table

Appendix Table 7.1 Long-term (1977-2017) monthly climatic data of MARC

Month	Tmin, ^0C	Tmax, ^0C	Humidity, %	Wind, m/s	Sunshine, hr	ETo, mm/day	Rainfall, mm
January	11.7	27.9	51	8.6	9	7.3	16
February	13.4	29.1	48.7	9.1	9.2	8.2	24.1
March	15.1	30.5	49.2	8.6	8.5	8.4	52.3
April	15.5	30.5	50.8	7.8	8.2	8.1	53.9
May	15.5	31	51.2	7.5	8.8	8.1	61
June	16.4	30.2	53.1	9	8.4	8.1	69
July	15.7	26.8	66.4	9.1	7	5.9	204.2
August	15.4	26.3	69.2	7	7.1	5.3	183.1
September	14.5	27.6	65.8	4.9	7.3	5.4	99.8
October	11.7	28.8	50	6.6	8.7	7.2	39.3
November	10.8	28.3	46.7	8.3	9.6	7.8	12.6
December	10.4	27.6	48.8	8.9	9.5	7.5	9.6

T_{max} and T_{min}= maximum and minimum air temperature (°C) respectively, RH= relative humidity (%), u= Wind speed at 2 m height (m/sec), n= sunshine hour (hr) and ETo= potential evapotranspiration (mm/day)

Source: Melkassa Agricultural Research Center (MARC) meteorological station.

Appendix Table 7.2 Discharge (l/s) for flumes of 3 inch throat width parshal flume

Head(cm)	Discharge(lit/s)
5	1.705
6	2.261
7	2.872
8	3.532
9	4.239
10	4.991
11	5.786
12	6.621
13	7.496
14	8.408
15	9.358
16	10.342

Appendix Table 7.3 Infiltration rate of experimental field

Elapsed time (min)	Cumulative time (min)	Reading (cm)	Difference (cm)	Cumulative intake (cm)	Infiltration rate (mm/hr.)	
					Immediate	Mean
0	0	14	0	0	0.0	0.0
0.25	0.25	13.7	0.3	0.3	720.0	720.0
0.25	0.5	13.5	0.2	0.5	480.0	600.0
0.5	1	13.2	0.3	0.8	360.0	480.0
1	2	12.7	0.5	1.3	300.0	390.0
3	5	12.1	0.6	1.9	120,0	228.0
5	10	11.4	0.7	2.6	84.0	156.0
10	20	10.5	0.9	3.5	54.0	105.0
10	30	9.7	0.8	4.3	48.0	86.0
15	45	8.8	0.9	5.2	36.0	69.3
15	60	8/10*	0.8	6	32.0	60.0
30	90	8.8	1.2	5.2	24.0	34.7
30	120	8	0.8	6	16.0	30.0
30	150	7.2	0.8	6.8	16.0	27.2
30	180	6.6	0.6	7.4	12.0	24.7
30	210	6	0.6	8	12.0	22.9

* The measuring stich marks before and after water addition.

Appendix Table 7.4 Daily ETo and ETc for green bean crop during the experiment at melkassa condition

Day	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m/day	ETo mm/day	Kc	CWR mm/day
1	16.5	29.5	56	3.5	9.7	23.3	6.03	0.50	3.02
2	17.5	30.5	55	3.4	6.6	18.8	5.64	0.50	2.82
3	17	30.5	56	2.6	10.8	24.9	5.94	0.50	2.97
4	17.5	30.5	59	2.9	10.4	24.3	5.91	0.50	2.96
5	18	30.2	54	2.8	10.1	23.9	5.99	0.50	3.00
6	18.5	29	58	3.6	6.2	18.2	5.38	0.50	2.69
7	17.5	30.5	60	2.9	5.7	17.4	5	0.50	2.50
8	16	25.5	70	2	3.6	14.4	3.48	0.50	1.74
9	18	29.5	64	2.5	7.5	20	4.95	0.50	2.48
10	15.5	29.5	64	2.5	10.4	24.3	5.44	0.50	2.72
11	16	30	60	2.7	10.2	24	5.66	0.50	2.83
12	18	31	60	2.5	8.7	21.8	5.43	0.50	2.72
13	17	29.5	61	2.9	8.3	21.2	5.33	0.50	2.67
14	16.5	29	60	3	6.7	18.9	5.05	0.50	2.53
15	16	30	50	3.1	9	22.2	5.99	0.50	3.00
16	17.5	28	55	2.8	4.3	15.4	4.69	0.52	2.45
17	18	29.5	55	3.1	7.8	20.5	5.61	0.54	3.05
18	18	29.5	56	2.9	7.7	20.3	5.42	0.57	3.07
19	15	28	59	2.9	8.1	20.9	5.16	0.59	3.03
20	16	28.2	66	2.6	8	20.7	4.8	0.61	2.93
21	17	30	62	3.1	9.9	23.5	5.73	0.63	3.62
22	17.5	28	64	3	8.8	21.9	5.16	0.65	3.37
23	15.5	27.2	75	2.9	5.8	17.6	4.05	0.68	2.74
24	16.5	29.5	63	3.1	9.7	23.2	5.56	0.70	3.88
25	16	27	72	2.8	5.8	17.6	4.15	0.72	2.99
26	17.2	29.5	63	3.1	9.9	23.5	5.61	0.74	4.16
27	16.5	29	60	3.2	5.5	17.1	4.94	0.76	3.77
28	17	29.5	59	4	7.7	20.4	5.75	0.79	4.52
29	17.5	28.5	66	4	6.9	19.2	5.12	0.81	4.14
30	14.5	21	83	2.7	1.5	11.3	2.47	0.83	2.05
31	16	27.2	69	3.9	8.9	22.1	5.09	0.85	4.32
32	17	26	74	2.9	5.7	17.5	3.99	0.87	3.49
33	16.5	25	78	2.8	4.8	16.2	3.55	0.90	3.18
34	16	27	68	3.4	8.5	21.6	4.93	0.92	4.53
35	16.5	28	66	3.4	7.5	20.1	4.98	0.94	4.68
36	15	22	84	2.6	0.2	9.4	2.27	0.96	2.18
37	16	27.5	67	3.2	8.8	22.1	5.05	0.98	4.96
38	16.5	28	65	3.5	9.5	23.1	5.41	1.01	5.44
39	17.5	28.5	63	3.4	8.9	22.2	5.45	1.03	5.60
40	15.5	23.5	81	2.7	4.6	15.9	3.27	1.05	3.43
41	16	26.2	75	1.9	5.7	17.6	3.77	1.05	3.96
42	16.5	29	69	2.5	9.1	22.6	5.03	1.05	5.28

43	16.5	27.2	68	3.1	9.5	23.2	5.1	1.05	5.36
44	16	22.5	82	2.1	1.4	11.2	2.54	1.05	2.67
45	16.5	27	69	2.6	9.2	22.8	4.87	1.05	5.11
46	15	27	65	3	8.9	22.4	5.03	1.05	5.28
47	16.5	27.5	66	2.8	6.8	19.3	4.65	1.05	4.88
48	16	27	68	2.6	6.6	19	4.42	1.05	4.64
49	16.5	27.2	70	2.1	7.3	20.1	4.38	1.05	4.60
50	16	28	68	2.4	9.9	23.9	5.09	1.05	5.34
51	17	28.5	62	2.7	8.9	22.5	5.28	1.05	5.54
52	15.5	29	63	2.4	9.1	22.8	5.2	1.05	5.46
53	14	29	64	1.7	10.6	25.1	5.16	1.05	5.42
54	16	27.5	68	2.1	8	21.2	4.6	1.05	4.83
55	15	29.2	67	1.4	8.3	21.7	4.58	1.05	4.81
56	17	29	70	1.8	6.6	19.1	4.32	1.05	4.54
57	15.6	28.5	71	2.3	9.4	23.3	4.95	1.05	5.20
58	16	24.8	80	1.1	2.5	13	2.8	1.05	2.94
59	16	28	71	2.4	10.5	25	5.15	1.05	5.41
60	16.6	26.5	72	2.2	6.9	19.7	4.25	1.05	4.46
61	16	27.5	67	2.4	11.1	26	5.34	1.05	5.61
62	16	29	60	2.5	10.4	25	5.62	1.05	5.90
63	16.2	29	69	1.6	6.5	19.1	4.28	1.05	4.49
64	15.6	25	62	1.4	3.6	14.7	3.47	1.05	3.64
65	16	26	70	1.9	6.7	19.4	4.15	1.05	4.36
66	15.5	26.5	66	2.7	9.6	23.8	5.06	1.04	5.24
67	16	26.8	67	3.1	6	18.4	4.53	1.02	4.62
68	17.2	27	66	2.5	7.4	20.5	4.7	1.01	4.72
69	17	26	65	2.3	6.1	18.6	4.33	0.99	4.29
70	17	25.2	70	2.6	1.9	12.2	3.39	0.98	3.31
71	16.5	27.2	66	2.6	9.5	23.8	5.14	0.96	4.93
72	15.5	26	69	2.4	8.3	22	4.61	0.95	4.36
73	15.5	26.5	71	2.6	7.5	20.8	4.5	0.93	4.19
74	16.2	28	69	2.5	10.2	24.9	5.24	0.92	4.79
75	15.5	28	66	2.6	7.8	21.3	4.89	0.90	4.40
76	15	26	75	2	5.6	17.9	3.82	0.90	3.44
77	15	26	76	2.2	8.4	22.2	4.39	0.90	3.95

Source: MARC Note: ETc=ETo*kc

Appendix Table 7.5 Analysis of variance /ANOVA for 50% Days to Flower

Source	DF	SS	MS	F	P
Rep	2	27.722	13.8611		
Main plot	2	9.556	4.7778	0.9	0.4762 NS
Error Rep*Mplot	4	21.278	5.3194		
Subplot	3	54.083	18.0278	8.18	0.0012**
Main plot x Subplot	6	26	4.3333	1.97	0.1244 NS
Error Rep*Mplot*Subplot	18	39.667	2.2037		
Total	35	178.306			

***** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.6 Analysis of variance /ANOVA for 50% Days to Maturity

Source	DF	SS	MS	F	P
Rep	2	15.389	7.6944		
Main plot	2	6.222	3.1111	0.91	0.471 NS
Error Rep*Mplot	4	13.611	3.4028		
Subplot	3	55.194	18.3981	7.15	0.0023**
Main plot x Subplot	6	22.222	3.7037	1.44	0.2544 NS
Error Rep*Mplot*Subplot	18	46.333	2.5741		
Total	35	158.972			

***** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.7 Analysis of variance /ANOVA for height

Source	DF	SS	MS	F	P
Rep	2	44.282	22.141		
Main plot	2	93.229	46.614	4.53	0.0938 NS
Error Rep*Mplot	4	41.171	10.293		
Subplot	3	351.968	117.323	11.24	0.0002**
Main plot x Subplot	6	53.509	8.918	0.85	0.5457 NS
Error Rep*Mplot*Subplot	18	187.853	10.436		
Total	35	772.012			

***** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.8 Analysis of variance /ANOVA for biomass

Source	DF	SS	MS	F	P
Rep	2	0.6667	0.33333		
Main plot	2	8.1667	4.08333	4.45	0.096 NS
Error Rep*Mplot	4	3.6667	0.91667		
Subplot	3	6.7778	2.25926	4.88	0.0118*
Main plot x Subplot	6	1.3889	0.23148	0.5	0.8002 NS
Error Rep*Mplot*Subplot	18	8.3333	0.46296		
Total	35	29			

**** Significant (p<0.05) and NS Not significant***

Appendix Table 7.9 Analysis of variance /ANOVA for Pod Length

Source	DF	SS	MS	F	P
Rep	2	7.0556	3.52778		
Main plot	2	8.7222	4.36111	8.26	0.0380*
Error Rep*Mplot	4	2.1111	0.52778		
Subplot	3	25.4167	8.47222	5.41	0.0078**
Main plot x Subplot	6	6.1667	1.02778	0.66	0.6848 NS
Error Rep*Mplot*Subplot	18	28.1667	1.56481		
Total	35	77.6389			

**** Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.10 Analysis of variance /ANOVA for pod diameter

Source	DF	SS	MS	F	P
Rep	2	1.6939	0.84694		
Main plot	2	1.3539	0.67694	0.79	0.5154 NS
Error Rep*Mplot	4	3.4461	0.86153		
Subplot	3	0.7322	0.24407	0.17	0.917 NS
Main plot x Subplot	6	9.5261	1.58769	1.09	0.4059 NS
Error Rep*Mplot*Subplot	18	26.2467	1.45815		
Total	35	42.9989			

NS Not significant

Appendix Table 7.11 Analysis of variance /ANOVA for yield

Source	DF	SS	MS	F	P
Rep	2	1.272	0.6358		
Main plot	2	36.372	18.1858	7.11	0.0482*
Error Rep*Mplot	4	10.237	2.5592		
Subplot	3	109.828	36.6092	60.69	0.0001**
Main plot x Subplot	6	6.122	1.0203	1.69	0.1805 NS
Error Rep*Mplot*Subplot	18	10.858	0.6032		
Total	35	174.688			

**** Significant (p<0.05), ** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.12 Analysis of variance /ANOVA for unmarketable yield

Source	DF	SS	MS	F	P
Rep	2	2.5667	1.2834		
Main plot	2	22.1318	11.0659	34.03	0.0031**
Error Rep*Mplot	4	1.3006	0.3252		
Subplot	3	2.7021	0.9007	1.62	0.2195 NS
Main plot x Subplot	6	6.0905	1.0151	1.83	0.1501NS
ErrorRep*Mplot*Subplot	18	9.9982	0.5555		
Total	35	44.7898			

***** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.13 Analysis of variance /ANOVA for Number of pod per five plant

Source	DF	SS	MS	F	P
Rep	2	67.17	33.583		
Main plot	2	2.69	1.343	0.03	0.9666 NS
Error Rep*Mplot	4	156.95	39.237		
Subplot	3	584.41	194.804	13.06	0.0001**
Main plot x Subplot	6	41.39	6.899	0.46	0.8269 NS
Error Rep*Mplot*Subplot	18	268.55	14.92		
Total	35	1121.16			

***** Highly Significant (p<0.01) and NS Not significant***

Appendix Table 7.14 Analysis of variance /ANOVA for CWUE

Source	DF	SS	MS	F	P
Rep	2	0.2395	0.1198		
Main plot	2	61.9382	30.9691	47.3	0.0016**
Error Rep*Mplot	4	2.6188	0.6547		
Subplot	3	7.837	2.6123	26.42	0.0001**
Main plot x Subplot	6	2.1575	0.3596	3.64	0.0153*
Error Rep*Mplot*Subplot	18	1.7795	0.0989		
Total	35	76.5705			

**** Significant (p<0.05), ** Highly Significant (p<0.01)***

Appendix Table 7.15 Yield response factor to irrigation levels and irrigation systems

	Treatments	Ym(kg/ha)	ETm(mm)	Ya(kg/ha)	ETa(mm)	ky
DPI	100%ETc	18833	230.85	18833	230.85	
	80%ETc	18833	230.85	16767	202.58	0.90
	60%ETc	18833	230.85	15100	174.31	0.81
	40%ETc	18833	230.85	14033	146.04	0.69
CFI	100%ETc	17330	346.5	17330	346.5	
	80%ETc	17330	346.5	15000	295.1	0.91
	60%ETc	17330	346.5	14233	243.7	0.60
	40%ETc	17330	346.5	12000	192.3	0.69
AFI	100%ETc	17330	346.5	15330	218	0.31
	80%ETc	17330	346.5	14667	192.3	0.35
	60%ETc	17330	346.5	14000	166.6	0.37
	40%ETc	17330	346.5	11000	140.9	0.62

Appendix B. Figures

Appendix Figure 7.1 During land preparation and soil sampling

Appendix Figure 7.2 Furrow and drip preparation

Appendix Figure 7.3 Field management and data collecting

Appendix Figure 7.4 Crop height measurment and field view

Appendix Figure 7.5 Data collection