EFFECTS OF WATER DEFICIT ON THE YIELD RESPONSES OF COMMON BEAN (Phaseolus Vulgaris L.) UNDER DRIP IRRIGATION SYSTEM IN MIZAN-AMAN SOUTHWEST, ETHIOPIA

M.Sc THESIS

AMBACHEW ASNAKE MULUNEH

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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AMBACHEW ASNAKE MULUNEH

ADVISOR: SHEMELIES ASSEFFA (PhD)

CO-ADVISOR: TEWODROS ASSEFA (PhD)

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We, the undersigned, members of the Board of Examiners of the final open defense by **Ambachew Asnake Muluneh** have read and evaluated his thesis entitled “**EFFECTS OF WATER DEFICIT ON THE YIELD RESPONSES OF COMMON BEAN (*Phaseolus Vulgaris L.)* UNDER DRIP IRRIGATION SYSTEM’** and examined the candidate’s oral presentation. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree master’s of Irrigation and Drainage Engineering.

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ABBREVIATION AND ACRONYMS

ATVET	Agricultural Technical Vocational Educational and Training
CU	Christiansen Uniformity Coefficient
DI	Deficit irrigation
DU	Distribution Uniformity
E	Evaporation
EC	Electrical Conductivity
ETc	Crop evapotranspiration
ETo	Potential evapotranspiration
FAO	Food and Agriculture Organization
FC	Field capacity
GC	Ground canopy Cover
gm	gram
ha	hectare
Kg/ha	Kilo gram per Hectare
Ky	yield response factor
LSD	Least Significant Difference
m.a.s.l	Meter above Sea Level
Mha	million hectares
MoARD	Ministry of Agricultural and Rural Development
Nᴏ̱	Number
NPS	Nitrogen, Phosphorus and Sulfur
PH	Potential of Hydrogen concentration

PWP	Permanent wilting point
RAW	Readily available water
RCBD	Randomized complete block design
RMSE	Root Mean Squared Error
SNNPRS	South Nation’s Nationalities and Peoples of Regional State
TAW	Total available water
Tr	Transpiration
TSP	Triple Super Phosphate
WP	Water Productivity
WUE	Water use efficiency

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ABSTRACT

Deficit irrigation consists in deliberately applying irrigation depths smaller than those required to satisfy the crop water requirements, thus affecting evapotranspiration and yields, but keeping a positive return from the irrigated crop. Deficit irrigation with low cost drip irrigation system is likely to be widely adopted by small-scale farmers to apply irrigation water efficiently and economically. This experiment was conducted at Mizan-Aman Southwest, Ethiopia to investigate the effect of deficit irrigation on water use efficiency and yield response of common bean (Phaseolus vulgaris L.) under drip irrigation system. Five level of irrigation water application were used as treatments in randomized complete block design with three replications. The first treatment T1 was 100% irrigation water application which was used as a control. The second, third, fourth and fifth treatments were given 80%, 60%, 40% and 20% irrigation water application respectively, as deficit irrigation treatments. Deficit irrigation practice was applied after the first growth stage and continued for the whole growth season. Data were collected on agronomic parameters, days to 50% emergence, days to 100% ground cover, days to 50% flowering, number of nodules per plant, number of branches per plant, plant height, number of pods per plant, number of seeds per pod and hundred seed weight to evaluate the effects of deficit irrigation water on yield, yield components and productivity of common bean; level of significance of $P \leq 0.05$*. The result showed that the highest yield was found under T1 (3.49 ton/ha). Applying 80% irrigation water application (T2), lead to saved 17.60% of the irrigation water and reduced the total yield by 10.13%,; applying 60 % irrigation water application (T3) lead to saved 35.21% of the irrigation water and reduced the total yield by 12.59%; applying 40 % irrigation water application (T4) lead to saved 52.81% of the irrigation water and reduced the total yield by 49.37% whereas applying 20% irrigation water application (T5) lead to saved 70.42% of the irrigation water which produced 31.58% of the total yield. The result showed that applying deficit irrigation water up to 40% (i.e. greater than 60% irrigation water application) during the growing season except first growth stage has no significant effect on productivity of common bean production but applying deficit irrigation water greater than this percent considerably reduced its productivity. Furthermore, it is recommended that these results are from only one season at one site; thus, such studies require to be repeated in space and time to put the recommendation on strong basis.*

Keywords: Common bean yield; deficit irrigation; drip irrigation; soil moisture.

1. INTRODUCTION

1.1 Background

Water is becoming scarce, both in quantity and quality, not only in traditionally prone arid and semi-arid zones, but also in regions where rainfall is abundant. Agriculture represents the major user worldwide, and a general perception that agricultural water use is often wasteful. Furthermore, energy analysis of agricultural operations has shown that irrigation consumes a significant amount of energy as compared to other operations (Topak *et al.* 2005). For these reasons, there is an urgent need to use water resources efficiently by enhancing crop water productivity (Capra *et al.* 2008).

Ethiopia is blessed with ample water resources in central, western and south western parts, while most of North Eastern and Eastern parts of the country are relatively dry. The distribution and availability of water is erratic both in space and time. Hence, despite abundance in some parts the country is highly water-scarce due to lack of water control infrastructure (Awulachew *et al.* 2007). Ethiopia has an irrigation potential of 5.3 Mha of which 3.7 Mha can be developed using surface water sources, and 1.6 Mha using groundwater and rainwater management. Irrigation contributes to rapid transformation of agriculture as present-day agriculture is dominated by rainfed single crops. The current irrigation development in Ethiopia is about 0.7 Mha, and the performance of the existing schemes is not well understood. Irrigation schemes in Ethiopia are not functioning at their optimal capacity (Awulachew and Ayana 2011). Irrigation systems reduce risks of low profitability from low yields and crop stress. Drip irrigation, essential for producing many specialty crops, is used throughout the state on farms of all sizes (Brent 2017).

Deficit irrigation was proposed long time ago as a technique that irrigates the entire root zone with less evapotranspiration and leads to reduce the irrigation water use with maintaining farmers' net profits (Hoffman *et al.* 1990). The decline in water availability for irrigation and the positive results obtained in some fruit tree crops have renewed the interest in developing information on deficit irrigation for a variety of crops (Dorji *et al.* 2005).

Deficit irrigation is performed differently from supplementary irrigation, as in deficit irrigation we reduce depth of application while irrigation frequency is maintained. Supplementary irrigation aims at meeting crop water requirements during critical development stages without natural precipitation (Zhang *et al.* 2006). Deficit irrigation consists in deliberately applying irrigation depths smaller than those required to satisfy the crop water requirements, thus affecting evapotranspiration and yields, but keeping a positive return from the irrigated crop (Kang *et al.* 2000). However, impacts of irrigation deficits on yields and related economic results may or not be negative, depending upon the adopted irrigation scheduling, irrigation performance, production costs and yield values (Lorite *et al.* 2007).

With drip irrigation systems, water and nutrients can be applied directly to the crop at the root zone, having positive effects on yield and increasing the irrigation performance by water savings and several other associated benefits. Irrigation system is one of the important components of farming system affecting the yield and quality of agricultural produce. Water should be applied in proper amount and at accurate time. Therefore, water management is a key to avoid plant moisture stress during the crop growth stages (Salokhe *et al.* 2005).

Drip irrigation provides the most efficient way to conserve irrigation water, but its cost of $1000 an acre is prohibitive for most small farmers in developing countries. In the case of the low cost drip irrigation system, farmers who are very poor can optimize divisibility and reduce the capital cost of the system further by using only one drip line and moving it more frequently. They can use the income generated by the system to add more drip lines in subsequent growing seasons. In areas with a high concentration of small farmer operations and a scarcity of water, the low cost drip system will provide access to water saving irrigation technology which is affordable on a small scale and divisible. The low cost drip system is likely to be particularly applicable to areas of the world where both water and crops have relatively high value, and where the high capital cost of existing drip irrigation technology constitutes a significant barrier to its adoption (Paul *et al.* 1997).

Common Bean (*Phaseolus vulgaris L.*) was originated in Tropical America (Mexico, Guatemala, and Peru), but there are also evidences for its multiple domestication within Central America (Kay 1979). Common Bean is the most important food legume worldwide, providing the chief source of dietary protein for more than 300 million people (CIAT 2001). It was most likely introduced to Ethiopia by the Portuguese in the 16th century (Wortmann and Eledu 1997). It is also widely grown in Ethiopia and is an increasingly important commodity in the cropping systems of smallholder farmers for food security and income generation. Major common bean producing regions are central, eastern, and southern parts of the country and in central Ethiopia (CSA 2005). The most common bean producing areas in the southern zone includes Gamo Goffa, Sidamo and Wolaita (Gemechu Gedeno, 1990).

Farmers grow a wide range of bean types, in terms of color and size, but the most common types are the pure red and white beans. Most of the beans produced, traded and consumed in the domestic Ethiopian bean markets, are the medium and small red beans whereas white beans are virtually all exported. These market types of beans are a valued source of foreign exchange with an annual value in the range of USD 25-30 million (Ferris and Kaganzi 2008).

Despite the economic and food security importance of these crops, actual smallholder farm yields are by far below the potential production. As reported CSA (2016) the current national production of common bean in Ethiopia is estimated at 673,848 hectares; with a total production of 845117 tons and average productivity of 1.25 tons per hectare, while the potential yield at research stations and researcher managed farmers' field is 3.4 t/ha (CVR 2012). The purpose of this study were to improve WUE, production and productivity by saving scarce water resources and to fill the gap of application of the right amount of irrigation water on common bean production in Mizan-Aman, Southwest, Ethiopia.

1.2 Statement of the problem

Increasing water use efficiency is one of the main strategic goals for worldwide researchers as well as decision makers due to water scarcity and continuing high demand of water for agricultural irrigation. With the low efficiency of irrigation water utilization, water requirement increase by 50% and this additional requirement of water could be met by increasing the effectiveness of irrigation. However, irrigation for agricultural uses over 70% of the world clean water and most of which is specially used in the protected environment (Ismail and Razi 2002). Understanding the behavior of every crop, regarding different amounts of applied water, is absolutely necessary to determine when lack or excess of water may cause production failure, thus enabling appropriate irrigation management is must (Bernardo *et al.* 2006).

It is necessary to optimize water use in order to maximize crop yields under water deficit conditions (Fereres and Soriano 2006). A recent innovative approach to save agricultural water is deficit irrigation (DI). DI practice is technique of withholding or reducing the amount of water applied per irrigation at some stages of the crop growth with the aim of saving water, labor, and in some cases energy. It consist deliberately applying irrigation depths smaller than the required to satisfy the crop water requirements, thus affecting evapotranspiration and yields, but keeping a positive return from the irrigated crop (Kang *et al.* 2000). The expectation is that any yield reduction will be insignificant compared with the benefits that are gained from the conservation of water.

Generally, the amount of water available for agriculture is limited overall the world, knowledge about the relationship between yield and quality of the product and irrigation regimes is important to maximize the benefit of the available water supply. To use this limited water efficiently, deficit irrigation method is preferable which is potentially able to improve water use efficiency. This study was intended to evaluate the effect of different level of irrigation water application and to determine the adequate quantity of water for common bean under low cost drip irrigation system in Mizan-Aman Southwest, Ethiopia.

1.3 Objectives of the study

1.3.1 General objective

The general objective of the study was to evaluate the yield response of common bean (*Phaseolus vulgaris L.*) crop to different levels of deficit water application under drip irrigation system at Mizan-Aman, Southwest Ethiopia.

1.3.2 Specific objectives

The specific objectives of the study were:

- To evaluate influence of different levels of irrigation water applications on growth characteristics of common bean.
- To evaluate the yield and yield components and productivity of common bean to different irrigation water application levels.
- To determine optimum irrigation level of common bean by considering different levels of water application.

1.4 Research questions

The research questions that will lead to the achievement of the formulated objectives of this study were:

- What is the response of the growth characteristics (days to 100% ground cover, days to 50% flowering, number of nodules, number of branches per plant, plant height, number of pods per plant , number of seeds per pod and hundred seed weight) of common bean for different level of irrigation water supply?

- What are the yield response, water productivity and land productivity for different levels of irrigation water application?
- How much is the optimum irrigation water of common bean?

1.5 Significance of the study

The study was mainly give emphasis on the impact of water application on the yield of common bean. As a result, the output of this research will play a vital role on to what extent to diminish the amount of water to be applied in the production of common bean without having a significant yield reduction. Beside this, smallholder farmers, investors and institutions will be benefited due to determined delta of common bean, and the researcher hope that this research will be a benchmark for other researchers for future to improve and establish water saving strategies using other crop types for the country, for the globe.

1.6 Scope of the study

Common bean cultivation may have different yield reducing factors, like variety, spacing, water quality, quantity of water applied, methods of water supply, disease, use of fertilizers etc. For this research, the researcher mainly focused on the yield response relative to different level of irrigation water application.

The experiment was undertaken using five levels of water applications (treatments) with three replications. Those were irrigation water application level of 100%, 80%, 60%, 40% and 20% of irrigation water requirement. To apply this amount of water on the experimentation process low cost drip irrigation system was employed and the water to be applied was measured & controlled for each treatment. The study realized the influences on the growing characteristics of common bean, irrigation water productivity, land productivity for the given treatments, and the general yield response of common bean production under deficit irrigation.

2. LITERATURE REVIEW

2.1 Irrigation

Irrigation can be defined as an artificial application of water to soil for the purpose of supplying the moisture essential in the plant root-zone to prevent stress that may cause reduced yield and/or poor quality of harvest of crops (Reddy 2010). Irrigation development is vital to the sustainable and reliable agricultural developments in Ethiopia. Subsistence dominated smallholder farmers' economy can be improved through the use of irrigation in the Ethiopian agriculture (MoA 2011b).

Irrigation development in Ethiopia can be considered as a cornerstone of food security and poverty reduction tool as it has a power to stimulate economic growth and rural developments (Hagos *et al.* 2009). Irrigation was practiced during ancient times in Ethiopia even if its exact date of emergence is unknown. Ancient use of irrigation water was through use of surface irrigation methods and spate irrigation types. Modern irrigation was started at the Awash River basin with bilateral cooperation of Ethiopia and Dutch company. This was started during the 1950s for the productions of commercial crops such as sugar cane and cotton. Irrigation of these crops was applied by surface irrigation methods and less efficient pressurized irrigation systems. Irrigation (Small-scale irrigation systems) schemes by governments, donors and NGOs (Haile and Kasa 2015).

Irrigation is believed as a key for food security and poverty reduction in Ethiopia. As a result, developments in the Ethiopian irrigation system have shown great advancements so as to assure Ethiopian livelihoods especially in the rural areas. However, the contribution of irrigation to the national economy as compared to its potentials is non-negligible. This indicates more investments on the area have paramount importance for the development of the country. Generally, the government and peoples of Ethiopia believes that irrigation can play a significant role for food security enhancement and economic growth. Therefore, intensive investments should be operated in the sector by governmental, nongovernmental and privates investors (Haile and Kasa 2015).

2.1.1 Importance of irrigation

Nata and Asmelash (2007) and Abraham *et al.* (2011) listed out the benefits of irrigation that includes; increase food production in arid and semi-arid regions, enhances food production, promotes economic growth and sustainable development, create employment opportunities, and improve living conditions of small-scale farmers. As a result, irrigation contributes to poverty reduction and protects the environment from degradation and pollution. Furthermore, it increases subsurface water levels and recharges groundwater. As a result, small, medium and large scale irrigation infrastructure needs to be developed in the country. This helps to produce export commodities that would earn foreign exchanges and provides raw materials to the local industries. Since, most of the irrigation development in Ethiopia is expressed through an expansion of small-scale irrigations. Medium and large scale irrigation developments are needed to be taken into consideration.

On the other way, irrigation development in Ethiopia is in its infancy stage (MoA 2011a). The Ethiopian government is therefore pursuing plans and programs to develop irrigation in an effort to substantially reduce poverty and create an atmosphere for social change. As a result, the Ethiopian average rate of irrigation development for the last 12 years was about 1,090-1,150 ha/year (Bekele *et al.* 2012).

In Ethiopia, 2% of cultivated lands are irrigated as stated by MoWR (2001) and only 10% of the estimated potential irrigable land is actually irrigated (Gebremedhin and Peden

2002). Similarly, irrigated agriculture comprises only 3% of the total national food production (Bacha et al., 2011). That is why; irrigated agriculture is far from satisfactory despite of considerable investment, public interest, and strategic support of the government.

2.1.2 Deficit irrigation

The concept of deficit irrigation (DI) was born in the 1970s. In 1971, James et al (1971) used the term DI in a book on the economics of water resource planning, and the first research into DI appeared in the early ’80s (English and Nuss 1982).

Deficit irrigation is an optimization strategy whereby net returns are maximized by reducing the amount of irrigation water; crops are deliberately allowed to sustain some degree of water deficit and yield reduction. Although the DI concept dates from the 1970s, this technique is not usually adopted as a practical alternative to full irrigation by either academics or practitioners. There are several obstacles hindering application of the technique: it involves the use of precision irrigation; the knowledge required spans a wide range of disciplines; the strategy involves risks associated with the uncertainty of the knowledge required; there is a need to convince farmers and irrigation practitioners not only of the economic value of DI but also of its practicability (Capra *et al.* 2008). The positive effects are mostly evidenced when the economics of DI is included in the research approach and when the application concerns planning purposes over large areas.

2.1.3 Experiences with deficit irrigation

Scientists affiliated with the Agricultural Research Service (ARS) of the USDA found that conserving water by forcing drought (or deficit irrigation) on peanut plants early in the growing season has shown to cause early maturation of the plant yet still maintain enough yield of the crop (English 1990). Inducing drought through deficit irrigation earlier in the season caused the peanut plants to physiologically "learn" how to adapt to a stressful drought environment, making the plants better able to cope with drought that commonly occurs later in the growing season. Deficit irrigation is beneficial for the farmers because it reduces the cost of water and prevents a loss of crop yield (for certain crops) later in the growing season due to drought. In addition to these findings, ARS scientists suggest that deficit irrigation accompanied with conservation tillage would greatly reduce the peanut crop water requirement (USDA 2010).

The correct application of DI requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest (English 1990). The saved water can be used for other purposes or to irrigate extra units of land and deficit irrigation is sometimes referred to as incomplete supplemental irrigation or regulated deficit irrigation (Kipkorir *et al.* 2001). In regions where water resources are restrictive, it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land (Fereres and Soriano 2006).

For certain crops, experiments confirm that DI can increase water use efficiency without severe yield reductions. For example, for winter wheat in Turkey, planned DI increased yields by 65% as compared to winter wheat under rain fed cultivation and had double the water use efficiency as compared to rain fed and fully irrigated winter wheat (Ilbeyi *et al.* 2006). Experiments in Turkey and India indicated that the irrigation water use for cotton could be reduced to up to 60% of the total crop water requirement with limited yield losses. In this way, high water productivity and a better nutrient-water balance was obtained.

Certain underutilized and horticultural crops also respond favorably to DI, such as tested at experimental and farmer level for the crop quinoa (Geerts *et al.* 2008). Yields could be stabilized at around 1.6 tons per hectare by supplementing irrigation water if rainwater was lacking during the plant establishment and reproductive stages. Applying irrigation water throughout the whole season (full irrigation) reduced the water productivity. Also, in viticulture and fruit tree cultivation, DI is practiced (Spreer *et al.* 2009).

Nigus Demelash (2013), in North Gondar, Ethiopia, recommended that applying irrigation water 75% of full irrigation depth throughout the whole growing season of potato resulted better yield, saved significant depth of water and improved WUE which can be taken as optimum irrigation depth and frequency.

2.2 Soil moisture depletion and rooting depth

2.2.1 Soil moisture content

Knowledge of volumetric soil moisture content is an important input into the soil water balance models. In the soil, water moves continuously in the direction of decreasing potential energy or from higher water content to lower water content. Field capacity (FC) is the amount of water a well-drained soil holds after free water has drained because of gravity. Above field capacity, the gravitational force will overcome the capillary forces suspending the moisture in the pore of the soil, allowing for downward movement of water in the soil column. Permanent wilting point (PWP) is the soil water content at which most plants cannot obtain sufficient water to prevent permanent tissue damage. The lower limit to the available water capacity has been reached for a given plant when it has so exhausted the soil moisture around its roots as to have irrecoverable tissue damage, thus yield and biomass are severely and permanently affected. The water content in the soil is then said to be the permanent wilting percentage for the plant concerned. Soil textural classes greatly influence FC and PWP. Fine textured soils generally hold more water than coarse textured soils. Medium textured soils actually have more available water for plant use than some clay soils. Water in clay soils can be held at a greater tension that reduces its availability to plants (Ross and Hardy 1997).

An important factor for quantifying the soil moisture balance is the evapotranspiration rate (ET). Evapotranspiration is the water that is transpiring out of the soil by the plant and the amount of water lost to evaporation. ET represents the rate of water consumed by the plant and lost by direct evaporation. The factors that affect the ET rate include wind, temperature, relative humidity, and solar radiation. Based on the Penman Monteith model for ET estimations, ET is not measured straight for an individual crop, but rather it is determined from a standard reference grass and then adjusted for different crops and plants with a crop coefficient (Allen *et al.* 1998b; Peres *et al.* 1998).

2.2.2 Soil moisture measurement techniques

One method that is commonly used to determine when to irrigate is to follow soil moisture depletion. As a plant grows, it uses up the water within the soil profile of its root zone. As the water is being used by the plants, the moisture in the soil eventually reaches a level at which irrigation is required or else the plant will experience stress. If water is not applied, the plant will continue to use what little water is left until it finally uses all the available water in the soil and dies. When the soil profile is full of water, reaching what is called field capacity (FC), the profile is said to be at 100% moisture content or at about 0.1 bars of tension. Tension is a measurement of how tightly the soil particles hold onto water molecules in the soil. The tighter the soil to hold water, the higher will be the tension. At FC, with a tension of only 0.1 bars, the water is not being held very tightly and it is easy for plants to extract water from the soil. As the water is used up by the plants, the tension in the soil increases as stated by (Jensen *et al.* 1990; NRSC 1997a).

The plants will use the water in the soil until the moisture level goes to the PWP. Once the soil dries down to the PWP, plants can no longer extract water from the soil and the plants die. Although there is still some moisture in the soil below the PWP, this water is held so tightly by the soil particles that it cannot be extracted by the plant roots. The PWP occurs at different moisture levels depending on the plant and soil type. Some plants, which are adapted to arid conditions, can survive with very little moisture in the soil (USDA 1997).

2.2.3. Allowable depletion of soil moisture for common bean

Allowable depletion (readily available water) is the amount of water the plant can use from the total available water before experiencing drought stress. Readily available water is the water that a plant can easily extract from the soil. RAW is the soil moisture held between field capacity and a nominated refill point for unrestricted growth (Richards and Wadleigh 1952). Management allowable depletion (MAD): Maximum amount of soil water the irrigation manager allows the crop to extract from the active rooting zone between irrigations. This amount can vary with crop, stage of growth, potential for rainfall, and the soil’s water holding capacity (Hansen *et al.* 1980).

As stated by Admasu Robel *et al.* 2019, the magnitude of Ky value indicates the sensitivity of the irrigation protocol for water deficit and subsequent yield decreases. The highest Ky was obtained from irrigating all stage except initial stage followed by irrigating all stage except development and irrigation except initial and development stage. Whereas, the minimum was obtained from irrigating all stage except initial and maturity stage. Development and mid-season stage (flowering and pod setting) is the most sensitive to moisture stress and the water shortage occur at this stage will reduce the yield significantly. Moisture stresses are among rapidly increasing constraints to agricultural production particularly for short season grain legume crops such as common bean. Imposing moisture stress at initial and maturity stage was not significantly reduced the common bean grain yields and dry biomass yield production.

The bulk of irrigation research recommends irrigating row crops such as grain or cotton when the MAD approaches 50%. For vegetable crops, the MAD is usually set at 40% or less, because they are more sensitive to water stress. These deficit amounts assure that water stress will not be so severe as to cause any negative effects, and yet will allow a little "breathing room," in case of a delayed irrigation (Blaney and Criddle 1962). Soil water depletion fraction for no stress for common bean crop is 0.45 (Allen *et al.* 1998a).

2.2.4 Effective rooting depth zone

Common beans have a relatively shallow rooting depth, poor nodulation, require frequent irrigations as stated by Calvache and García (1987) and large supplies of N fertilizers (Calvache *et al.* 1989).

Common beans are sensitive to water stress, especially during the flowering period (Thung 1991). They are also sensitive to excess water and are ideally planted on well-drained soils. The amount of water available to the bean plant is affected by the extent of the root system. The effective root depth of common bean is 30 cm (Carvalho *et al.* 2016).

2.3 Deficit irrigation and common bean yield response

Common bean requires frequent irrigations and soil matric potential of -10 to -30 kPa for optimum growth (Calvache *et al.* 1997). Common bean (Phaseolus vulgaris L.) crop can give yield by applying deficit irrigation up to 25% RAW with combination of 100% RAW by dividing the growing season into two phases: Vegetative stage (from seed germination to the beginning of flowering) and reproductive stage (from the flowering to the last fruit harvesting) while the result was lower than the yields obtained from the control treatments by 41% as stated by (Mehmet *et al.* 2011). They were recommended to growers regulated deficit irrigation regime with 25% deficit at reproductive stage had better results without a significant decrease in the yield in semi arid zone. By considering this, in this experiment, common bean was tested up to 20% of full irrigation to save irrigation water.

Carvalho *et al.* (2016), conducted an experiment on growth and production of common bean in direct seeding under irrigated deficit condition to evaluate different levels of water replacement combined in two periods (2010 and 2011) of the bean cycle with 100, 80, 60 and 40% of crop evapotranspiration (ETc) applied in two phases during the cycle (vegetative – I – from beginning after emergence to flowering, and reproductive –II – from flowering to physiological grain maturity) with drip irrigation system. The result showed that the characteristics, number of nodes per plant, plant height and seed yield were sensitive to water stress. The largest water reductions of the bean cycle in phase I combined with phase II resulted in greater effects on plant height. The higher the water deficit in the reproductive phase, the smaller the grain yield in kg ha-1 is.

Asrat Asfaw *et al.* (2016), evaluate 64 common bean (Phaseolus vulgaris L.) genotypes grown under drought-stress (irrigated when soil moisture was depleted to 30% field capacity) and non-stress condition in Ethiopia and states that most of the genotypes showed adaptation to drought stress by reducing their days to physiological maturity, thereby minimizing the effect of drought and their yield were well under the drought-stressed condition.

Saleh *et al.* (2018), conducted a study in an environmentally controlled greenhouse on the effect of irrigation on growth, yield, and chemical composition to evaluate two green bean cultivars under three application volumes of irrigation water based on replacing 100, 80, and 60% of evapotranspiration (ET). The results showed that there were no differences between 80% ET and 100% ET for most parameters. In addition, 80% of ET increased the pod yield and improved the pod parameters and chemical composition.

Admasu Robel *et al.* (2019), investigated the response of common bean (Phaseolus vulgaris L.) to moisture stress at different growth stages for yield and water productivity under sub-humid climate conditions over a three-year period from 2016 to 2018 by applied irrigation water to refill the crop root zone depth close to field capacity (by irrigating and imposing moisture stress within its crop stage differently). The result showed that the yield of common bean was significantly affected due to moisture stress imposed at different growth stages. Accordingly, the highest was obtained from irrigating all growth stage, followed by irrigating all stage except initial stage. In contrast, imposing moisture stress at three growth stage except initial stage was recorded the lower yield relatively, which followed by irrigating only at maturity stage. The results revealed that water stress imposed at development and mid-season stages reduced the yield significantly.

Deficit irrigation strategy may focus on withholding water supply at early plant growth and maturity stages of common bean. The reduction of grain yield in water stress at development and mid-season stage as compared to the rest treatments may have been attributed to a lower percentage of pods formed due to flower abscission and embryo abortion when drought occurred at flowering and pod filling growth stages. Under limited water condition, it is better to start by subjecting the crops to stress early in the season. By doing so, the crop adapts to limited watering conditions with the stress not being severely concentrated in any one time period (Admasu Robel *et al.* 2019).

Chibarabada *et al.* (2019), were assessed water use and water productivity of selected grain legumes in response to varying irrigation regimes with under rainfed, deficit and optimum irrigation conditions during 2015/16 and 2016/17 with irrigation approach for deficit irrigation (MAD: 20% TAW). The result showed that, for dry bean, early maturity led to low water use and had high harvest index and water productivity.

2.4. Common bean production and its economic importance in Ethiopia

Common bean plays a vital role in reducing blood cholesterol level and combating chronic heart diseases, cancers and diabetics is also gaining recognition from human health point of view (Singh 1999). The world demand for common bean ever increasing because of its significance in human nutrition as a source of proteins, complex carbohydrates, vitamins, and minerals (Bennink 2005). Common bean is the world’s most important food legume. Beans offer a low cost alternative to beef and milk because bean seed is rich in protein, iron, fibres, and complex carbohydrates (Mwale *et al.* 2008).

Currently, common beans cover the dominant part of the Ethiopia’s pulses export. With regard to economic importance of common bean, it is used as a source of foreign currency, food crop, means of employment, source of cash, and plays great role in the farming system (CSA 2005). The country's exports of common beans have increased over the last few years, and Ethiopia earned 63 million dollar from common bean market in 2005 (Legese *et al.* 2006). White beans from the Northern Rift Valley were sold into export markets to supply European canning factories and red Beans were exported from the southern Rift Valley areas to supply drought affected areas in Northern Kenya (Ferris and Robbins 2004).

The common bean is cultivated primarily for dry seeds, green pods (as snap beans), and green-shelled seed. There are wide ranges of common bean types grown in Ethiopia including mottled, red, white and black varieties (Ali *et al.* 2006). The most commercial varieties are pure red and pure white color beans and these are becoming the most commonly grown types with increasing market demand (Ferris and Kaganzi 2008).

The two major common bean producing regions in Ethiopia are Oromia and Southern Nations, Nationalities and People's Region (SNNPR), which produce 70 and 60 thousand tons per year, respectively, and these two regions make up 85% of the total production (CSA 2005). Average national production is approximately 150 thousand tons per annum. The level of production in 2005 was approximately 175 thousand tones with a domestic market value of USD 25- 30 million (Ferris and Kaganzi 2008).

The common bean yield gap is caused by numerous production constraints including decline in soil fertility, rainfall variability, pest pressure, poor agronomic practices, and poor accessibility to good seed (Katungi *et al.* 2010). More recent data showed that the total national production in Ethiopia was estimated to be 845116.905 tons in 2015/2016, on total area of 673,847.61 hectares with average productivity of 1.25 ton/ha (CSA 2016). However, the national average yield is very low, compared to their production potential of 2.5 ton/ha.

3. MATERIAL AND METHODS

3.1 Description of the study area

This experiment was conducted in South Nation's Nationalities and Peoples of Regional State (SNNPRS) at Bench Sheko Zone, Mizan Aman District in Mizan Agricultural Technical Vocational Educational and Training (ATVET) College farm site. The Zone is located 584 km southwest of Addis Ababa and 859 km Hawassa. The geographic location of the study area is located between 6^0 57' 30'' and 7^0 0' 0'' north longitude and between 35^0 30' 0" and 35^0 35' 0" east latitude with an altitude of 1356 m.a.s.l as shown in figure 1.

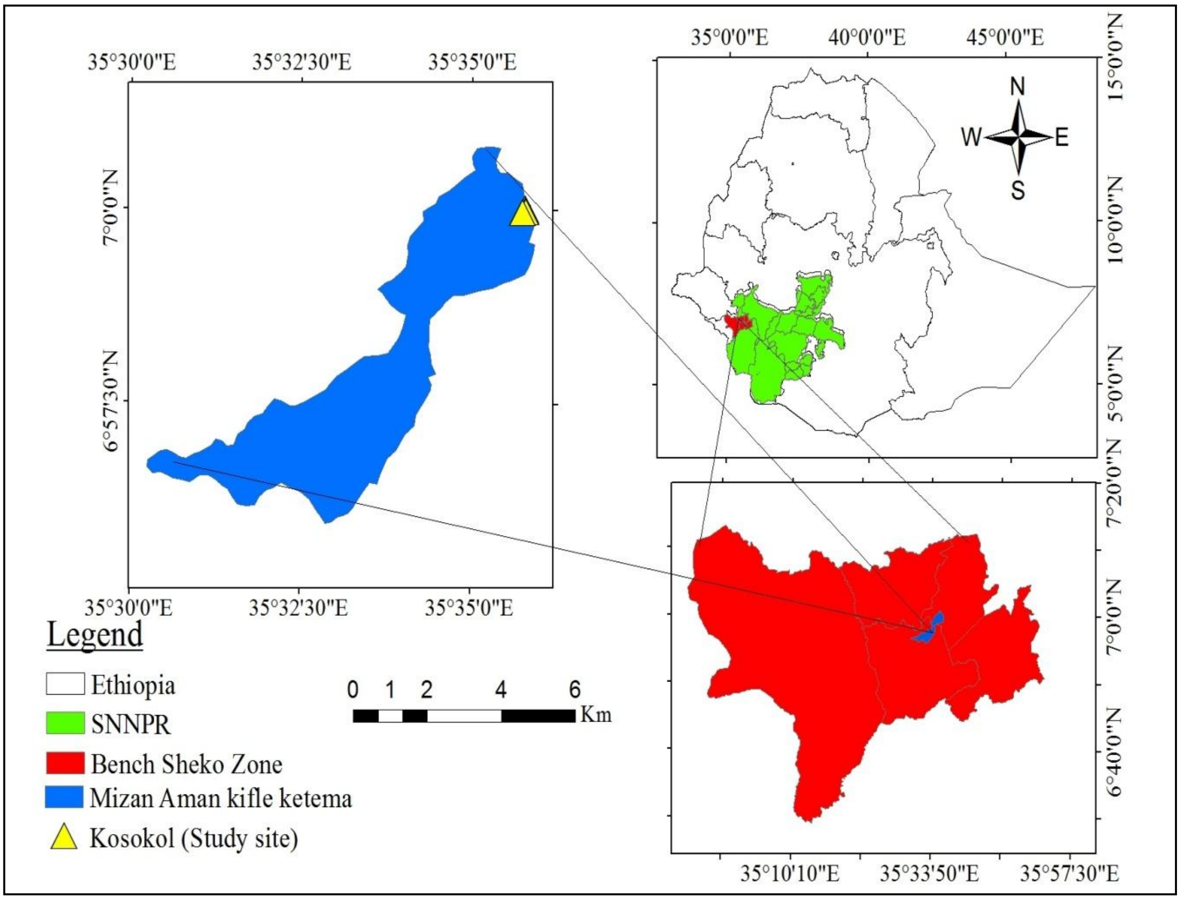

Figure 1: Map of the study area

The total area of the zone is 19326.6 square km, of which 52 %, 43% and 5% are low land (<500m.a.s.l), mid high land (1500m-2400m.a.s.l) and highland (2400m-3200m.a.s.l), respectively. Of the total area mass 47% constitutes sloppy and rugged mountains, 28% hilly and 25% flat. The annual rainfall varies from 1256 to 2000 mm with annual average rain fall is 1546 mm. According to Jimma Meteorological Station, 2012, the average monthly rainfall of the experiment site during the experiment season (from January to March) is 1303.27mm as shown in annex 4. The annual maximum and minimum temperature range from 20^0C to 40^0C with the average annual temperature in Mizan Teferi is 20.5 ^{0}C (MoARD 1998). The average daily room and outside temperature of the experiment site during the experiment season was 26.74 ^{0}C and 24.71 ^{0}C respectively as shown in annex 4.

The major crops growing within the experimental areas are sorghum (Sorghum bicolor), maize (*Zea mays L.*), tef (*Eragrostis tef*), faba beans (*Vicia faba*), common bean (*Phaseolus vulgare*), coffee (*Coffee arabica*), mango (*Mangifera Indica*), banana (*Musa paradisiaca var.sapiertum*) and root crops. The experimental site was selected based upon their relative land area allocated for bean growing, accessibility and engagement for research project.

3.2. Methods of estimating crop water requirement

Crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al.*, 1998).

The depth of irrigation water was calculated as stated by (Rahim *et al.* 2014).

$$Depth\ of\ \text{irrigation water requirement} = Drz * (\Theta FC - \Theta PWP) * Dp \ldots\ldots\ldots\ldots.. (3.1)$$

This gives the depth of the water that applied in millimeter.

Where, Drz is the depth of root zone in cm, and

Dp is depletion point (%).

Based on the field capacity, (FC) and permanent wilting point, (PWP) of the area, available moisture content was computed in mm/cm and the required depth of water was calculated based on the available moisture content and expected depth of root zone. The available moisture content (AMC), was computed by the following relationship:

$$\mathrm{AMC} = (\Theta FC - \Theta PWP) * Dp \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.2)$$

Approximate duration for common bean were 15, 25, 35 & 20 days for initial, development, middle and late growth stage, respectively (Jobe 2019).

3.3 Experimental setup

3.3.1 Crop variety selection

The common bean crop selected for this experiment was Hawasa Dume variety. Reason to select this variety is one of the most important legume crops grown in all continents of the world except Antarctica, because of its high protein, fiber, and complex carbohydrate content. Beans (Phaseolus spp.) are extremely diverse crops in terms of cultivation methods, in diverse environments and elevations ranging from sea level to 3,000m height, morphological variability, and utilities (dry as pulse and green as vegetable). The tremendous variability for plant types and growth behavior makes beans part of the most diverse production systems of the world (Broughton *et al.* 2003).

3.3.2 Soil texture and irrigation water quality

For determination of selected physicho-chemical characteristics of the experimental site, composite (0-30cm depth) top soil sample were taken using a soil auger from research farm site of a rectangular experimental area by diagonal method to analyze soil pH, EC, soil texture, bulk density, organic matter content and soil moisture contents at FC and PWP. These selected physicho-chemical characteristics of the soil were analyzed in Hawassa soil testing Laboratory; whereas depth to groundwater table was tested at field, using auger. The results of these soil characteristics were as shown in table 1 below.

Table 1: Tested and observed values of soil characteristics of the study area

S.N	Soil parameter		Reading	Rating	References
1	Particle Size	Sand (%)	14	Silt loam	USDA, 1987
		Silt (%)	63		
		Clay (%)	23		
2	pH		5.3	Strongly acid	Landon, 1991
3	CEC cmol(+) kg-1		23.6	moderate	Landon, 1991
4	Organic matter content (%)		5.78		
5	Bulk density (g/cm^3)		1.13		
6	Groundwater table depth (m)		>2.5		
7	Soil moisture	FC (volumetric, %)	35.4		
		PWP (volumetric, %)	18.8		

The volumetric water content data was used to compute readily available water holding capacity deficit ranges. Field capacity (FC) and permanent wilting point (PWP) data were used to calculate irrigation requirements and plan irrigation design and scheduling (Rahim *et al.* 2014).

3.3.3 Field preparation and plotting

Any plants and residues were cleared from the field appropriately and layout was prepared as shown in Figure 2. Land leveling was undertaken manually and leveled using water level to have uniform slopes for plots and then plots were prepared based on spacing.

Figure 2: Field preparation and lay outing

3.3.4 Experimental design and treatment combination

The experiment was conducted from January 2020 to March 2020 in randomized complete block design (RCBD) with three replications. Five treatments were randomly arranged in equally sized beds of 1.4m long and 2.4m wide (3.36m^2 plot size), with 0.5m between plots and 2m distance between blocks of area. Each plot has six (6) rows and six (6) laterals (each have 1.4m) and the total area of the experimental field size was (14m*8.2m) 114.8m^2. For this experiment, spacing of plant to plant 10cm and between rows 40cm was used (MoARD 2009). Based on this spacing, one lateral supplied for 14 plants per row, and a plot consists 84 plants and totally of 1260 plants (84 plant/plot * 5 treatment * 3 replications) were used. The treatments were taken as a full irrigation treatment (T1) was given 100% irrigation water application for the whole growing season and considered as control. The second, third, fourth & fifth treatments (T2, T3, T4 and T5) were given 80%, 60%, 40% and 20% of irrigation water application respectively and considered deficit irrigation treatments. As shown in figure 3 below, the field layout for the experimentation was such a like:

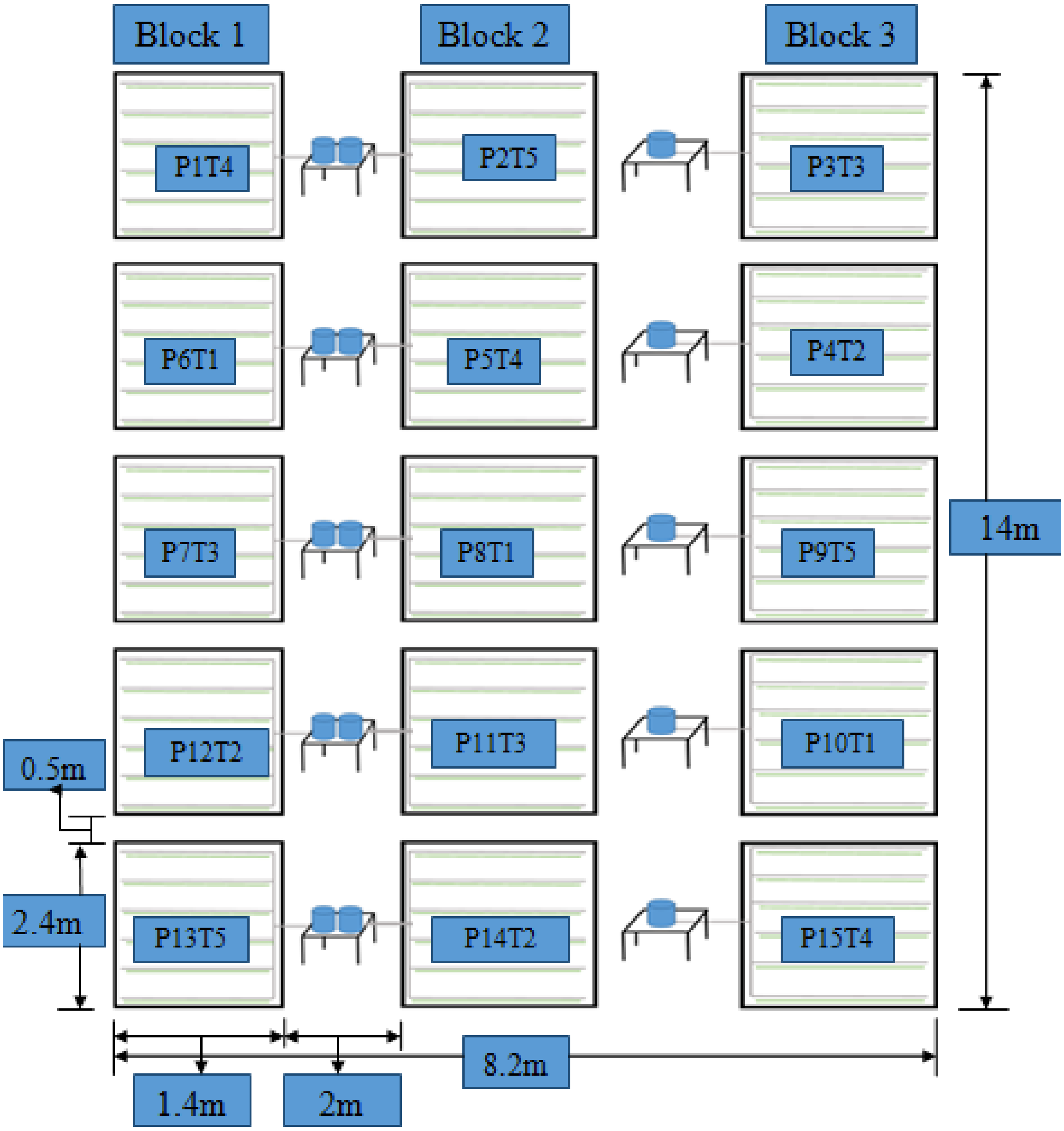

Figure 3: Field layout considering storage positioning

During initial crop growth stage, full supplied irrigation water applications were used for all treatments. After initial stage plants were subjected to the following five irrigation water application treatments as shown in table 2.

Table 2: Description of growth stage with water application level during the experiment

Irrigation applied (%)	Treatment representation	Growth stage and irrigation water applied (%)			
		Initial	Development	Mid-season	Late season
100	T1	100	100	100	100
80	T2	100	80	80	80
60	T3	100	60	60	60
40	T4	100	40	40	40
20	T5	100	20	20	20

As shown in table 3 below, the treatments of the experiment were placed for each plot using a lottery method to assign a treatment for a plot and plots were assigned on rows of blocks consecutively.

Table 3: Treatment & plot allocation

Replication 1	Replication 2	Replication 3
Plot 1 (T4)	Plot 2 (T5)	Plot 3 (T3)
Plot 6 (T1)	Plot 5 (T4)	Plot 4 (T2)
Plot 7 (T3)	Plot 8 (T1)	Plot 9 (T5)
Plot 12 (T2)	Plot 11 (T3)	Plot 10 (T1)
Plot 13 (T5)	Plot 14 (T2)	Plot 15 (T4)

3.3.5 Drip installation

A Low-cost drip irrigation system is a complete drip irrigation unit and operates by water gravity from a tank placed at 1–1.5 meters high. It is a closed piped gravity system, localized method, and solid seasonal installation for growing crops on flat or minor slope land (FAO 2007). A low-cost drip irrigation system was introduced in Mkindo village and tested for its affordability, acceptability, and performance under farmer-managed environment. When integrated with improved crop management practices, low-cost drip irrigation can be a water smart technology compared with conventional drip irrigation (Kahimba *et al.* 2015). For bucket seating, at least 1m above the planting surface is recommended.

For this study during experimentation, fixed storage and fixed laterals with a head of 1m raised seating for buckets were used as shown in figure 4. In this method, there were lifting structures, storage buckets and the lateral hoses which were determined by the amount of water applied at a time and the area intended to be covered. Drip irrigation installation components like wood, bucket, lateral hose, valves, bared elbow, bared T-crossing, Teflon tape, water level, measuring tape, string and mesh were used during the installation.

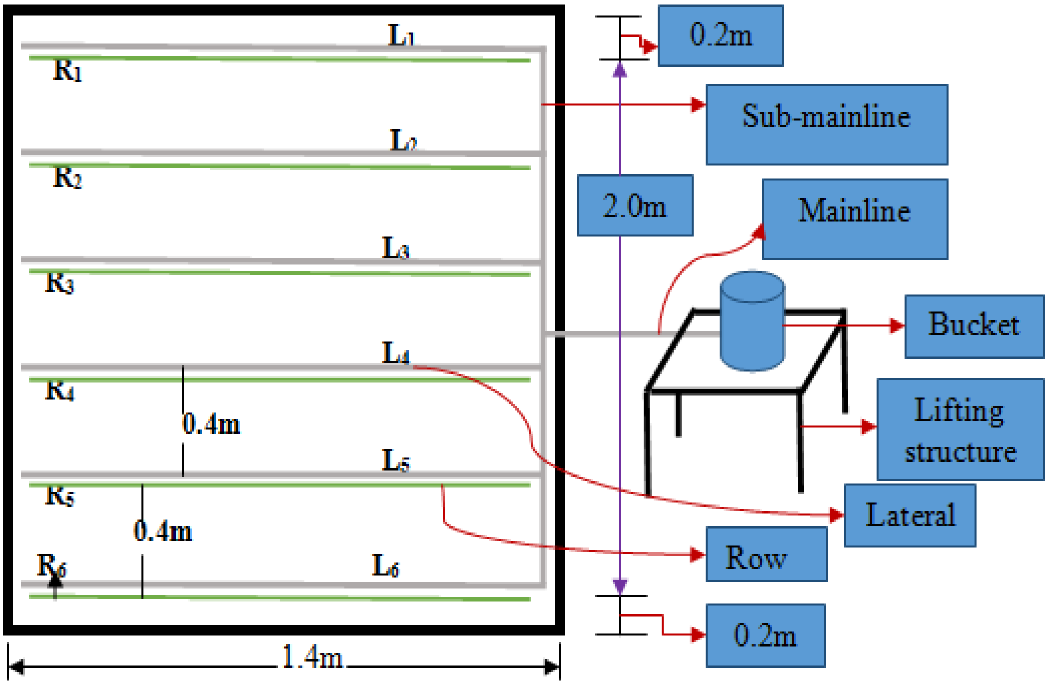

Figure 4: Field layout of low-cost drip irrigation (for one plot)

Where, R1, R2 … R6 are row 1, row 2 … row 6 and L1, L2 … L6 are lateral 1, lateral 2 … lateral 6.

As shown in figure 5 below, the experiment site during installation and initial crop growth stage was such a like:

Figure 5: Experiment site during installation and initial crop growth stage

For the experimentation the site during development, mid and ripening crop growth stage of the experimentation was shown in figure 6 below.

Figure 6: Experiment site

3.3.6 Agronomic practices

The land was prepared in order to make the soil suitable to provide the best soil structure for root growth and development. The experimental field was prepared manually and leveled. Low cost drip irrigation system by rising reservoir (bucket) seating was installed. The seed was sown in row in shallow furrows drawn 0.1m apart, and covered to a depth of 0.05m. The recommended fertilizer rate, 100 kg/ha NPS were applied (MoARD 2009). The experimental plots were free from weeds by weeding manually by hand.

Drip irrigation lines were installed on each row and plants were irrigated through emitter placed on the side of the plant, 0.05m away from the stem. As shown in table 2 after completing the initial growing season, plants were subjected to deficit irrigation treatments. The irrigation water was applied based on the soil moisture level and refilling was done based on the full supplied treatment.

3.3.7 Measurement of soil moisture level

Soil moisture content was measured at the expected rooting depth from 10 to 30 cm depth, before and after 24 hrs. each application of irrigation by using Digital Moisture Meter method throughout the growing season as shown in figure 7. The irrigation schedule was determined based on the requirements of the fully supply treatment (T1).

Based on the Laboratory result, FC (35.4%) and PWP (18.8%) of the area, TAW was 16.6% volumetric content. To compute the moisture content, allowable depletion of 45% was used as stated by Allen *et al.* (1998a) and the moisture content is 0.747 mm/cm and then multiply by any rooting depth, it gives the required irrigation water within depth. Then, measure the degree of soil moisture by using Digital Moisture Meter and apply the required irrigation water based on expected rooting depth and surface area when the moisture level less than 3.5. Digital Moisture Meter indicates the level of moisture in the soil and if the measured value is below 3.5 the soil is require water. Then refilling for the overall treatment was applied when measured value below 3.5 for T1, based on experiment requirements.

Figure 7: Soil moisture measurement using Digital Moisture Meter

3.3.8 Irrigation water application

During the experimentation the irrigation system has an average emitter application rate of 0.485 lit/hr. as shown in annex 1. The irrigation system has an average coefficient of uniformity (CU) of 97.94% as shown in annex 2 calculated by using Christiansen's Coefficient of Uniformity equation 3.3 and distribution uniformity of 96.61% as shown in annex 3 using distribution uniformity equation 3.4 based on six randomly selected laterals.

$$Christiansen\ coefficient\ of\ uniformity\ = 100 * \left(1 - \frac{sum\ of\ |xi - \bar{x}|}{\bar{x} * n}\right) \dots\dots\dots\dots\dots (3.3)$$

$$Distribution\ Uniformity\ = \left(\frac{average\ of\ lower\ quarter}{overall\ mean}\right) * 100\ \dots\dots\dots\dots\dots\dots. (3.4)$$

Where: xi is applied irrigation water per emitter, $\bar{x}$ is the mean of the observed values and n is the number of observations.

3.3.9 Common bean water productivity (water use efficiency)

Water productivity can be defined as the agricultural output per consumed unit of water. It is defining as produced yield divided by the effective rainfall plus the amount of applied water (Oweis 1997).

$$WP = \frac{Ya}{CU} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where; WP is water productivity, Ya is yield and CU is consumed water.

Water productivity improved either by enhancing the yield (nominator) or reducing the water application (denominator). From the stand point of resources conservation, it is important to save as much water as the consequence on economic return is acceptable. It means producing more with less water.

Productivity of water is a measure of the economic, livelihood or biophysical outputs derived from the use of a unit of water. Such outputs could be brick making, crop production, fishing, livestock watering etc. Units are jobs per m3, $/m^3, total biomass (kg/m^3), families per command area etc. The productivity of water in an irrigation system is more than what comes from the intended or unintended products within the total command area i.e. water diverted for irrigation system can be used for many other uses e.g. domestic purposes, fishing, brick making etc. Water productivity is therefore a wider consideration of the products that comes from the diverted water for the irrigation system (Alcamo 2000).

Moisture stress at different growth stage had a significant influence on water productivity. As stated by Admasu Robel *et al.* 2019, the water productivity ranged from 0.34Kg/m^3 under full irrigation to 1.33Kg/m^3 irrigating only initial stage. The maximum water productivity is obtained from irrigating only initial stage (1.33Kg/m^3) followed by irrigating only maturity stage (0.80Kg/m^3); whereas, the minimum is obtained from full irrigation treatment (0.34Kg/m^3). Although irrigating only initial stage seems to result highest water productivity due to high water savings, the yield reduction is also high. Such tradeoff, higher water productivity for lower yield, should be carefully interpreted. Acceptable level of water saving and hence water productivity is the highest value level that can be achieved without significant reduction in yield.

Water use efficiency (WUE) is referred to as evapotranspiration (ET) efficiency as stated by Tanner and Sinclair (1983) which includes water loss by soil evaporation (E) as stated by Wright *et al.* (1993). WUE is also defined as the ratio between photosynthesis and transpiration (Jones 2004). WUE is considered a good trait that contributes to increasing yield under drought (Prasad *et al.* 2008).

Singer *et al.* (1996), have exposed common bean to drought stress by 50% of field capacity. The results were reduction of leaf area. There are several traits that may increase WUE in the common bean such as early vigor, osmo-regulation and smaller photosynthetic surfaces when exposed to drought stress (Araus *et al.* 2002).

In addition, WUE in the common bean has a strong association with specific plant characteristics and soil type. A reduced leaf area leads to reducing the rate of transpiration and water loss. Therefore, decreased leaf area is one of the most important mechanisms to moderate water loss from the canopy and minimize plant exposure to drought (Prasad *et al.* 2008). Leaf temperature is an important element in the rate of transpiration, so WUE can be affected by lower leaf temperature. In fact, there are many morphological traits associated with lower leaf temperature, such as ‘epicuticular wax, chlorophyll content, and leaf position (erect leaves) (Prasad *et al.* 2008).

The relative reductions in yield and water saving can be calculated from the following equations (Ismail 2010);

$$Reduction\ in\ yield = 100 - \left(\frac{yield\ of\ T2\ or\ T3\ or\ T4\ or\ T5}{yield\ of\ T1} * 100\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.6)$$

$$Water\ saving = 100 - \left(\frac{water\ consumption\ of\ \ T2\ or\ T3\ or\ T4\ or\ T5}{water\ consumption\ of\ T1} * 100\right) \ldots (3.7)$$

3.3.10 Experimentation

During the experimentation, the activities included were measuring soil moisture before and after irrigation, applying water based on soil moisture depletion from the full supplied treatment and based on deficit levels for deficit treatments, measuring of agronomic parameters of the crop during different growth stages and crop land management. The major tasks were measuring the agronomic parameters of the crop includes days to full ground canopy cover, first day of flowering & days to 50% flowering , number of nodules per plant, number of branches per plant, plant height, number of pods per plant and number of seeds per pod. The overall crop management includes applying irrigation water, weeding, harvesting, and weighing of seeds were undertaken.

3.4 Data collection and analysis

For data collection (days to 95% maturity, plant height, number of pods per plant, number of seeds per pod and hundred seed weight) ten systematically selected plants from the four center row of each plot (to avoid border effects) were selected, and every required data were collected during the whole growing season from those selected sample plants representing their plot. Days to full ground canopy cover, number of nodules, number of branches per plant and above ground dry biomass data were obtained from five systematically selected representing plants from each plot. The crops were harvested two

(2) times at 95% of the pods mature in a plot. Treatment four and five were harvested after 78 days of sowing and treatment one, two & three were harvested after 82 days of sowing.

Agronomic parameter data collection

Number of 50% plant emergence in each plot were counted two times (after six (6) and seven (7) days of sowing) during the experimentation. At every five days (after initial stage), days to full ground canopy cover of selected plants from each plot measurements were taken using grids. Grid having a square area of 2.5cm*2.5cm which was subdivided in to 6.25cm^2 small squares was used. A total of 64 small square areas were prepared for the full covering of one plant. Counting of squares to differentiate full, 75%, 50% and 25% square coverage photo was taken from each representing plant, then counting was undergone in each measurement. Days to 50% flowering were recorded as the number of days from sowing to 50% of the plants produced flowers.

Total numbers of nodules were determined by counting systematically taken plants from each plot at pod setting time. The numbers of primary and secondary branches at the beginning of maturity were recorded. The height of the plant was measured from the base of the plant (soil surface) to the top node bearing when the plant reached maturity (CIAT, 1987). The number of pods per plant was determined as the total number of pods from those selected plants from each plot at physiological maturity. Numbers of seeds per pod were determined as the total number of seeds per pod from those selected plants at maturity from each plot and hundred seed weight was determined by taking 100 seeds from systematically taken plants and weighted by sensitive balance for every treatment.

The total crop yield per hectare (ton/ha) was obtained by converting the crop yield per plant which obtained from each plot harvest area into hectare. The above ground dry biomass (ton/ha) was obtained from five systematically selected representing plants from each plot. During 90% of the plants in a plot reached maturity, the above ground plant bodies (excluding the roots) were subjected to oven dry with 70 °C for 48 hrs to a constant weight and weighted using sensitive balance. Converting to the plot and summing up the result obtained from plot, the dry biomass of each treatment was obtained.

Irrigation water application:

The experiment was conducted during the dry season using irrigation water only (no rainfed) in which shelters (greenhouse) were used to exclude rain. Irrigation water was applied based on the soil moisture depletion on the control treatment with a delivery patterns as shown in figure 8. During the growing season, the maximum volume of water 1194.87 litre/plot was delivered to the full applied treatment T1 and followed by T2 (984.52 litre/plot), T3 (774.20 litre/plot), T4 (563.82 litre/plot) and the minimum volume of water 353.50 litre/plot was given to treatment, T5 with 33 total number of application as shown in annex 5.

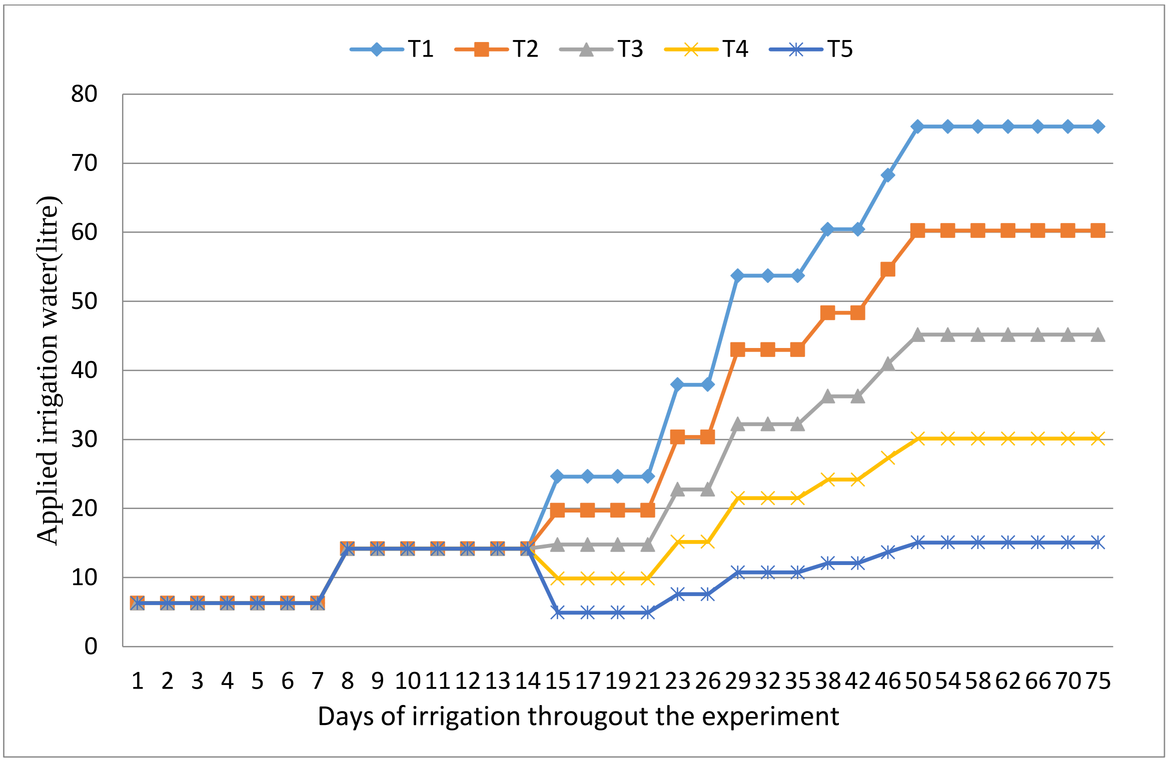

Figure 8: Patterns of irrigation water delivery

3.5 Data analysis

The post field work includes all the activities undertaken after the accomplishment of the field work mainly data analysis, discussion, evaluation and allover thesis writing and documentation.

3.6 Statistical analysis

Agronomic parameter data were collected and statistical analyses of variance were performed using Minitab 16. Effects were considered significant in all statistical calculations if the P-values are ≤ 0.05 and means were separated using Fisher's individual error rate (Noelle 2014).

4. RESULTS AND DISCUSSION

4.1 Growth characteristics response of common bean to water deficit

Physical responses (days to 50% emergence, days to 100% ground cover, days to 50% flowering, number of nodules per plant, number of branches per plant, plant height (cm), number of pods per plant, number of seeds per pod, and hundred seed weight (gm)) of common bean for different level of irrigation water applications were observed during the experimentation. The resulting physical responses mean quantitative data with respective error interval and Fisher's comparisons for individual error rate between each treatment for every crop growth characteristic of common bean to those levels of applications was shown in table 4.

Table 4: Physical response of common bean to water deficit

Crop growth parameter	Treatment responses				
	T1	T2	T3	T4	T5
DE	6.00±0.00^{A}	6.33±0.58^{A}	6.00±0.00^{A}	6.33±0.58^{A}	6.33±0.58^{A}
GC	46.67±2.89^{A}	45.00±0.00^{A}	45.00±0.00^{A}	46.67±2.89^{A}	48.33±2.89^{A}
DF	41.33±0.57^{A}	41.00±0.00^{A}	41.00±1.00^{A}	41.00±1.00^{A}	41.33±0.58^{A}
NN	59.33±3.43^{A}	41.77±6.04^{B}	36.87±9.95^{BC}	25.93±9.90^{CD}	18.67±8.54^{D}
NBP	3.47±0.12^{A}	3.20±0.40^{A}	3.40±0.53^{A}	3.20±0.72^{A}	2.20±0.60^{B}
PH	51.67±2.64^{A}	46.00±0.46^{AB}	42.50±5.07^{BC}	35.40±5.90^{CD}	31.73±5.02^{D}
NPP	17.77±0.55^{A}	16.89±0.25^{A}	16.77±1.07^{A}	13.50±0.50^{B}	11.20±0.44^{C}
NSP	5.13±0.17^{A}	4.98±0.21^{AB}	4.96±0.04^{AB}	4.48±0.34^{BC}	4.19±0.12^{C}
HSW	30.75±0.44^{A}	30.60±0.87^{A}	29.25±1.43^{A}	25.52±1.16^{B}	22.82±0.44^{C}

Note: Means that do not share a letter are significantly different.

Where, DE is days to 50% emergence, (days), GC is days to 100% ground cover, (days), DF is days to 50% flowering, (days), NN is number of nodules per plant (No.), NBP is number of branches per plant, (No.), PH is plant height (cm), NPP is number of pods per plant, (No.), NSP is number of seeds per pod (No.) and HSW is hundred seed weight (gm).

4.1.1 Days to 50% emergence (DE)

The numbers of days to 50% emergence were showed statistically non-significant between treatments. From this study, days to 50% emergence were observed between 6.00 and 6.33 days. As shown in Table 4, the experiment showed that days to 50% emergence, for the same water application levels was resulted similar days to emergency. Hence, different water application (deficit irrigation) levels were applied starting from development growth stage (after sowing day of 15).

4.1.2 Days to 100% ground cover (GC)

The full GC of common bean showed statistically no significant difference among treatments. The full GC of common bean has been not influenced by water stress as shown in Table 4. From this study result, the treatment that covers 100% of the plot ground in 45 days were T2 & T3 and the other treatment such as T1, T4 & T5 covers in so days as shown in Table 4 even though the average value for T5 was 48.33 days. Generally in this experiment, applying deficit irrigation (after initial crop growth stage) in common bean production has no significant effect on the canopy expansion.

De Medeiros *et al.* (2016), conducted an experiment to evaluate the relation between cumulative degree-days index and the development, growth, and water consumption of irrigated bean under different soil tillage systems in Southeast Brazil and described the days to full GC of common bean were between 41 - 51 days after emergency with supplied full water needs by drip irrigation system. Days to full GC of common bean in this experiment were close to theses stated values.

4.1.3 Days to 50% flowering (DF)

Days to 50% flowering showed statistically non-significant between treatments. This implies in this experiment, applying deficit irrigation water after initial crop growth stage has not significant effect on the days to 50% flowering date. The experiment showed that days to 50% flowering for different water application levels was resulted similar days of flowering as shown in Table 4. The average fastest days to 50% flowering for treatments was observed at T2, T3 and T4 (41 days) and followed by T1 and T5 at (41.33 days).

Amanuel Alemu *et al.* (2018), conducted an experiment to investigate the growth and yield of common bean (Phaseolus vulgaris L.) cultivars as influenced by rates of phosphorus at Jimma, Southwest Ethiopia and stated that the average values of days to 50% flowering that taken from three common bean cultivars were 47.67. This value was greater than the value obtained in this experiment and this is due to the greenhouse temperature effect in this experiment. But, days to 50% flowering mean value of this experiment is in the range of Crop Variety Register mean value 41-55 which stated by (MoARD 2009).

4.1.4 Number of nodules (NN)

The NN showed statistically significant variability at ($p = 0.003$) which indicates practicing deficit irrigation water on NN of common bean were resulted significant differences within treatments. As indicated in Table 4, the NN per plant of bean was sensitive to water stress (i.e. NN were decreased with reduced irrigation water application level). From this experiment, the highest NN per plant produced were observed at treatment, T1 (59.33), followed by T2 (41.77) and the least were observed at treatment, T5 (18.67).

Amanuel Alemu *et al.* (2018) *et al.* (2018), stated that the highest and the least average NN per plant produced were 67.47 and 29.87. When compare to full irrigation application treatment, T1 the highest average value was moderately closed to this experiment values, but when compare to extremely deficit irrigation supplied treatment, T5 of this experiment, the least average values was significantly greater than to this experiment values.

On the other hand, Carvalho *et al.* (2016), conducted an experiment under irrigated deficit condition to evaluate different levels of water replacement combined in two periods (2010 and 2011) of the bean and stated that the highest and the least average NN per plant produced were 12.25 from full supplied and 8.58 from 40% irrigation water supplied. These stated values were significantly less than to this experiment values in both cases (the highest and the least).

4.1.5 Number of branches per plant (NBP)

The experiment showed that practicing deficit irrigation water on common bean, statistically non-significant in NBP. The response of NBP from observed data shown at Table 4 has no linear proportionality with different level of water application. As shown in the Table, from treatment T1 up to T4 there were no effect on NBP due to water stress but T5 was affected. Based on the results of this study, NBP was affected only at T5 (applying 20% irrigation water requirement) due to water stress and the other treatments (applying deficit irrigation water greater than 40% irrigation water requirement) were not affected by water stress. The maximum mean number of branches was observed at T1 (3.47) and the least at T5 (2.20).

El-Dahshouri *et al.* (2017), conducted an experiment to improving seed production of common bean (Phaseolus vulgaris L.) plants as a response for Calcium and Boron and stated that the mean number of branches per plant was 4.20 from control treatments which was slightly greater than to this experiment values.

Saleh *et al.* (2018), conducted a study in an environmentally controlled greenhouse on the effect of irrigation on growth, yield, and chemical composition to evaluate two green bean cultivars under three application volumes of irrigation water 100, 80 and 60% ET, and stated that the mean highest and lowest number of branches per plant were 8.00 and 6.00 respectively and both these stated values were greater than to this experiment values.

4.1.6 Plant height (PH)

The plant height (cm) showed statistically significant variability at (p = 0.003) which indicates practicing deficit irrigation water has a significant effect on the height of common bean crop. As shown in Table 4, common bean plant height was response to water deficit proportionally. That was for those applied irrigation water levels as the percent of the water delivered reduces the PH also reduces. From the experiment, the tallest mean plant height was observed at treatment, T1 (51.66 cm), followed by T2 (46.00 cm) and the shortest was observed at T5 (31.73 cm).

The recommended mean PH value that described from Crop Variety Register was 50.53cm which stated by (MoARD 2009); and this value is more alike to this experiment full supplied treatment values. On the other hand, the shortest mean PH observed value in this study was severely decline due to water stress as introduced 20% irrigation water requirement.

Asrat Asfaw *et al.* (2016), evaluate 64 common bean (Phaseolus vulgaris L.) genotypes grown under drought-stress (irrigated when soil moisture was depleted to 30% field capacity) and non-stress condition in Ethiopia and states that the maximum and minimum plant heights were 47.50 cm and 24.00 cm respectively. The maximum stated value was nearly close to this experiment values, but the minimum stated value was less than to this experiment values.

Carvalho *et al.* (2016), conducted an experiment to evaluate growth and production of common bean in direct seeding under irrigated deficit condition and stated that the largest water reductions of the bean cycle after emergence to flowering combined with from full flowering to physiological maturity resulted in greater effects on PH and the tallest and the shortest mean plant height were 55.62 and 36.15 cm. In this experiment, the tallest and the shortest mean PH observed values were less than to the above stated values in both cases.

Saleh *et al.* (2018), conducted a study in an environmentally controlled greenhouse under three application volumes of irrigation water, and stated that the tallest and the shortest mean plant height were 52.30 cm from full supplied and 47.80 cm from 60% ET. The tallest mean PH stated value was much closed to this experiment full supplied treatment value, but the shortest mean PH stated value was greater than to this experiment value.

The effect of growth stage moisture stress on common bean (Phaseolus vulgaris L.) yield and water productivity were investigated under sub-humid climate conditions at Jimma, Ethiopia by Admasu Robel *et al.* (2019), with irrigating to refill the crop root zone depth close to field capacity and imposing moisture stress within its crop growth stage differently and stated that the tallest plant height was 48.00 cm which observed at treatments that supplied irrigation during all growth stages and the shortest mean plant height was 42.60 cm which was observed at treatment applied irrigation only initial stage. The tallest plant height stated value was most likely close to this experiment value, but the shortest mean plant height in this experiment was significantly less than to this stated value.

4.1.7 Number of pods per plant (NPP)

The result of analysis of variance showed that, NPP was extremely significant different at (P = 0.000). As shown in Table 4, as the amount of water applied extremely reduced (extreme deficit irrigation 40% and 20% of irrigation water application) the mean NPP of common bean also reduced. The treatments such as T1, T2 and T3 practicing deficit irrigation has shown no significant effect on NPP where as it has significant effect on T4 & T5. In this experiment, the maximum mean NPP were observed at treatment, T1 (17.77) and the minimum were at T5 (11.20).

The maximum and minimum mean numbers of pods per plant of common bean were 23.50 and 15.58 respectively that evaluated from deficit irrigation at different growth stages of the common bean (Phaseolus vulgaris L.) with combinations of normal watering, full stress (traditional management practice) and single stress by (Calvache *et al.* 1997). The result of this study, maximum pod number value was between these stated values but the minimum mean number of pods was less than the above stated value due to water stress.

Under full supplied treatment, the average mean number of pods per plant were 18.55 (Yacob Alemayehu *et al.* 2015). This experiment was done to evaluate the effect of intra-row spacing on haricot bean (Phaseolus vulgaris L.) production in humid tropics of southern Ethiopia and stated the above value under full supplied treatment. The full supplied treatment mean number of pod per plant value of this experiment was very close to this stated value.

Saleh *et al.* (2018), stated that the maximum and minimum mean numbers of pods per plant were 15.30 from 80% supplied and 13.00 from 60% ET. These stated values were under the range of this experiment value.

Admasu Robel *et al.* (2019) evaluated common bean (Phaseolus vulgaris L.) genotypes for drought stress adaptation in Ethiopia and states that the reduction of common bean grain yield in water stress at development and mid-season stage as compared to the rest treatments may have been attributed to a lower percentage of pods formed due to flower abscission and embryo abortion when drought occurred at flowering and pod filling growth stages. In this experiment also water stress was reduced pod number similarly.

4.1.8 Number of seeds per pod (NSP)

In this experiment, NSP of common bean was significantly different at (P = 0.001). This indicates that there is a significant difference among treatments due to water stress. As shown in Table 4, as the amount of water applied reduced the NSP of common bean was decreased. As shown in the Table, the maximum mean NSP were observed at treatment, T1 (5.13), followed by T2 (4.98) and the minimum were at T5 (4.19).

Deficit irrigation at different growth stages of the common bean (Phaseolus vulgaris L.) was evaluated with combinations of normal watering, full stress (traditional management practice) and single stress by Calvache *et al.*, (1997). As they stated, the maximum and minimum mean NSP of common bean were 4.47 and 3.87 respectively which is nearly similar to this experiment value.

The effects of the regulated deficit irrigation on yield and yield components of common bean (Phaseolus vulgaris L.) under semi-arid conditions were tested with combining 25% to 100% RAW by Mehmet *et al.* (2011); and they were stated that, the maximum and minimum mean NSP of common bean were 5.90 from full supplied and 3.80 from combined of 25% with 100% RAW respectively. These values were close to this experiment values.

Asrat Asfaw *et al.* (2016), evaluate common bean (Phaseolus vulgaris L.) under drought-stress and non-stress condition in Ethiopia and states that the maximum and minimum numbers of seed per pod were 6.60 and 4.00 respectively. The maximum stated value was greater than to this experiment values, but the minimum stated value was very close to this experiment values.

4.1.9 Hundred seed weight (HSW)

The result of analysis of variance depicted that, 100 seed weight of common bean were highly significant different at (P = 0.000), which implies there is a significant difference among treatments. Applying deficit irrigation on common bean production has a significant effect on HSW like that of number of pod per plant as shown in Table 4. This Table shows that HSW at different growth stages of common bean has been influenced by extreme deficit irrigation. As indicates from the Table, from treatment T1 to T3, applying deficit irrigation water has no significant effect on HSW while on treatment T4 & T5 has significant effect. The maximum mean HSW during the growing season were observed at treatment, T1 (30.75gm) and the minimum were at T5 (22.81 gm).

Amanuel Alemu *et al.* (2018), conducted an experiment to investigate the growth and yield of common bean (Phaseolus vulgaris L.) cultivars as influenced by rates of phosphorus at Jimma, Southwest Ethiopia and described the HSW values were 28.37 and 23.43 gm respectively, which were very close to the results of this study.

Asrat Asfaw *et al.* (2016), evaluate common bean (Phaseolus vulgaris L.) genotypes for drought stress adaptation in Ethiopia and states that the maximum and minimum mean HSW were 33.50 and 15.20 gm respectively. The maximum stated value was close to this experiment values, but the minimum stated value was less than to this experiment values.

On the other hand the maximum and minimum mean HSW of common bean was 53.85 and 44.76 gm respectively, that were evaluated deficit irrigation at different growth stages of the common bean (Phaseolus vulgaris L.) with combinations of normal watering, full stress (traditional management practice) and single stress (Calvache *et al.*, 1997). These stated values were greater than to this experiment values.

4.2 Yield response and productivity of common bean

4.2.1 Yield response of common bean to water deficit

The yield response of common bean has been evaluated in two ways; and these are the above ground dry biomass & the seed yield. Their responses to water deficit were as shown in Table 5 below.

Table 5: Yield response of common bean to water deficit and productivity of common bean

Parameter	Treatment responses				
	T1	T2	T3	T4	T5
DB	5.32 ± 0.80^{A}	5.06 ± 0.84^{A}	4.81 ± 0.58^{A}	3.89 ± 0.52^{AB}	2.74 ± 0.14^{B}
Y (LP)	3.49 ± 0.23^{A}	3.14 ± 0.10^{A}	3.05 ± 0.26^{A}	1.77 ± 0.07^{B}	1.10 ± 0.12^{C}
WP	0.98 ± 0.06^{B}	1.07 ± 0.03^{B}	1.32 ± 0.11^{A}	1.05 ± 0.04^{B}	1.05 ± 0.11^{B}

Note: Means that the treatments response of bean that do not share a letter are significantly different to water deficit and productivity

Where, DB is above ground dry biomass yield (ton/ha), Y is Mean seed yield (ton/ha), WP is water productivity (kg/m^3) and LP is land productivity (ton/ha).

4.2.1.1 Above ground dry biomass (DB)

Above ground dry biomass was significantly influenced by deficit irrigation water at (P = 0.009). The mean DB yield of common bean within treatments was varied across different application of deficit irrigation water. As shown in Table 5, the DB for all studied treatments of common bean has been influenced by extreme deficit irrigation water (i.e. as the amount of water applied extremely reduced total DB of common bean was decreased). As indicates from the Table, the total above ground dry matter has shown no significant difference from treatments T1 to T3 with decreasing the water supply, but on treatment T4 & T5 it has shown significant effect. This implies practicing deficit irrigation on common bean from full supplied up to 60% irrigation water requirement supplied has no significant effect on DB. The highest DB weight was obtained from the fully supplied treatment T1 (5.32 ton/ha) and the lowest (2.74 ton/ha) was obtained from treatment T5.

The highest and the lowest average dry matter weight were 5.04 and 3.36 ton/ha respectively as stated by Amanuel Alemu *et al.* (2018). The highest average dry matter weight was closed to this experiment values when compare to full supplied treatment, T1, but the lowest weight was greater than to this experiment lowest weight values.

Admasu Robel *et al.* 2019, investigated the response of common bean (Phaseolus vulgaris L.) to moisture stress at different growth stages for yield and water productivity under sub-humid climate conditions by irrigating and imposing moisture stress within its crop stage differently and stated that the highest and the lowest average dry matter weight were 6.00 and 4.00 ton/ha respectively. The highest stated dry matter weight was to some extent greater than to this experiment values which observed at full irrigation supplied all growth stages and the smallest stated dry matter weight was significantly higher than to this experiment smallest values which observed at treatment, T5.

4.2.1.2 Seed yield (Y)

In this experiment, grain yield of common bean was significantly different at (P = 0.000) and affected by the deficit irrigation. This indicates that there is a significant difference between treatments as the amount of water applied changed under this study. As shown in Table 5, the letter of comparison has shown no significant yield difference between treatments T1, T2 & T3 rather than T4 and T5. As shown in the Table, the highest mean seed yield was observed from treatment T1 (3.49 ton/ha) and the lowest from T5 (1.10 ton/ha). Based on these quantitative data, the relative yield responses were affected due to extreme water stress.

Carvalho *et al.*, (2016) conducted an experiment to evaluate growth and production of common bean in direct seeding under irrigated deficit condition and stated that the higher the water deficit in the reproductive phase beginning of full flowering to physiological grain maturity, the smaller the grain yield of bean in kg/ha. The seed yield of this experiment also similarly influenced by extreme deficit irrigation.

As stated by Carvalho *et al.* (2016) the highest and lowest mean seed yield of common bean were 2.991 and 1.164 ton/ha) respectively that evaluated the deficit irrigation at different growth stages of the common bean (Phaseolus vulgaris L.) with combinations of normal watering, full stress (traditional management practice) and single stress. These stated values are less than to this experiment value. However, its potential at managed farm is 3.4 ton/ha (CVR 2012).

Asrat Asfaw *et al.* (2016), evaluate common bean (Phaseolus vulgaris L.) grown under drought-stress (irrigated when soil moisture was depleted to 30% field capacity) and non-stress condition in Ethiopia irrigation water requirement states that the maximum and minimum seed yield were 3.82 & 1.08 ton/ha respectively. The maximum stated value was greater than to this experiment values, but the minimum stated value was closed to this experiment smallest values.

4.2.1.3 Harvest index (HI)

The seed yield, DB and HI of common bean crop were presented in Table 6. The HI which refers to the ratio of grain yield to total plant biomass as stated by Rana *et al.* (2019), was decreasing with decreasing application of irrigation water except treatment T3. In this experiment, the highest value of HI was 0.66 and the lowest was 0.40.

Deficit irrigation at different growth stages of the common bean (Phaseolus vulgaris L.) was evaluated with combinations of normal watering, full stress (traditional management practice) and single stress by Calvache *et al.*, (1997). They were stated that the highest and the lowest values of HI were 0.65 and 0.52 which were very close to this experiment values.

Table 6: Seed yield, above ground biomass and harvest index for different irrigation treatments of common bean

Treatment	Y (ton/ha)	DB (ton/ha)	HI (-)
T1	3.49	5.32	0.66
T2	3.14	5.06	0.62
T3	3.05	4.81	0.63
T4	1.77	3.89	0.46
T5	1.10	2.74	0.40

4.2.2 Productivity of common bean

The productivity of common bean has been evaluated as water productivity and land productivity of treatments and the results were shown in Table 5.

4.2.2.1 Water productivity (WP)

In this experiment, common bean had good WP without severe yield reduction even though exposed to drought stress by 40% of field capacity; however exposed greater than to this percent was reduced yield severely as shown in Table 5. As stated by Singer *et al.* (1996) and Prasad *et al.*, (2008), the most important mechanisms of common bean crop to moderate water loss is reduced leaf area which leads to reducing the rate of transpiration and water loss from the canopy and minimize plant exposure to drought.

Crop WP (kg/m^3) was calculated as the ratio of actual yield produced (kg) to the volume of water consumed (m^3) by referring equation 3.5. As shown in Table 5, based on the calculation results, the best mean WP treatment was T3 (1.32 kg/m^3) and the least was T1 (0.98 kg/m^3).

As shown in Table 5 using Fishers letter representation, there was no significant difference among treatments based on the WP except treatment T3. The mean value of WP was increased as introduced deficit level reduced up to treatment T3, but it declines after treatment T3. Based on this, applying 60% irrigation water requirement except initial stage resulted highest WP due to high water savings without severe yield reduction.

Admasu Robel *et al.* (2019), investigated the response of common bean (Phaseolus vulgaris L.) to moisture stress at different growth stages for yield and water productivity under sub-humid climate conditions at Jimma, Ethiopia and stated that the WP of common bean ranged from 0.34Kg/m^3 under full irrigation to 1.33Kg/m^3 irrigating only initial stage. The WP of common bean in this experiment was ranged under this category.

4.2.2.2 Land productivity (LP)

The land productivity of common bean crop was presented in Table 5. As shown in this Table, based on the experimentally observed data the highest land productive treatment was T1 (3.49 ton/ha) and the lowest was treatment T5 (1.10 ton/ha). As shown in the Table, no significant yield difference was observed between treatments T1, T2 and T3 while treatments T4 and T5 produces yield which were significantly different from the control treatment T1 and also treatment T4 & T5 produces yield significantly different with each other.

4.2.2.3 Measurements on yield reduction and water use efficiency

The measurements on yield reduction and WUE of treatments were done using equation 3.6 and 3.7 relative to the full supply treatment, T1 as indicated in Table 7 below.

Table 7: Relative yield reduction and water saving of deficit treatments

Treatment	Relative yield reduction (%)	Actual water saved (%)
T2	10.13	17.60
T3	12.59	35.21
T4	49.37	52.81
T5	68.42	70.42

As shown in Table 7, applying 80% of irrigation water requirement during the growing season reduced the total yield by 10.13% and saved 17.60% of irrigation water. Increasing the deficit irrigation resulted in a severe yield reduction. Applying 20% of irrigation water requirement reduced the yield by 68.42%, even though the water saved was 70.42%.

4.3 Optimum irrigation water level for common bean crop

Most of the growth characteristics, the yield response and productivity of common bean to water deficit were showed application of 60% irrigation water requirement has not significant difference to full supplied treatment, T1. This indicates the optimum irrigation water level for common bean crop was the depth of the water that applied in treatment, T3.

5. SUMMARY AND CONCLUSIONS

5.1 Summary

The effect of water deficit on the yield responses of common bean (Phaseolus Vulgaris L.) was evaluated under low cost drip irrigation system with five level of irrigation water. The result of this experiment shows common bean crop agronomic characteristics were response inconsistently to deficit irrigation water. The characteristics, days to full ground canopy cover and days to 50% flowering were not sensitive to water stress up to 20% irrigation water application except initial growth stage, whereas number of branches per plant and above ground dry biomass were sensitive only at extremely deficit irrigation (supply 20% irrigation water application). Number of pods per plant, number of seeds per pod, hundred seed weight and seed yield were sensitive when deficit irrigation water greater than 40%; this implies supply greater than 60% irrigation water requirement (treatment, T1, T2 and T3) were not affect these attributes. Common bean plant height was influenced after 20% deficit irrigation water (i.e. greater than 80% irrigation water application was not affect plant height); whereas number of nodules per plant was affect with all deficit irrigation level which practices in this experiment.

From the result of the study, even though there was a numerical difference on the land productivities of treatments T2 and T3 with T1, they had not statistically significant different and in water productivity also no significant difference was observed among treatments except treatment T3 which was the best mean water productive treatment. This implies supplying deficit irrigation water up to 40% (supplying 60% irrigation water requirement) during the whole growing season except first growth stage has no significant difference on productivity of common bean production.

From the result of this experiment, it was observed that the highest yield (3.49 ton/ha) which grown with no-stress at treatment, T1 (100% of irrigation water application). Irrigating common bean with 80% and 60% of the irrigation water requirement were lead to a reduction of yield 10.13% and 12.59% from the full supplied treatment, while adding water 17.60% and 35.21% respectively. These applications of irrigation water were non-significant in seed yield with full supplied treatment. This implies application of 60% irrigation water requirement was the optimum depth of irrigation water for common bean crop. On the other hand, irrigating with 40% & 20% of the irrigation water requirement were severely reduced the yields by 49.37% & 68.42% due to the low soil moisture during the growing season even though saved 52.81% and 70.42% of irrigation water respectively.

5.2 Conclusions

Production of common bean by introducing deficit irrigation water could make an important contribution to increase water and land productivity. This study results confirmed that with deficit irrigation strategies it is possible to increase yield, water productivity and save significant depth of water for irrigation. In this study, application of deficit irrigation water with 80% and 60% of irrigation water requirement were not much affect common bean growth characteristics, yield response and land productivity, however 40% and 20% of irrigation water application were significantly affect. On the other hand, application of deficit irrigation water were had similar responses to full supplied treatment on water productivity except treatment, T3 which had the highest water productivity. The optimum irrigation water of common bean was the depth of the water that applied in treatment, T3.

Cultivating common bean with supplying 60% of irrigation water requirement during the whole growing season except the first stage had no significant yield difference with the highest yield producing treatment T1 (100% of irrigation water application). The best water stress level under water stress condition for common bean production is application of 60% irrigation water requirement with maintaining reasonable yield as close to fully irrigated. That means with this application, water and other irrigation expenses can be saved without severe yield reduction. By doing so, more land can be irrigated with the saved water to enhance production. Cultivating common bean with 40% irrigation water application was reduced the grain yield and had not much difference with traditional cultivation, however when the water source is scarce, we can cultivate and produce similar production to current national production of common bean in Ethiopia via using 40% irrigation water application, but 20% was severely reduced the yield.

Based on land and water productivity of this study, cultivating common bean with supplying 60% irrigation water requirement during the whole growing season except the first stage is recommended under Mizan-Aman conditions. Since, this research was done one season experimentation, to reach at concrete recommendations it is recommended to repeat the study in different areas under Mizan-Aman woreda's. In areas' which having sufficient water source, it is preferable to use full supply for better land productivity, but for areas having insufficient water, it is possible to produce common bean with supplying irrigation water up to 60% of irrigation water requirement without having significant yield difference compared to full supply. In addition, if there is sever water scarcity it is recommended to apply up to 40% of irrigation water requirement with low cost drip irrigation system in Mizan-Aman condition for a better water productivity even if there is high yield decline.

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7. APPENDICES

Annex 1: Application rate of the irrigation system during the experimentation

Emitter (no.)	Time (min)	Volume, V (ml) and discharge, Q (l/hr.)											
		Lateral #1		Lateral #2		Lateral #3		Lateral #4		Lateral #5		Lateral #6	
		V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
1	10	82	0.49	82	0.49	80	0.48	80	0.48	82	0.49	78	0.47
2	10	85	0.51	80	0.48	81	0.49	82	0.49	80	0.48	80	0.48
3	10	80	0.48	78	0.47	78	0.47	80	0.48	83	0.50	82	0.49
4	10	82	0.49	82	0.49	81	0.49	76	0.46	84	0.50	83	0.50
5	10	84	0.50	80	0.48	81	0.49	77	0.46	82	0.49	81	0.49
6	10	81	0.49	78	0.47	82	0.49	78	0.47	79	0.47	80	0.48
7	10	84	0.50	84	0.50	78	0.47	76	0.46	79	0.47	84	0.50
8	10	79	0.47	83	0.50	79	0.47	77	0.46	77	0.46	81	0.49
9	10	82	0.49	79	0.47	82	0.49	80	0.48	83	0.50	80	0.48
10	10	83	0.50	81	0.49	79	0.47	77	0.46	78	0.47	78	0.47
11	10	80	0.48	81	0.49	80	0.48	76	0.46	84	0.50	82	0.49
12	10	81	0.49	82	0.49	81	0.49	80	0.48	84	0.50	78	0.47
13	10	78	0.47	81	0.49	78	0.47	82	0.49	83	0.50	82	0.49
14	10	83	0.50	80	0.48	80	0.48	83	0.50	84	0.50	81	0.49
average			0.49		0.49		0.48		0.47		0.49		0.49
max			0.51		0.50		0.49		0.50		0.50		0.50
min			0.47		0.47		0.47		0.46		0.46		0.47
overall average application rate				(0.49+0.49+0.48+0.47+0.49+0.49)/6 = **0.485 l/hr**									

Annex 2: Christiansen’s coefficient of uniformity (CU)

Christiansen’s coefficient of uniformity from lateral 1 to 3:

Emitter no.	lateral #1			lateral #2			lateral #3		
	V	xi-x̄	|xi-x̄ |	V	xi-x̄	|xi-x̄ |	V	xi-x̄	|xi-x̄ |
1	82	0.29	|0.29|	82	1.21	|1.21|	80	0.00	|0.00|
2	85	3.29	|3.29|	80	-0.79	|-0.79|	81	1.00	|1.00|
3	80	-1.71	|-1.71|	78	-2.79	|-2.79|	78	-2.00	|-2.00|
4	82	0.29	|0.29|	82	1.21	|1.21|	81	1.00	|1.00|
5	84	2.29	|2.29|	80	-0.79	|-0.79|	81	1.00	|1.00|
6	81	-0.71	|-0.71|	78	-2.79	|-2.79|	82	2.00	|2.00|
7	84	2.29	|2.29|	84	3.21	|3.21|	78	-2.00	|-2.00|
8	79	-2.71	|-2.71|	83	2.21	|2.21|	79	-1.00	|-1.00|
9	82	0.29	|0.29|	79	-1.71	|-1.71|	82	2.00	|2.00|
10	83	1.29	|1.29|	81	1.21	|1.21|	79	-1.00	|-1.00|
11	80	-1.71	|-1.71|	81	0.21	|0.21|	80	0.00	|0.00|
12	81	-0.71	|-0.71|	82	1.21	|1.21|	81	1.00	|1.00|
13	78	-3.71	|-3.71|	81	0.21	|0.21|	78	-2.00	|-2.00|
14	83	1.29	|1.29|	80	-0.79	|-0.79|	80	0.00	|0.00|
mean	81.71	∑|xi-x̄|	22.58	80.79	∑|xi-x̄|	20.34	80	∑|xi-x̄|	16
n	14			14			14		
CU	98.03%			98.20%			98.57%		

Christiansen’s coefficient of uniformity from lateral 4 to 6:

Emitter no.	lateral #4			lateral #5			lateral #6		
	V	xi-x̅	|xi-x̅ |	V	xi-x̅	|xi-x̅ |	V	xi-x̅	|xi-x̅ |
1	80	1.32	|1.32|	82	0.43	|0.43|	78	-2.71	|-2.71|
2	82	3.32	|3.32|	80	-1.57	|-1.57|	80	-0.71	|-0.71|
3	80	1.32	|1.32|	83	1.43	|1.43|	82	1.29	|1.29|
4	76	-2.68	|-2.68|	84	2.43	|2.43|	83	2.29	|2.29|
5	77	-1.68	|-1.68|	82	0.43	|0.43|	81	0.29	|0.29|
6	78	-0.68	|-0.68|	79	-2.57	|-2.57|	80	-0.71	|-0.71|
7	76	-2.68	|-2.68|	79	-2.57	|-2.57|	84	3.29	|3.29|
8	77	-1.68	|-1.68|	77	-4.57	|-4.57|	81	0.29	|0.29|
9	80	1.32	|1.32|	83	1.43	|1.43|	80	-0.71	|-0.71|
10	77	-1.68	|-1.68|	78	-3.57	|-3.57|	78	-2.71	|-2.71|
11	76	-2.68	|-2.68|	84	2.43	|2.43|	82	1.29	|1.29|
12	80	1.32	|1.32|	84	2.43	|2.43|	78	-2.71	|-2.71|
13	82	3.32	|3.32|	83	1.43	|1.43|	82	1.29	|1.29|
14	83	4.32	|4.32|	84	2.43	|2.43|	81	0.29	|0.29|
mean	78.68	∑|xi-x̅|	30	81.57	∑|xi-x̅|	29.72	80.71	∑|xi-x̅|	20.58
n	14			14			14		
CU	97.28%			97.40%			98.18%		

$$\text{Overall average CU} = \frac{\text{lateral 1 CU} + \text{ lateral 2 CU} \ldots\ldots + \text{ lateral 6 CU}}{6}$$

$$\text{CU} = \frac{(98.03\% + 98.20\% + 98.57\% + 97.28\% + 97.40\% + 98.18\%)}{6}$$

$$\text{CU} = \frac{587.66}{6} = \mathbf{97.94}\%$$

Overall average coefficient of uniformity of the system, CU = **97.94%**

Where, V is Volume, (ml)

Annex 3: Distribution uniformity (DU)

Emitter no.	Volume (ml)					
	lateral #1	lateral #2	lateral #3	lateral #4	lateral #5	lateral #6
1	78	78	78	76	77	78
2	79	78	78	76	78	78
3	80	79	78	76	79	78
4	80	80	79	77	79	80
5	81	80	79	77	80	80
6	81	80	80	77	82	80
7	82	81	80	78	82	81
8	82	81	80	80	83	81
9	83	81	81	80	83	81
10	83	82	81	80	83	82
11	83	82	81	80	84	82
12	84	82	81	82	84	82
13	84	83	82	82	84	83
14	85	84	82	83	84	84
mean of LQ	79	78.33	78	76	78	78
mean	81.79	80.79	80	78.86	81.57	80.71
DU	96.59%	96.96%	97.50%	96.32%	95.62%	96.64%
Overall average distribution uniformity of the system, DU						**96.61%**

Annex 4: Climatic data of the experiment site

Average annual rainfall of Bench Sheko Zone (1996-2011)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1996	0.2	38.4	77.8	141.9	218.5	210.4	190.6	306.1	291.7	198.4	129.4	235.8	2039.2
1997	79.4	33.2	135.7	172.2	159.6	387.1	227.4	283.2	284.6	171.5	74.3	56.3	2064.5
1998	46.5	67.7	163.2	325.5	218.8	199.0	232.1	203.0	262.9	149.4	267.7	79.8	2215.6
1999	80.8	45.3	170.1	245.5	178.6	221.2	263.0	278.9	215.2	246.1	88.8	34.9	2068.4
2000	62.6	75.3	112.2	280.8	267.9	187.0	295.6	310.2	230.0	276.0	70.2	84.2	2252.0
2001	22.2	76.0	79.5	161.3	246.7	221.0	400.4	271.3	132.6	253.4	86.3	24.4	1975.1
2002	26.5	49.3	129.3	148.5	206.0	234.0	257.0	286.0	143.0	216.7	87.3	113.4	1897.0
2003	83.3	43.7	134.1	137.2	126.1	225.1	249.5	197.5	126.4	201.3	68.9	111.1	1704.2
2004	32.7	48.7	116.4	222.8	111.8	320.7	178.5	310.8	275.2	138.5	115.7	104.3	1976.1
2005	31.2	44.1	49.3	266.1	386.0	142.9	253.5	278.6	213.3	145.9	123.4	116.2	2050.5
2006	35.4	83.8	150.0	130.8	220.6	278.9	133.3	452.9	226.8	164.8	200.1	112.5	2189.9
2007	74.6	68.8	104.9	205.7	267.0	234.2	378.5	245.5	256.1	147.2	96.6	121.3	2200.4
2008	36.1	43.1	125.1	154.2	189.5	173.5	409.4	156.6	273.1	157.5	56.7	121.3	1896.1
2009	26.0	95.4	168.0	109.0	119.0	188.0	257.0	238.0	213.3	169.0	190.7	45.7	1819.1
2010	131.0	121.6	81.0	66.0	95.9	272.6	298.4	156.0	219.0	228.0	11.0	14.0	1694.5
2011	107.3	143.8	159.2	130.8	315.5	246.4	233.3	212.6	216.8	164.8	190.0	87.6	2208.1
Total	875.8	1078.2	1955.8	2898.3	3327.5	3742.0	4257.5	4187.2	3580.0	3028.5	1857.1	1462.8	

Source: (Jimma Meteorological Station, 2012)

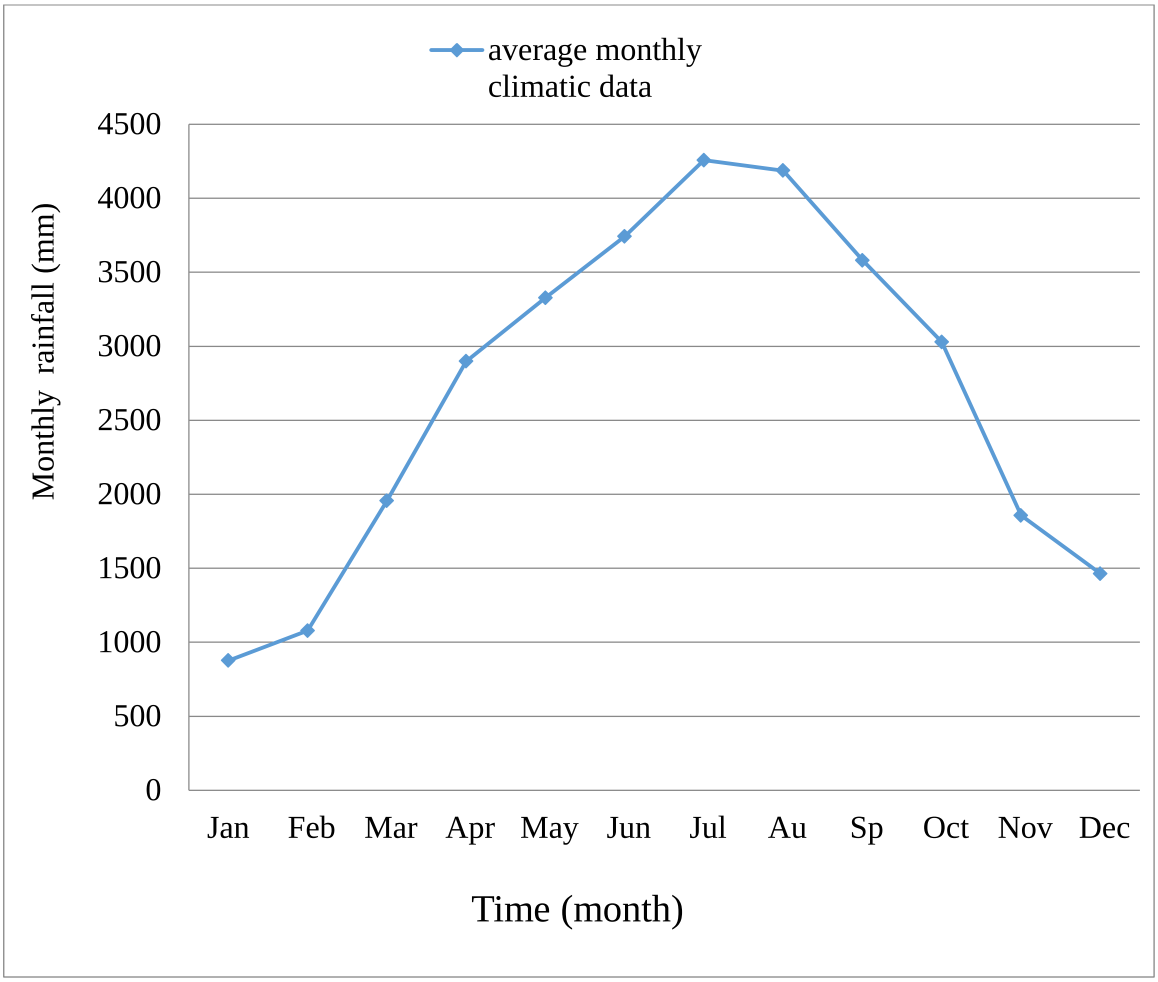

Figure: Average monthly rainfall of Bench Sheko Zone (1996-2011)

Room and outside daily temperature (^{0}C) of the experiment site during the growing season

Date	Crop date	Room and outside T^0	Time					average
			6:00:00 AM	9:00:00 AM	12:00:00 AM	3:00:00 PM	6:00:00 PM	
11/2/20	30	OT^0	18.5	25	28	27.5	24	24.6
		RT^0	18	28	32	27	23.5	25.7
12/2/20	31	OT^0	19	24	27.5	28	24	24.5
		RT^0	17.5	27	34	32	23	26.7
13/2/20	32	OT^0	19	24	28	27.5	24	24.5
		RT^0	18	27	34	33	23	27
2/3/20	50	OT^0	19	24	28	27	24	24.4
		RT^0	18	27	34	32	23	26.8
3/3/20	51	OT^0	18	23	27.5	27	24	23.9
		RT^0	17	27	34	32	23.5	26.7
4/3/20	52	OT^0	19	24	27	26.5	23.5	24
		RT^0	18	28	33	31	23	26.6
22/3/20	70	OT^0	20	27	29.5	25	28	25.9
		RT^0	17	34	38.5	28	26	28.7
23/3/20	71	OT^0	20	24	28	27	26	25
		RT^0	17.5	26	31	30.5	25	26
24/3/20	72	OT^0	19	22	28	32	27	25.6
		RT^0	17	27	32	30	26.5	26.5

Where, RT^0 is room (Greenhouse) temperature, and OT^0 is outside temperature (^{0}C) of the experiment site during the growing season

Average room and outside daily temperature (^{0}C) of the experiment site during the growing season

Date	Crop date	Average OT^0	Average RT^0
11/2/2020	30	24.60	25.70
12/2/2020	31	24.50	26.70
13/2/2020	32	24.50	27.00
2/3/2020	50	24.40	26.80
3/3/2020	51	23.90	26.70
4/3/2020	52	24.00	26.60
22/3/2020	70	25.90	28.70
23/3/2020	71	25.00	26.00
24/3/2020	72	25.60	26.50

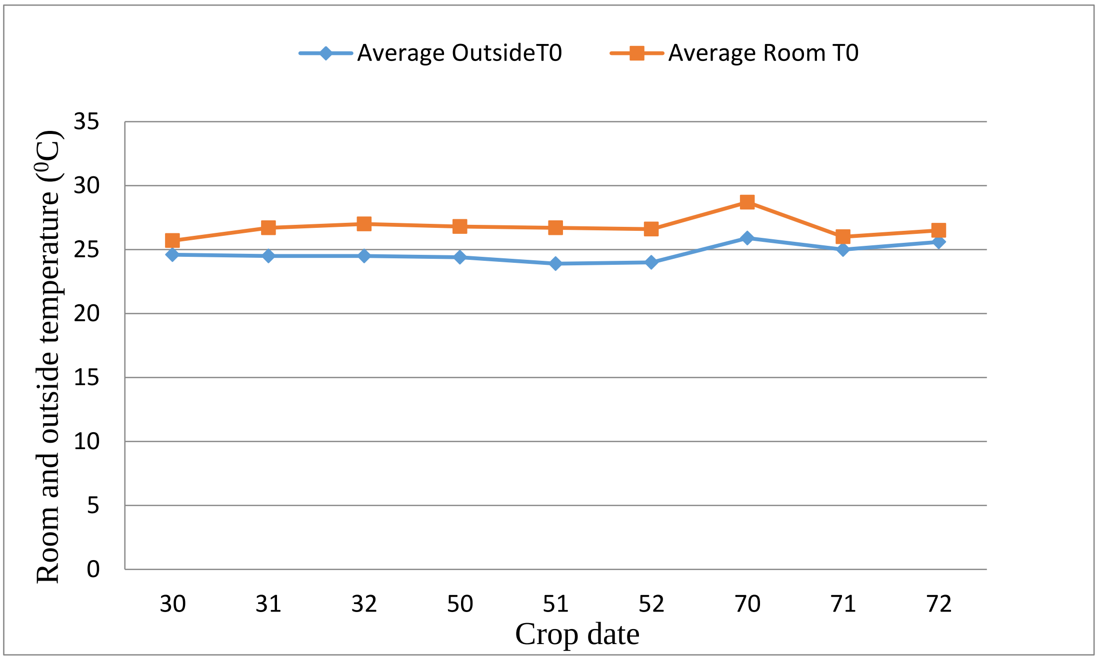

Figure: average room and outside temperature, (^{0}C)

Annex 5: Irrigation water delivery during the experimentation

Date	Days from sowing (day)	Day	Irrigation days	Expected max. Effective rooting depth, Rz (m)	Expected max. Surface area, AS (m^2)	Irrigation req't, (mm/cm)	Irrigation depth applied (mm)	Irrigation per plot (litre)				
								T1 (100%)	T2 (80%)	T3 (60%)	T4 (40%)	T5 (20%)
13/01/2020	1	Monday	Day 1	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
14/01/2020	2	Tuesday	Day 2	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
15/01/2020	3	Wednesday	Day 3	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
16/01/2020	4	Thursday	Day 4	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
17/01/2020	5	Friday	Day 5	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
18/01/2020	6	Saturday	Day 6	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
19/01/2020	7	Sunday	Day 7	0.100	0.010	0.747	7.740	6.28	6.28	6.28	6.28	6.28
20/01/2020	8	Monday	Day 8	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17
21/01/2020	9	Tuesday	Day 9	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17
22/01/2020	10	Wednesday	Day 10	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17
23/01/2020	11	Thursday	Day 11	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17
24/01/2020	12	Friday	Day 12	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17
25/01/2020	13	Saturday	Day 13	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17
26/01/2020	14	Sunday	Day 14	0.129	0.0175	0.747	9.636	14.17	14.17	14.17	14.17	14.17

27/01/2020	15	Monday	Day 15	0.157	0.025	0.747	11.728	24.63	19.7	14.78	9.85	4.93
29/01/2020	17	Wednesday	Day 16	0.157	0.025	0.747	11.728	24.63	19.7	14.78	9.85	4.93
31/01/2020	19	Friday	Day 17	0.157	0.025	0.747	11.728	24.63	19.7	14.78	9.85	4.93
02/02/2020	21	Sunday	Day 18	0.157	0.025	0.747	11.728	24.63	19.7	14.78	9.85	4.93
04/02/2020	23	Tuesday	Day 19	0.186	0.0325	0.747	13.894	37.93	30.34	22.76	15.17	7.59
07/02/2020	26	Friday	Day 20	0.186	0.0325	0.747	13.894	37.93	30.34	22.76	15.17	7.59
10/02/2020	29	Monday	Day 21	0.214	0.040	0.747	15.986	53.71	42.97	32.23	21.48	10.74
13/02/2020	32	Thursday	Day 22	0.214	0.040	0.747	15.986	53.71	42.97	32.23	21.48	10.74
16/02/2020	35	Sunday	Day 23	0.214	0.040	0.747	15.986	53.71	42.97	32.23	21.48	10.74
19/02/2020	38	Wednesday	Day 24	0.243	0.040	0.747	17.982	60.42	48.34	36.25	24.17	12.08
23/02/2020	42	Sunday	Day 25	0.243	0.040	0.747	17.982	60.42	48.34	36.25	24.17	12.08
27/02/2020	46	Thursday	Day 26	0.272	0.040	0.747	20.318	68.27	54.62	40.96	27.31	13.65
02/03/2020	50	Monday	Day 27	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
06/03/2020	54	Friday	Day 28	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
10/03/2020	58	Tuesday	Day 29	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
14/03/2020	62	Saturday	Day 30	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
18/03/2020	66	Wednesday	Day 31	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
22/03/2020	70	Sunday	Day 32	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
27/03/2020	75	Friday	Day 33	0.300	0.040	0.747	22.410	75.30	60.24	45.18	30.12	15.06
Total applied irrigation water							**457.44**	**1194.87**	**984.52**	**774.20**	**563.82**	**353.50**

Annex 6: ANOVA: Crop growth parameters, above ground plant dry biomass and seed yield versus treatment

Crop growth parameters	Source	DF	SS	MS	F	P	R-Sq. (%)
DE	Treatment	4	0.40	0.10	0.40	0.804	16.67
	Replication	2	0.00	0.00	0.00	1.000	
	Error	8	2.00	0.25			
	Total	14	2.40				
GC	Treatment	4	23.33	5.83	1.00	0.461	36.36
	Replication	2	3.33	1.67	0.29	0.759	
	Error	8	46.67	5.83			
	Total	14	73.33				
DF	Treatment	4	0.40	0.10	0.18	0.941	23.26
	Replication	2	0.93	0.47	0.85	0.463	
	Error	8	4.40	0.55			
	Total	14	5.73				
NN	Treatment	4	2936.74	734.19	10.63	0.003	72.93
	Replication	2	83.70	41.85	0.61	0.569	
	Error	8	552.66	69.08			
	Total	14	3573.10				
NBP	Treatment	4	3.16	0.79	2.90	0.093	34.52
	Replication	2	0.49	0.24	0.89	0.448	
	Error	8	2.18	0.27			
	Total	14	5.83				
PH	Treatment	4	771.60	192.90	10.43	0.003	72.95
	Replication	2	37.90	18.95	1.02	0.402	
	Error	8	147.99	18.50			
	Total	14	957.50				

NPP	Treatment	4	92.36	23.09	58.45	0.000	94.25
	Replication	2	0.74	0.37	0.93	0.433	
	Error	8	3.16	0.40			
	Total	14	96.25				
NSP	Treatment	4	1.88	0.47	13.34	0.001	78.44
	Replication	2	0.13	0.06	1.79	0.228	
	Error	8	0.28	0.04			
	Total	14	2.29				
HSW	Treatment	4	146.08	36.52	55.55	0.000	94.07
	Replication	2	3.78	1.89	2.87	0.115	
	Error	8	5.26	0.66			
	Total	14	155.12				
DB	Treatment	4	13.35	3.34	7.24	0.009	62.64
	Replication	2	0.23	0.12	0.25	0.783	
	Error	8	3.69	0.46			
	Total	14	17.26				
Y	Treatment	4	12.54	3.14	113.50	0.000	96.99
	Replication	2	0.07	0.04	1.34	0.316	
	Error	8	0.22	0.03			
	Total	14	12.83				

Abbreviations: DF is degree of freedom; SS is sum square; MS is mean square; P is probability and R-sq is regression sum of square.

BIOGRAPHICAL SKETCH

Ambachew Asnake Muluneh was born in Amhara regional state, East Gojam Zone, Motta Woreda, Beza Bizuhan Kebele in October, 1981 E.C. He attended his primary education in Beza Bizuhan Elementary School from 1993 to 1994 E.C., Motta Ewuketfan Elementary School from 1995 to 1996 E.C., Motta Primary school from 1997 to 1998 E.C., and his secondary and Preparatory School in Motta Secondary and Preparatory School from 1999 to 2002 E.C. He joined Debre Berhan University in 2003 E.C. and graduated with B.Sc. degree in Water Resource and Irrigation Management in 2005 June E.C.

After his graduation, he was employed in Dejen Woreda in Irrigation developmental agent from 01/12/2005 to 18/03/2007 E.C and in Mizan Agricultural, Technical, Vocational and Educational Training (ATVET) College as a junior Water Resource and Irrigation Management instructor in 23/03/2007 E.C. After two years, he joined the School of Graduate Studies, at Hawassa University Institute of Technology in 2009 E.C, for M.Sc degree in Irrigation and Drainage Engineering. Currently, he has been working at Mizan ATVET College as a senior Water Resource and Irrigation Management instructor.