

# Effects of Deficit Irrigation on Water Use Efficiency and Common Bean (*Phaseolus vulgaris* L.) Yields Under Furrow Irrigation System at Malkasa, Central Rift Valley of Ethiopia

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**Abstract:** Expansion of irrigated area combined with efficient management of water will enhance the attainment of food security and poverty alleviation goals of the country. Irrigation agriculture significantly contributes to food security, producing 40% of food and 70% of global freshwater withdrawals. This study investigates the effect of furrow irrigation on the yield of common beans in Ethiopia's central Rift Valley. The experiment was conducted on loam soil with three furrow irrigation methods: alternate, fixed, and conventional, and three deficit irrigation levels of 100, 85, 70, and 55%. The analysis of variance showed that the grain yield of common beans was significantly affected by irrigation levels and furrow irrigation methods. The highest grain yields, plant height, and above-ground biomass were obtained with 100% ETc under conventional furrow irrigation. The maximum water use efficiency obtained from alternative furrow 70% ETc (1.4kg/m<sup>3</sup>) followed by alternative furrow 55% ETc (1.38kg/m<sup>3</sup>). where as, the minimum was obtained from conventional 100% ETc. An irrigation application of 70% ETc under alternate irrigation could be considered optimal irrigation management in a water-scarce area.

**Keywords:** Furrow Irrigation, Deficit Irrigation, Common Bean, Water Use Efficiency

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## 1. Introduction

Irrigation agriculture significantly contributes to food security, producing 40% of food and 70% of global freshwater withdrawals [13]. Ethiopia's agriculture dominates the economy, contributing 45% to GDP and 85% to export earnings. Rain-fed agriculture, influenced by rainfall variability, affects crop production and productivity [21].

Water accessibility significantly impacts agricultural productivity [7]. Among the environmental factors affecting crop production, the water input, rainfall, and irrigation during the growing period explained a large part of the yield variability [4]. Irrigation development is increasingly implemented in Ethiopia, more than ever, to supplement rain-fed agriculture. It aims to increase agricultural productivity

and diversify the production of food and raw materials for the agro-industry [18]. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop [10]. The rift valley area is semi-arid with limited water resources and an increasing demand for water combined with high evapotranspiration rates.

The common bean (*Phaseolus vulgaris* L.) is an important food grain legume grown in the tropics and sub-tropics. It has the ability to fix atmospheric nitrogen and plays a significant role in crop rotation and sustainable cropping systems. Also, it plays a vital role in human nutrition, providing as much as 45% of the total protein consumed in parts of Africa. and introduced to Africa in the past four centuries, and the continent is the second-most important bean producer in the world next to Latin America, the center

of origin for the common bean [2]. The economic significance of the common bean in Ethiopia is quite considerable since it represents one of the major food and cash crops [13].

#### Objectives

The general objective of this study is to investigate the response of common beans to deficit irrigation on yield and water use efficiency

## 2. Materials and Methods

### 2.1. Description of the Study Area

The study was conducted during the warm cropping season of 2020 at the Malkasa Agricultural Research Center. It was found in the East Shoa zone within the Central Rift Valley of the country and contained within the Awash River Basin. The climate of the area is characterized as semi-arid with a low, erratic, and unimodal rainfall pattern. Loam and clay-loam soil textures are the dominant textural classes.

### 2.2. Treatments and Design

The treatments include four levels of irrigation, viz., 100, 85, 70 and 55% ETc and three furrow irrigation system, viz., alternate furrow irrigation, AFI, fixed furrow irrigation, FFI and conventional furrow irrigation, CFI.

Table 1. Treatment combination.

| Treatment | Description                                 |
|-----------|---|
| T1        | Alternative Furrow Irrigation with 100%Etc  |
| T2        | Alternative Furrow Irrigation with 85%Etc   |
| T3        | Alternative Furrow Irrigation with 70%Etc   |
| T4        | Alternative furrow Irrigation with 55%Etc   |
| T5        | Fixed Furrow Irrigation with 100%Etc        |
| T6        | Fixed Furrow Irrigation with 85%Etc         |
| T7        | Fixed Furrow Irrigation with 70%Etc         |
| T8        | Fixed Furrow Irrigation with 55%Etc         |
| T9        | Conventional Furrow Irrigation with 100%Etc |
| T10       | Conventional Furrow Irrigation with 85%Etc  |
| T11       | Conventional Furrow Irrigation with 70%Etc  |
| T12       | Conventional Furrow Irrigation with 55%Etc  |

ETc is Crop evapotranspiration, AFI is alternative furrow irrigation, CFI is conventional furrow irrigation and FFI is fixed furrow irrigation.

### 2.3. Soil Sampling and Analysis

The representative composite soils were collected from four depths (0–15, 15–30, 30–45, and 45–60 cm) before sowing to investigate the soil's physical and chemical properties. Soil particle size distribution was determined in the laboratory by the modified Bouyoucos hydrometer method using sodium hexameter phosphate as a dispersing agent [5]. The soil bulk density was determined from undisturbed soil samples using a core sampler of 5 cm diameter and 5 cm depth, oven dried, and determined by using equation 1 given by [11]

$$BD = \frac{W_s}{V_t} \quad (1)$$

where BD is the soil bulk density (gm/cm<sup>3</sup>). W<sub>s</sub> is mass of dry soil (g) and V<sub>t</sub> is total volume of soil in the core (cm<sup>3</sup>).

Soil samples for determination of moisture content at field capacity, FC, and permanent wilting point, PWP, were collected from 0–15, 15–30, 30–45, and 45–60 cm soil depth. The pressure plate and pressure membrane apparatus were used to get the moisture content at 1/3 and 15 bar for FC and PWP, respectively, and to compute the total available water within the root zone. Total available water (TAW) is computed as Eq. (2).

$$TAW = \frac{(FC - PWP) * BD * Z_d}{100} \quad (2)$$

where: TAW is the total available soil water in the root zone (mm/root depth), FC is Field capacity (%wt), PWP is Permanent wilting point (%wt), BD is bulk density of soil (g/cm<sup>3</sup>) and Z<sub>d</sub> is root depth (mm).

The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available water (RAW) given by [2].

$$RAW = p * TAW \quad (3)$$

where, RAW in mm, p is in fraction for allowable soil moisture depletion for no stress

### 2.4. Soil Chemical Characteristics

The soil chemical analyzed included soil pH, electrical conductivity, ECe, total OC and total nitrogen were analyzed at Melkassa Agricultural Research center soil laboratory Walkely black methods for determine organic matter and carbon [27]. Were Kjeldahl methods for total nitrogen determination [21]

Determination of Crop Water requirement and Irrigation requirement.

### 2.5. Crop Water Requirement

The daily reference evapotranspiration (ET<sub>o</sub>) was computed by the CROPWAT model version 8.0 based on actual climatic data, and the daily evapotranspiration (ET<sub>c</sub>) was determined by multiplying the crop coefficient, K<sub>c</sub>, by the daily reference evapotranspiration (Eq 4). The crop coefficient was collected from FAO Irrigation and Drainage Paper 33 [6] and adjusted for the area. The K<sub>c</sub> values for respective growth stages after adjustment were 0.37, 1.15, and 0.4 for the initial, mid-season, and late-season growth stages, respectively.

$$ET_c = ET_o * K_c \quad (4)$$

where, ET<sub>c</sub> is crop evapotranspiration (mm/day), K<sub>c</sub> is crop factor in fraction and ET<sub>o</sub> is reference evapotranspiration (mm/day).

### 2.6. Irrigation Water Requirement

The daily crop evapotranspiration was deducted from the net irrigation depth for the control treatment (100% ET<sub>c</sub>)

until the cumulative subtraction from the net irrigation depth applied approached to nil. Irrigation was applied when the cumulative deficit irrigation approach to net depth of irrigation required for the control treatment. The effective root depth of the crop was taken as 0.30m at planting and increase linearly until the crop reaches mid-season. The net irrigation requirement was computed as (Eq. 5).

$$IR_n = CWR - P_{eff} \quad (5)$$

Where  $IR_n$  is the net irrigation requirement (mm),  $CWR$  is the crop water requirement (mm) and  $P_{eff}$  is the effective rainfall (mm).

## 2.7. Field Application Efficiency and Gross Irrigation Water Requirement

Field irrigation application efficiency,  $E_a$  is the ratio of water directly available in crop root zone to water received at the field inlet [10]. For this particular experiment, irrigation efficiency was taken as 60%. Based on the net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was calculated as.

$$dg = \frac{I_n}{E_a} \quad (8)$$

where:  $dg$  is gross irrigation (mm),  $I_n$  is net irrigation (mm),  $E_a$  is application efficiency

Irrigation water was applied to each experimental plot using 3-inch Parshall flume. Calculated gross irrigation was finally applied to each experimental plots based on the treatments proportion. The time required to deliver the desired depth of water into each furrow or plot was calculated using equation given by Eq. 9 [19].

$$t = \frac{A * dg}{6q} \quad (9)$$

where,  $dg$  is gross irrigation depth (cm),  $A$  is plot area ( $m^2$ ),  $q$  is flow rate (l/s) and  $t$  is time (min).

Water Use Efficiency.

Water use efficiency was determined based on the ratio of yield per hectare to the net irrigation depth plus effective rainfall as kg of common bean yield per  $m^3$  of water (Eq 10).

$$WUE = \frac{Y}{ET_c} \quad (10)$$

where,  $WUE$  is water use efficiency ( $kg/m^3$ ),  $Y$  is actual grain yield ( $kg/ha$ ) and  $ET_c$  is the seasonal crop water consumption ( $m^3/ha$ ).

## 2.8. Data Collection

The data were collected from three central ridges (4 m\* 1.8 m or 7.2  $m^2$ ). Randomly five plants were selected for growth and yield component data. The crop was harvested in May 2020 when 90% of the seed become completely mature.

*Plant height, branch number per plant, pods per plant and*

*seeds per pods.*

Plants were randomly selected and tagged from each plot for data measurement. Plant height, branch number per plant, pods per plant and seed per plant in each experimental unit were determined from selective five samples in the central three ridges.

*Grain yield, 100 seed weight and above ground biomass.*

Data on yield of common bean in each experimental unit was collected by weighing the yield obtained after trashing. Finally, the yield obtained from the sample area was converted to hectare base by Eq 11.

$$Yield (kg/ha) = \frac{yield \text{ of sample } (kg) * 10000}{\text{sample area}} \quad (11)$$

The above ground dry biomass was determined by harvesting all plants from net plot and weighted after sun drying to constant weight. Finally, the above ground biomass obtained from the sample area was converted to hectare base.

## 2.9. Yield Response Factor

The  $K_y$ , was obtained by the angular coefficient of the regression line passing through the origin between the relative evapotranspiration decrement and the relative production decrements observed in the different irrigation treatments [10]. Eq. (12)

$$\left[1 - \frac{Y_a}{Y_m}\right] = k_y \left[1 - \frac{ET_a}{ET_m}\right] \quad (12)$$

where,  $Y_m$  is maximum yield ( $kg \text{ ha}^{-1}$ ),  $Y_a$  is actual yields ( $kg \text{ ha}^{-1}$ ),  $ET_m$  is maximum Evapotranspiration ( $m^3 \text{ ha}^{-1}$ ),  $ET_a$  is actual Evapotranspiration ( $m^3 \text{ ha}^{-1}$ ) and  $K_y$  -is the yield response factor.

## 2.10. Statistical Analysis

The collected data were subject to analysis of variance (ANOVA) appropriate to factorial RCBD analysis using statistical analysis system (SAS) package. Simple correlation analysis was also used to see the association of growth parameters, yield component, yield and water use efficiency.

# 3. Results and Discussions

## 3.1. Soil Physical Properties

Physical soil properties analysis showed that the average composition of clay, silt, and sand percentages were 26.5, 40, and 33.5, respectively (Table 2). Thus, according to the USDA soil textural classification, the particle size distribution of the experimental site revealed that the soil textural class is loam soil, and bulk density shows a slight increase with depth. The average weighted bulk density of the experimental site was  $1.16 \text{ g/cm}^3$ , and soil moisture content on a weight basis at FC and PWP was 36.9% and 22.25%, respectively. The volumetric value of TAW was 101.6mm with a common bean root depth of 0.60m and

40.6mm of readily available water (RAW).

**Table 2.** Analysis of physical properties of soil for experimental site.

| Soil depth (cm) | % Particle sizedistribution |      |      | Textural Class | Bulk density (g/cm <sup>3</sup> ) | FC mass base (%) | PWP mass base (%) | TAW (mm/ depth) |
|-----------------|-----------------------------|------|------|----------------|-----------------------------------|------------------|-------------------|-----------------|
|                 | Clay                        | Silt | Sand |                |                                   |                  |                   |                 |
| 0-15            | 24.0                        | 42.5 | 33.5 | Loam           | 1.10                              | 33.9             | 20.9              | 21.5            |
| 15-30           | 26.5                        | 45.0 | 28.5 | Loam           | 1.16                              | 36.7             | 22.0              | 25.6            |
| 30-45           | 28.0                        | 36.0 | 36.0 | clay loam      | 1.19                              | 39.4             | 23.2              | 28.9            |
| 45-60           | 26.5                        | 37.5 | 36.0 | Loam           | 1.20                              | 37.6             | 22.9              | 26.5            |
| Average         | 26.5                        | 40.0 | 33.5 | Loam           | 1.16                              | 36.9             | 22.3              | 25.6            |

TAW=Total water available, FC=Field capacity and PWP= permanent wilting point

### 3.2. Crop Water Requirement

Seasonal crop water requirement of common bean was obtained from the seasonal water application depth from sowing to harvest. As shown in Table 3, actual seasonal crop water requirement was 501.1mm/season with common irrigation depth of 21.6 mm and effective rain fall of 54.4mm.

**Table 3.** Seasonal irrigation water application for common bean in (mm).

| Furrow irrigation system | Irrigation level |       |       |       |
|--------------------------|------------------|-------|-------|-------|
|                          | 100%             | 85%   | 70%   | 55%   |
| CFI                      | 501.1            | 437.3 | 373.6 | 309.8 |
| AFI                      | 288.6            | 256.7 | 224.8 | 192.9 |
| FFI                      | 288.6            | 256.7 | 224.8 | 192.9 |

AFI=Alternative furrow irrigation, CFI=Conventional furrow irrigation, FFI= fixed furrow irrigation.

Deficit and furrow irrigation on Agronomic characteristics of common bean.

Days to flowerings and maturity.

Days to flowering and maturity were significantly influenced by the treatment. The longest days to maturity (96 days) were recorded in the experimental plots that received 100% ETc with the CFI irrigation system. The possible reason for days to maturity being longer under higher rates of irrigation was that optimal irrigation helped to create a more conducive soil micro-environment for vegetative growth of common bean development over an extended period of time. The finding is in line with [12], who reported that the length of days to maturity of onions became longer as the frequency and amount of water application increased. Similarly, [26] also showed a significant decrease in the number of days to flowering of the common bean under the deficit level. The shortest days to maturity (87.6 days) were recorded from FFI and AFI with 55% ETc application (Table 4). This is due to the fact that plants under water deficit tend to complete their life cycle shortly, which enables them to escape from the unfavorable conditions by ending their life cycle a few days earlier than those under normal or high soil moisture conditions. [3] Results obtained under the present investigation are, in general, in line with those obtained by [1], who reported that water stress leads to a significant decrease in the number of days to flowering and maturity stages of crops.

Plant height.

The interaction effect of irrigation methods by level of

irrigation water significantly affected the plant height of common beans (Table 5). The highest plant height (77.1cm) was recorded at the irrigation level of 100% ETc in CFI, which is statistically equivalent to 69.2cm measured at 85% ETc. The shortest plant height of 53.5cm was recorded from deficit irrigation of 55% ETc FFI and was significantly inferior to all other treatments. Generally, the mean showed a decreasing trend in plant height with decreasing water application depth with any furrow irrigation methods, indicating that there is a direct relationship between vegetative growth of the crop and water depth. The increase in plant height with an increase in irrigation water could be mainly due to the better availability of soil moisture, which has enhancing effects on the vegetative growth of plants by increasing cell division and elongation [22].

Number of pod, Branch per plant and 100seed weight.

The interaction effect of irrigation methods by level of irrigation water significantly affected the number of pods per plant (Table 4). The highest pod number of 37 was recorded at the irrigation level of 100% ETc CFI. The treatment of 55% ETc CFI gave the lowest pod per plant. Increasing pod numbers per plant with increasing irrigation depth indicates that pod formation was initiated by the better moisture available in the soil. The present results also showed that the level of water stress imposed in this experiment induced a significant reduction in the number of pods per plant, which is in line with [20].

The interaction effect of irrigation methods by level of irrigation water significantly affected the number of seeds per pod (Table 4). The average seed number per pod of 6.7 was recorded from the irrigation level of 85% ETc CFI, which was superior to the other treatment. The seed formed in the pod decreased with an increase in deficit level because soil moisture stress limited the formation of pods and their development, which directly affected the seed number per pod. The seed formed is not in good health and is not markable, especially on deficit treatment, because moisture stress restricts photosynthesis and initiates the crop's life cycle before the formed seed is mature.

**Table 4.** Effects of deficit and furrow irrigation on agronomic characteristics of common bean.

| Treatment  | DF                 | DM                 | PH                 | BNP               | PNP                |
|------------|--------------------|--------------------|--------------------|-------------------|--------------------|
| AFI (100%) | 41 <sup>c</sup>    | 91 <sup>c</sup>    | 68.3 <sup>bc</sup> | 8.1 <sup>a</sup>  | 31.4 <sup>b</sup>  |
| AFI (85%)  | 39.7 <sup>cd</sup> | 89.7 <sup>cd</sup> | 63.8 <sup>b</sup>  | 7.9 <sup>ab</sup> | 28.8 <sup>bc</sup> |
| AFI (70%)  | 38 <sup>ef</sup>   | 88.7 <sup>de</sup> | 60.5 <sup>bc</sup> | 7.4 <sup>ab</sup> | 25.2 <sup>cd</sup> |

| Treatment  | DF                  | DM                  | PH                  | BNP               | PNP                  |
|------------|---------------------|---------------------|---------------------|-------------------|----------------------|
| AFI (55%)  | 37 <sup>f</sup>     | 87.7 <sup>c</sup>   | 53.6 <sup>cd</sup>  | 7.8 <sup>ab</sup> | 23.6 <sup>cd</sup>   |
| FFI (100%) | 41 <sup>c</sup>     | 91 <sup>c</sup>     | 65.7 <sup>bcd</sup> | 8.2 <sup>a</sup>  | 30.93 <sup>b</sup>   |
| FFI (85%)  | 39.3 <sup>de</sup>  | 89.3 <sup>cde</sup> | 56.5 <sup>bcd</sup> | 6.5 <sup>b</sup>  | 27.73 <sup>bcd</sup> |
| FFI (70%)  | 38.67 <sup>de</sup> | 89 <sup>de</sup>    | 57.2 <sup>d</sup>   | 7.8 <sup>ab</sup> | 24.3 <sup>cd</sup>   |
| FFI (55%)  | 37 <sup>f</sup>     | 87.7 <sup>c</sup>   | 53.5 <sup>c</sup>   | 7.3 <sup>ab</sup> | 23.3 <sup>cd</sup>   |
| CFI (100%) | 46 <sup>a</sup>     | 95.7 <sup>a</sup>   | 77.1 <sup>a</sup>   | 7.6 <sup>ab</sup> | 37.2 <sup>a</sup>    |
| CFI (85%)  | 43.3 <sup>b</sup>   | 93.3 <sup>b</sup>   | 69.2 <sup>b</sup>   | 8.3 <sup>a</sup>  | 23.8 <sup>cd</sup>   |
| CFI (70%)  | 41 <sup>c</sup>     | 91 <sup>c</sup>     | 63.2 <sup>cd</sup>  | 7.1 <sup>ab</sup> | 26.2 <sup>bcd</sup>  |
| CFI (55%)  | 38.3 <sup>de</sup>  | 89 <sup>de</sup>    | 58.4 <sup>c</sup>   | 7.2 <sup>ab</sup> | 23.1 <sup>d</sup>    |
| CV         | 2.45                | 1.17                | 12.65               | 10.98             | 12.24                |
| LSD(0.05)  | 0.8*                | 0.86*               | 13.52*              | Ns                | 2.713*               |

Means followed by the same letter are not significantly different at 5% level of significance.

BNP=Branch number per plant, DF=days to flowering, DM= days to maturity, PH=plant height, PNP= pods number per plant and SNP= seed number per pods.

Effect of furrow and Deficit level on common bean yield and yield component.

Grain yield.

The grain yields of common bean was significantly ( $p < 0.05$ ) affected by irrigation levels and furrow irrigation systems. CFI 100%ETc gave the highest grain yield of (3473.3kg/ha), has no significant difference with CFI 85%ETc (3213.9kg/ha). The application of 85 and 100% of the water demand of common bean in Alternative furrows (2284.2 kg/ha) and fixed furrow irrigation (2461.5 kg/ha), respectively. The lowest grain yield of common bean (1389.7 kg/ha) was harvested from plots irrigated with 45% reduced water demand of common bean in fixed furrows. Results yield of common bean increased with increase in irrigation water amount with furrow irrigation methods which is a linear relationship. Similar results were also reported by [16] who showed that dealing with improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield i.e., if the amount of water applied decreases similarly the crop yield will also drop. The water stress induced by AFI and reduced level of irrigation water enhances the nutrient use by stimulating plant growth through extending the root system to the deeper soil layers [17] Thus, controlled irrigation water supply as in the case of 70% of the crop demand improved the yield by enhancing the plant nutrient-use efficiency.

*Above ground dry bio-mass.*

The above ground dry biomass of common bean was significant ( $p < 0.05$ ) by irrigation methods and level of irrigation water. The above ground dry biomass of common bean was the highest in the convtional furrows irrigated with full water demand of common bean (4216.2kg/ha). The same irrigation method along with 85% of the water demand of common bean also brought statistically equivalent above ground dry biomass of common bean(3851.9 kg/ha). The application of 85 and 100% of the water demand of common bean in Alternative furrows (3051.9 kg/ha) and fixed methods of irrigation (3102.3 kg/ha), respectively. The lowest above ground dry biomass of common bean (2675.5 kg/ha) was harvested from plots irrigated with 45% reduced water demand of common bean in fixed furrows. Biomass

accumulation have strong positive correlation with yield under stress condition. From the result of the study, as a stress level increase the above ground dry biomass reduced significantly.

**Table 5.** Interaction Effects of furrow irrigation by deficit on yield, biomass and water use efficiency of common bean.

| Treatment  | Yield (kg/ha)        | Above ground biomass (kg/ha) | WUE (kg/m <sup>3</sup> ) |
|------------|----------------------|------------------------------|--------------------------|
| CFI (100%) | 3473.3 <sup>a</sup>  | 4216.2 <sup>a</sup>          | 0.82 <sup>c</sup>        |
| CFI (85%)  | 3213.9 <sup>ab</sup> | 3851.9 <sup>ab</sup>         | 0.87 <sup>de</sup>       |
| CFI (70%)  | 3128.2 <sup>ab</sup> | 3150 <sup>bc</sup>           | 1.05 <sup>bcd</sup>      |
| AFI (100%) | 2656.3 <sup>bc</sup> | 3406.5 <sup>abc</sup>        | 1.25 <sup>bc</sup>       |
| FFI (100%) | 2461.5 <sup>bc</sup> | 3102.3 <sup>bc</sup>         | 1.16 <sup>bcd</sup>      |
| AFI (85%)  | 2284.2 <sup>bc</sup> | 3052.3 <sup>bc</sup>         | 1.26 <sup>bcd</sup>      |
| FFI (85%)  | 2148 <sup>c</sup>    | 2833.3 <sup>bc</sup>         | 1.19 <sup>cde</sup>      |
| FFI (70%)  | 1978.2 <sup>c</sup>  | 2949.1 <sup>bc</sup>         | 1.3 <sup>b</sup>         |
| AFI (70%)  | 2089.2 <sup>c</sup>  | 3069.4 <sup>bc</sup>         | 1.4 <sup>a</sup>         |
| CFI (55%)  | 2030.4 <sup>c</sup>  | 3100.5 <sup>bc</sup>         | 0.87 <sup>cde</sup>      |
| AFI (55%)  | 1608 <sup>d</sup>    | 3196.3 <sup>bc</sup>         | 1.38 <sup>b</sup>        |
| FFI (55%)  | 1389.7 <sup>d</sup>  | 2675.5 <sup>bc</sup>         | 1.19 <sup>cde</sup>      |
| CV         | 13.9                 | 16.99                        | 15.85                    |
| LSD(0.05)  | 607.6*               | 446.36*                      | 0.153*                   |

Means with the same letter are not significant at =0.05 \*=significant at 0.05, Ns=non significant.

### 3.3. Effects of Irrigation Level and Irrigation System on WUE

Water use efficiency (WUE) of common bean was significantly influenced ( $p < 0.01$ ) by irrigation methods and level of irrigation water. This is because of the difference in percentage of water actually converted to evapotranspiration out of the total amount applied. This is consistent with the significant improvements in water use efficiency that have been associated with alternate furrow irrigation [29]. The maximum water use efficiency obtained from alternative furrow 70% ETc (1.4kg/m<sup>3</sup>) followed by alternative furrow 55% ETc (1.38kg/m<sup>3</sup>). where as, the minimum was obtained from conventional 100% ETc. The amount of water saved ranges from 15% to 70% of control treatment. This implies that deficit irrigation enhances water use efficiency. Different research conducted by [15] stated that higher water use efficiency was obtained from 70 to 85% water deficit level which similar with the current findings. [28] Investigated that yield increment is generally accompanied with an increase in the total water use, higher water productivity was recorded with the optimum deficit application level.

Attaining higher yields with increased water use efficiency is only economical when the increased gains in crop yield are not offset by increased costs of other inputs. Consequently, the intention of deficit irrigation is to improve yield and water use efficiency by efficiently managing agricultural water. This suggests that increasing the irrigated areas with the saved water could compensate for any yield loss due to deficit irrigation. Here in, crop water requirement under (100% ETc) was about 501.1 mm and that under 55% ETc with fixed and alternative furrow irrigation system was about 192.9 mm, on an average. The water saved which was about 308.9 mm could be used to irrigate 0.7 ha common bean cropped land or similar crop and

extra yield might be produced as a result of saved water. The result agreed with [12] who reported that by 40% DI throughout

the growing season, a water saving of about 272 mm may be used to irrigate additional half a hectare cropped area.

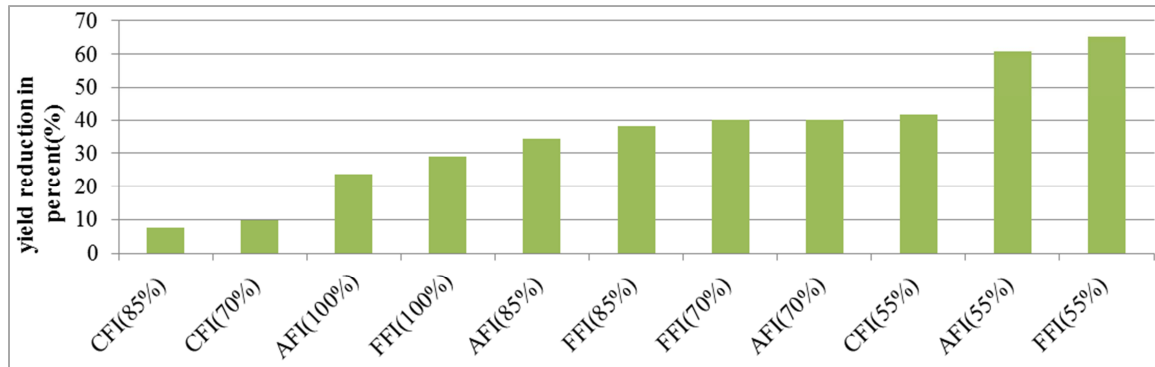


Figure 1. Yield reduction of common bean due to deficit irrigation.

As shown in figure 1 the percent of yield reduction is increased as the amount of water saved increased, besides the water application system has a significant impact on yield reduction. Fixed furrow irrigation system and 100%ETc irrigation level treatment combinations have a minimum of 29.1% yield reduction as compared with the control treatment. Whereas alternate furrow irrigation showed 23.5% yield reduction to save 50 % irrigation water. [25] reported that AFI exhibited 50% reduction in irrigation water without significant variation of grain yield. This is achieved due to precise measurement and application of irrigation water minimizing percolation losses in alternate furrow irrigation. Furthermore the scheduling of irrigation was done by soil moisture observation and most of the irrigation events were performed to replenish soil moisture within field capacity of the soil. This reveals that well scheduled and controlled irrigation can also help coping with water scarcity along with appropriate irrigation water application method.

### 3.4. Effects of Deficit and Furrow Irrigation System on Yield Response Factor

Observed yield response factors ( $K_y$ ) for common bean from 0.4 to 1.09, the lowest and highest being for 70%ETc with conventional and 55% ETc with conventional furrows irrigation methods, respectively (Table 6). The  $K_y$  observed was decreasing as irrigation water application decreasing.

Treatments receiving 100%ETc with alternative and 85%ETc with conventional furrow irrigation methods showed almost similar yield response factor. The higher  $K_y$  values indicate that the crop will have a greater yield loss when the crop water requirements are not met and sensitive to soil moisture deficit.

Different studies revealed that yield response factor varies for different crop types and deficit conditions. The result of this experiment was almost the same with that of the experiment by Rosadi (2007) on soybean. The result showed that only those treatments with a lower crop yield response factor ( $K_y < 1.0$ ) can generate significant savings in irrigation water through deficit irrigation. [14] report the  $K_y$  value for field crops goes from 0.2 to 1.15 which agrees with this results.

The result of this experiment indicated that effects of deficit level and furrow irrigation system treatments influence common bean yield. When  $K_y > 1$ , the crop is very sensitive to water deficit with proportional larger yield reductions;  $K_y < 1$ , the crop is more tolerant to water deficit and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use;  $K_y = 1$ , the yield reduction is directly proportional to reduced water use [6]. Therefore, application of 55% ETc with conventional furrow irrigation system resulted in pronounced decrease in yield ( $K_y = 1.09$ ) compared to the other deficit irrigation and furrow irrigation system.

Table 6. Effects of deficit and furrow irrigation on yield response factor of common bean.

| Treatment | Yield (kg/ha) | ETc(mm) | $1 - \left(\frac{Y_a}{Y_m}\right)$ | $1 - \left(\frac{ET_a}{ET_m}\right)$ | $K_y = \frac{1 - \left(\frac{Y_a}{Y_m}\right)}{1 - \left(\frac{ET_a}{ET_m}\right)}$ |
|-----------|---------------|---------|------------------------------------|--------------------------------------|---|
| CFI(100%) | 3473.3        | 501.1   | 0.000                              | 0                                    | —   |
| CFI(70%)  | 3128.2        | 373.57  | 0.099                              | 0.25                                 | 0.40  |
| AFI(100%) | 2656.3        | 288.5   | 0.235                              | 0.42                                 | 0.56  |
| CFI(85%)  | 3213.9        | 437.3   | 0.075                              | 0.13                                 | 0.57  |
| FFI(100%) | 2461.5        | 288.5   | 0.291                              | 0.42                                 | 0.69  |
| AFI(85%)  | 2284.2        | 256.67  | 0.342                              | 0.49                                 | 0.70  |
| AFI(70%)  | 2089.2        | 224.78  | 0.398                              | 0.55                                 | 0.72  |
| FFI(85%)  | 2148          | 256.67  | 0.382                              | 0.49                                 | 0.78  |
| FFI(70%)  | 1978          | 224.78  | 0.431                              | 0.55                                 | 0.78  |
| AFI(55%)  | 1608          | 192.9   | 0.537                              | 0.62                                 | 0.87  |
| FFI(55%)  | 1389          | 192.9   | 0.600                              | 0.62                                 | 0.97  |
| CFI(55%)  | 2030.4        | 309.8   | 0.415                              | 0.38                                 | 1.09  |

ETa = actual evapotranspiration, ETm= maximum evapotranspiration, Ya = actual yield, Ym= maximum yield, ky= crop response factors.

## 4. Summary, Conclusion and Recommendation

### 4.1. Summary and Conclusion

The majority of cropping system in our country is rain-fed agriculture and heavily reliant on rainfall and productivity and production are strongly influenced by climatic variability. However, the proper management of irrigation water has received inadequate attention. Efficient use of irrigation water using appropriate irrigation system and management is an important consideration for improved crop production. The appropriate irrigation system and management in agriculture adopted to have significant impact on water saving is the integrated use of deficit irrigation with different furrow irrigation method.

It was necessary to determine optimum supply of irrigation water under furrow irrigation method for common bean. Hence this study initiate to study the effect of deficit irrigation level and furrow irrigation methods on growth and grain yield of common bean with three deficit irrigation levels of application, viz. 100% 85% ETc, 70% ETc and 55% ETc, and three furrow irrigation methods, viz. conventional, Alternative and fixed furrows and the experiment had a total of twelve treatment combinations. The experiment was designed as a two-factor under Randomized Complete Block Design arrangement with three replications. The effect of irrigation treatments were tested using yield and yield components: i.e. plant height, branch number per plant, pod number per plant, seed number per pod and above ground dry biomass. The water in terms of crop water use efficiency for each irrigation treatment was also evaluated.

The most important result from the investigation was that the interaction effect of irrigation methods by level of irrigation water was significantly influence ( $p < 0.05$ ) the days to maturity, plant height, pod number per plant, above ground dry biomass, water use efficiency and grain yield of common bean. The grain yield and above ground dry biomass of common bean was the highest in the CFI(100%) and lowest in FFI (55%) respectively.

The interaction effect of irrigation methods by level of irrigation water was significantly influence the water use efficiency of common bean. The maximum water use efficiency obtained from alternative furrow 70% ETc(1.4kg/m<sup>3</sup>) followed by alternative furrow 55% ETc(1.38kg/m<sup>3</sup>). where as, the minimum was obtained from conventional 100% ETc. As the deficit level decreased the water use efficiency also decreased at some extent. The reason for this finding is the grain yield produced by the applied less water is very low because of a high level of moisture stress generated in the root zone.

Generally, among all irrigation treatments 55%ETc deficit irrigation level applied under AFI and FFI method was efficient in conserving significant irrigation water as compere to other treatment, but high yield penalty was recorded from this treatment. The investigation showed that yield increased

when irrigation level increased from 55ETc% deficit irrigation level to full application level of 100% ETc. Based on crop yield and water saved, the optimal WUE of 1.4kg/m<sup>3</sup> was obtained from AFI with 70%ETc application. Considering crop yield and water use efficiency, deficit irrigation application of 70%ETc under alternate irrigation could be considered as optimal irrigation management in a water scarce area of central rift vallely of Ethiopia. In conclusion, proper management of irrigation water alternative furrow irrigation (AFI) can be used and save a substantial amount of irrigation water for additional production of common bean yield.

### 4.2. Recommendation

Based on the findings of this experiment from one season experiment and one location the following important issue recommendations are made:

- 1) Conventional furrow irrigation gave the highest yield should be evaluated under different agro climatic and soil conditions in order to give sound recommendation for wide range of common bean production systems.
- 2) Better WUE were obtained in the AFI with 70% water demand of common bean with optimum grain yield is need further investigation.
- 3) In water limiting area alternative furrow irrigation (AFI) is possible to get better yield and water use efficiency and where as excess water area CFI method can be practiced and gave high yield.

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## Conflicts of Interest

The authors declare tha they have no conflict of interest.

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