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# Effect of Moisture Stress Level on Growth Components of Common Bean (*Phaseolus vulgaris* L.) at Melkasa Central Rift Valley of Ethiopia

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## Abstract

The study was carried out at Melkassa Agricultural Research Center, Central Rift Valley of Ethiopia. The objective was to determine irrigation level under soil moisture stress condition and investigate the effect of soil moisture stress on common growth components under scarce water resource condition. The treatment comprised seven moisture levels (100, 85, 75, 65, 55, 45 and 35% ETc) and laid out in randomized complete block design with three replications. Results indicated that, both days to flowering and physiological maturity had shown decreasing trend with increasing soil moisture stress level. Significance differences($p<0.05$) were also observed on days pod maturity, Days to attain 50% flowering, Leaf area and relative leaf water content among irrigation water level whereas, high significance difference($p<0.01$) was observed among treatment on plant height and Leaf area index. Treatment stressed by 55% and 65% of its crop water requirement records minimum days (86 and 85.67) respectively to first pod maturity. Full irrigation has maximum relative leaf water content at development (67.58%) and mid-season (74.37%) growing stage, which is statistically similar with those treatments stressed by 15 and 25% crop water requirement. The largest plant height of (70.58 cm) was recorded from full irrigation (100% ETc), while the smallest plant height was observed under treatment stressed by 65% (48.95 cm) which is inferior to all other treatments. Leaf area of 21.4cm2 was recorded from 75% ETc treatment which is not significant from control treatment (85 and 100% ETc).The reduction of irrigation water amount from 100% ETc to 35% ETc showed decreasing gradient of leaf area and leaf area index.

## Article Info

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## Keywords

yield component, plant height, leaf area index, maturity, growth stage, *Phaseolus vulgaris* L.

## Introduction

Legume crops are important component of many agricultural systems and are major contributor to global food systems. Common bean (*Phaseolus vulgaris* L.) is planted worldwide on approximately 26 million hectares (Emam *et al.*, 2010) and it is the most widely grown legume crop in Ethiopia. It is an important source of food, income, and soil fertility management (Abera *et al.*, 2020). It is largely cultivated by smallholder farmers as cash crops in the Rift Valley area, and in the southeastern and southwestern parts of the country, as a sole crop or intercropped with non-legumes, such as maize, sorghum, enset, and coffee (Katungi *et al.*, 2010). In the past, crop irrigation requirements did not consider limitations of the available water supplies. Therefore practice of new irrigation technologies such as deficit irrigation is one of the water management strategies to conserve water resources in addition to increasing water use efficiency in agriculture (Horst *et al.*, 2005)

Decreasing of water level in common bean minimizes cell turgor, which, in turn, reduces leaf expansion, induces stomata closure and reduces plant physiological processes, ultimately compromising grain production. Leaf area is one of the most important parameters in the evaluation of plant growth, since it is interconnected with photosynthetic rate (Taiz *et al.*, 2017).

When water stress occurs during a specific crop development period, the yield response can vary depending on irrigation level and time of deficit occurrence (Steduto *et al.*, 2009). The yield response factor, which relates relative yield decrease to relative evapotranspiration deficit, is the proportionality factor between relative yield loss and relative reduction in evapotranspiration.

Legume crop such as, common bean respond differently to soil moisture stress levels. But there is no sufficient information on what stress level the crop is susceptible for moisture stress. Therefore, appropriate information on irrigation at different soil moisture level on yield components of common bean is useful for effective irrigation water management.

## Materials and Methods

### Climatic characteristics of study site

The field experiment was conducted at Melkassa Agricultural Research Center; MARC. The area lies at about 107 km from Addis Ababa in East Shoa zone 17 km Southeast of Adama town. The climate of the area is characterized as semi-arid with uni-modal low and erratic rainfall pattern.

About 60%of the total rainfall of the area occurs from start of July to mid of September, with its peak in the month of July (Figure 1). The mean maximum and minimum monthly rainfall values are 222 mm and 8mm occurring in the month of July and December, respectively. The average maximum temperature varies from 26°C to 31°C while the mean minimum temperature varies from 10°C to 16°C.

### Design of the Experiment

The study was conducted by using furrow Irrigation water application methods and it includes six moisture stress level, viz., 85, 75, 65,55, 45 and 35% ETc and control irrigation of 100% ETc. A total of seven treatments**.** Control irrigation implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT program to refill the soil to its field capacity. The experiment was laid out in randomized complete block design (RCBD) with three replications resulting in a total of 21 plots.

The treatment setting and layout are shown in (Table 1). Treatments were arranged in each of the three blocks randomly based on randomization using R-software version 4.0.0.

### Procedure and Agronomic Practice of the experiment

Six moisture stress treatments consisting of 35%ETc, 45%ETc, 55%ETc, 65%ETc, 75%ETc, 85%ETc and full irrigation (100% ETc) were used.100% crop water requirements (ETc) was used as a control.

Prior to sowing, all plots were uniformly pre-irrigated and light irrigations were applied before starting treatment application until the plants were reaching the fully germinating stage.

Irrigation was applied to each treatment was determined based on the plot area and gross irrigation requirement. The irrigation scheduling was done based on the full irrigation treatment and the rest treatment was took the assigned percentage of each treatment of the full irrigation. The plots and replications had buffer zone of 2m and 3m. Common bean variety (SER-119) was used for the study, with Plot size of 4 m x 3.6 m consists of 7 ridges spaced at 60 cm. Each experimental treatment was fertilized with recommended fertilizer application for common bean in the area, that was 27kg/ha and 69kg/ha of N and $P_2O_5$ respectively (Nigatie *et al.*, 2021). Half of the dose of N was applied during seed sowing and the rest half was applied 35 days after sowing.

### Determination of crop evapotranspiration

Actual meteorological data was used to calculate crop water requirement for Common bean during the growing season. The length of growing season at Initial, Development, Mid and Late season stage were 15, 30, 30 and 20 days respectively.

### Common bean Agronomic data

Crop data like growth, yield and yield components of the common bean was collected. The data includes Plant height, days to flowering and physiological maturity, leaf area, leaf area index, number of pod per plant, number of seed per pod, 1000 seed weight, relative leaf water content, above ground biomass yield, Harvest index and grain yield. Those parameters were determined according to the following ways:

### Plant height (cm)

Common bean Plant height data was recorded from a sample of five randomly selected plants per plot from ground level to the top of main branch at physiological maturity stage, the mean from the sampled plants was then taken as Plant height.

### Leaf area ($cm^2$)

The leaf area was determined by the non-destructive method using the linear model of (Bhatt and chanda, 2003) for common bean crop.

LA = 0.88*(L+W)… (1)

Where LA – leaf area ($cm^2$), L=leaf length (cm), W – width of the leaf (cm)

### Leaf area index

After the average area of each of the fresh leaves of the sampled plants was determined, Leaf Area Index for each plot was then calculated by the following formula:

$$LAI = \frac{LA}{GA} \quad \text{…(2)}$$

LAI=leaf area index which is the ratio of leaf area per plant to ground area for row spacing and plant spacing of 60cm and 10cm respectively, GA=Ground area($cm^2$)

### Relative Leaf Water Content

It was an important indicator of water status in plants; it reflects the balance between water supply to the leaf tissue and transpiration rate (Lugojan and Ciulca, 2011).

In order to calculate RLWC, leaf fresh weight samples were weighed, then submerged in distilled water for 24 hours and finally oven dried at 72ºC for 48 hr and were weighed again. RLWC was calculated according to Caturegli *et al.*, (2015):

$$RLWC = \frac{FW-DW}{TW-DW} * 100 \quad \text{…(3)}$$

Where, RLWC – Relative leaf water content, FW- fresh leaf weight, DW- Dry leaf weight and TW-turgid leaf weight.

### Days to flowering and maturity

Days to flowering was determined by counting days from sowing to 50% flowering, whereas, days to maturity was determined by recording days from sowing until plant reaching 85% physiological maturity.

### Crop Yield Response Factor (Ky)

Yield response factor was determined as the following (Doorenbos and Kassam, 1979):

$$Ky = \left(1 - \frac{Ya}{Ym}\right) = Ky\left(1 - \frac{ETa}{ETm}\right) \quad \text{…(4)}$$

Where, Ya = actual yield, Ym = maximum yield, ETa= the actual crop evapotranspiration,

ETm = the maximum crop evapotranspiration and Ky = crop yield response factor.

### Statistical Analysis

Collected data were subjected to ANOVA using R software (version 4.0.0). For the variance analysis, mean comparisons were executed using least significant difference (LSD) at 5% probability level when treatments show significant difference to compare difference among treatments mean.

## Results and Discussion

### Soil physical properties

Soil bulk density of the study site ranges from 1.07-1.18 g/$cm^3$ and average of 1.13 g/$cm^3$. The results from soil Bulk density showed that it increases with soil depth (Table1) since subsurface layers are more compacted and have less organic matter, less aggregation, and less root penetration compared to surface layers, therefore contain less pore space (Wolkowski and Lowery, 2008). From particle size analysis average composition of Silt, Sand and Clay percentages were 32.5%, 46.5% and 21%, respectively. Soil texture of the experimental site was classified as loam soil (Table1). Average moisture content on mass base at field capacity and permanent wilting point were 36.6% and 21% respectively. Average value of total available water (TAW) at the study site was 105.98mm per root depth of 0.6m.

### Effective rainfall

During the experiment, Total effective rainfall of 50.3 mm was calculated and reduced from net irrigation depth during the next irrigation treatment application (Table 3).

### Effect of moisture stress on growth parameter of common bean

### Days to flowering and maturity

Days to attain 50% flowering among the treatment differed significantly (P≤0.05) as summarized in (Table 4). These result obtained indicated that treatment received 35% ETc took minimum days (40.33) to flower, whereas treatment with full irrigation (100% ETc) took the maximum days (45.33) to flowers. Significance differences were also observed in case of days required to pod maturity (table 4). Treatment stressed by 55% and 65% of its crop water requirement records minimum days (86 and 85.67) respectively to first pod maturity. The maximum days required to reach maturity stage was observed at 100% ETc water application level. Days to maturity for 100, 85 and 75% ETc treatments were statistically similar which could be due to good moisture contents of the soil that supplied water to the plants. The treatments under 35% and 45% deficit stress flowered and matured early may be to escape from unfavorable stress conditions by flowering few days earlier than those under optimal conditions as drought tolerance mechanisms. Result obtained from current study was in line with those obtained by Huluager (2022) on rice, Nanesa (2019) on onion who reported that water stress leads to significant decrease in number of days to flowering and maturity stages of crop. Same results of the genotypic variation in days to flowering and maturity at the different moisture regimes of chickpea indicated the potential of crop for drought escape (Tesfaye *et al.*, 2011).

### Relative leaf water content

Relative leaf water content was considerably affected by moisture stress level. Significant (P<0.05) difference among treatments were observed at development and mid-season growing stage. As shown in (Table 4) full irrigation has maximum relative leaf water content at development (67.58%) and mid-season (74.37%) growing stage. Whereas, treatment received 35% of its crop water requirement revealed the minimum relative leaf water content (45.54%) which was not statistically different with treatment received 45% of its crop water requirement (48.03). Those treatments stressed by 15 and 25% crop water requirement had relatively good relative leaf water content as compared to the rest stressed treatments. Consistent with this observation, the findings of Chowdhury *et al.*, (2017) on soybean showed that Plants grown under water stress conditions showed a lower relative leaf water content than those grown under non stress conditions.

### Plant height

Water stress has a largest effect on the plant height. High significance difference was observed among treatment on plant height. The largest plant height of (70.58 cm) was recorded from full irrigation (100%ETc), while the smallest plant height was observed under treatment stressed by 65% (48.95cm) which is inferior to all other treatments (Table 5). From this study it was considered that plant height increased with irrigation level because of the increase in soil moisture content. In line with this, Admasu *et al.*, (2019) demonstrated that moisture stress levels no matter of the degree of its severity has the capacity to affect/ reduce plant height, above ground dry biomass and finally yield at different growing stages.

From the current finding the common bean height is not significantly affected by the different moisture stress levels at initial stage but, at this stage plant height improved as a moisture stress level reduced (figure 5). This indicated that water deficit at establishment stages have not significantly affected the common bean height. During these growth stages, water and other irrigation expenses can be saved. The maximum plant height recorded under full irrigation was 17.45cm, 48.33cm and 64.8cm at initial, development and mid-season growing stage respectively. The plant height ranged from 17.45cm to 16.23cm at initial, 48.33cm to 18.83cm at development stage and 64.8 cm to 29.17 cm at mid-season stage (figure 5).The analysis of variance revealed that high significance influence (p<0.01) was observed on plant height at development and mid-season growth stage. The finding is in line with Ntukamazina *et al.*, (2017) who reported that plant height is reduced when the moisture stress occurs at development (vegetative) and mid-season (flowering) stages.

**Table.1** Treatment combination

| Treatment | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|
| **Combination** | 100%ETc | 85%ETc | 75%ETc | 65%ETc | 55%ETc | 45%ETc | 35%ETc |

**Table.2** Soil Physical Properties

| Soil depth(cm) | Particle size distribution (%) | | | Textural Class | Bulk density (g/cm$^3$) | FC (Mass base (%)) | PWP (Mass base (%)) | TAW (mm) |
|---|---|---|---|---|---|---|---|---|
| | silt | sand | clay | | | | | |
| **0-15cm** | 32 | 44 | 24 | Loam | 1.07 | 34.2 | 20.3 | 22.36 |
| **15-30cm** | 32 | 46 | 22 | Loam | 1.11 | 36.5 | 19.6 | 28.19 |
| **30-45cm** | 34 | 44 | 22 | Loam | 1.16 | 38.9 | 22.1 | 29.23 |
| **45-60cm** | 32 | 52 | 16 | Loam | 1.18 | 36.7 | 21.9 | 26.20 |
| **Average** | 32.5 | 46.5 | 21 | Loam | 1.13 | 36.6 | 21 | 26.49 |

**Table.3** Effective rainfall during common bean growth stage

| Month and date | Rain fall (mm) | Effective rainfall (mm) |
|---|---|---|
| **March 21/2022** | 5 | 0 |
| **March 23/2022** | 21 | 9.3 |
| **April 25/2022** | 4.6 | 0 |
| **April 26/2022** | 37.5 | 22 |
| **April 27/2022** | 1.5 | 0 |
| **May 5/2022** | 23.3 | 10.6 |
| **May 13/2022** | 6 | 0.3 |
| **May 29/2022** | 16.1 | 6.3 |
| **May 30/2022** | 1.9 | 0 |
| **May 31/2022** | 8.7 | 1.9 |
| **Total** | | 50.3 |

**Table.4** Influence of moisture deficit on Phenological stages and Relative leaf water content

| Treatment | Days to maturity | Days to flowering | Relative leaf water content | |
|---|---|---|---|---|
| | | | Development stage | Mid stage |
| **100%ETc** | 45.33$^{a}$ | 95.33$^{a}$ | 67.58$^{a}$ | 74.37$^{a}$ |
| **85%ETc** | 45$^{ba}$ | 92.67$^{b}$ | 66.1$^{a}$ | 70.05$^{ba}$ |
| **75%ETc** | 43.67$^{bac}$ | 92.33$^{b}$ | 63.17$^{a}$ | 65.13$^{bc}$ |
| **65%ETc** | 42.5$^{bdac}$ | 88.67$^{c}$ | 55.6$^{ba}$ | 60.73$^{c}$ |
| **55%ETc** | 42b$^{dc}$ | 88.33$^{c}$ | 54.78$^{ba}$ | 59.50$^{c}$ |
| **45%ETc** | 40.67$^{dc}$ | 86.00$^{d}$ | 48.03$^{ba}$ | 50.06$^{d}$ |
| **35%ETc** | 40.33$^{d}$ | 85.67$^{d}$ | 45.54$^{b}$ | 48.00$^{d}$ |
| **LSD$_{(0.05)}$** | 3.15 | 1.67 | 13.85 | 8.81 |
| **CV (%)** | 4.14 | 1.02 | 13.87 | 8.1 |

***=statistically Very highly significant (p<0.001) **= statistically highly significant (p<0.01),*=statistically significant (p<0.05), ns= statistically not significant (p>0.05).*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different.*

**Table.5** Influence of irrigation level on plant height, leaf area and leaf area index

| Treatment | Plant height (cm) | Leaf area | Leaf area index |
|---|---|---|---|
| **100%ETc** | 70.58[a] | 22.3[a] | 3.1[a] |
| **85%ETc** | 67.44[a] | 21.9[a] | 2.9[ab] |
| **75%ETc** | 65.38[b] | 21.4[ab] | 2.8[ab] |
| **65%ETc** | 63.44[b] | 21.0[ab] | 2.6[b] |
| **55%ETc** | 55.63[c] | 19.6[bc] | 2.2[c] |
| **45%ETc** | 55.44[c] | 19.5[bc] | 2[cd] |
| **35%ETc** | 48.95[d] | 18.6[c] | 1.9[d] |
| **LSD(0.05)** | 4.43 | 1.99 | 0.33 |
| **CV (%)** | 4.08 | 5.44 | 7.5 |

*****= statistically Very highly significant(P<0.001), **= statistically highly significant (p<0.01),*= statistically significant (p<0.05), ns= statistically not significant (p>0.05).*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different***

**Table.6** Effect of moisture stress level on yield response factor of common bean

| Treatment | 1-[Ya/Ym] | 1-[Ea/Em] | Ky |
|---|---|---|---|
| **100% ETc** | 0 | 0 | - |
| **85% ETc** | 0.04 | 0.15 | 0.27 |
| **75% ETc** | 0.07 | 0.25 | 0.28 |
| **65% ETc** | 0.15 | 0.35 | 0.42 |
| **55% ETc** | 0.19 | 0.45 | 0.43 |
| **45% ETc** | 0.24 | 0.55 | 0.44 |
| **35% ETc** | 0.34 | 0.65 | 0.53 |

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

**Fig.1** Long-term monthly climatic water balance of the study area (1977-2021)

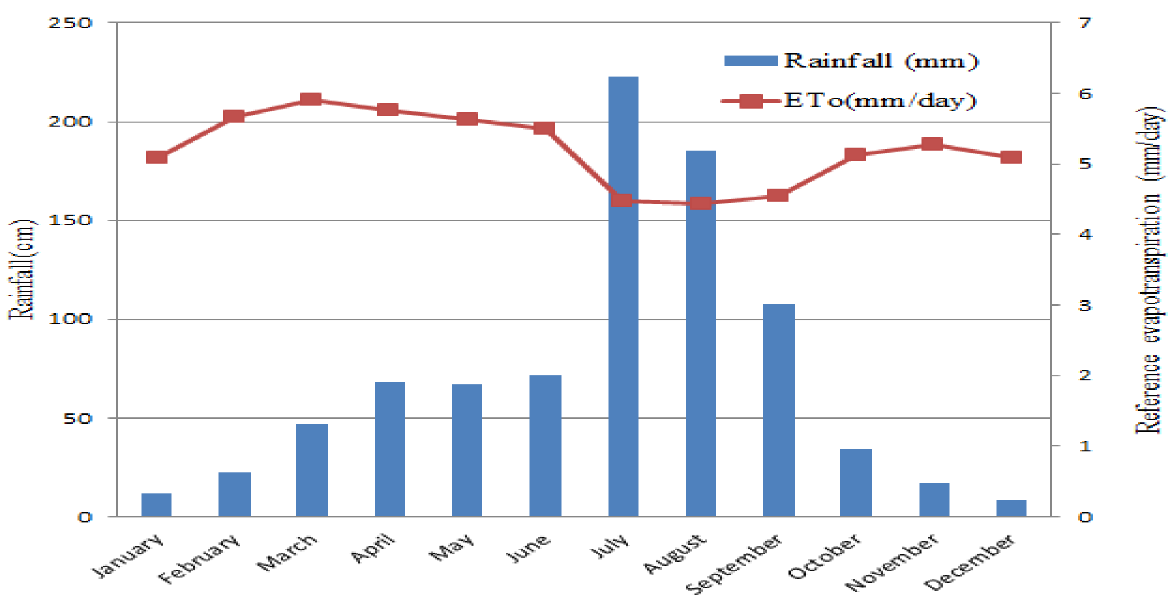


**Fig.2** Reference evapotranspiration and crop evapotranspiration during the crop growth period.

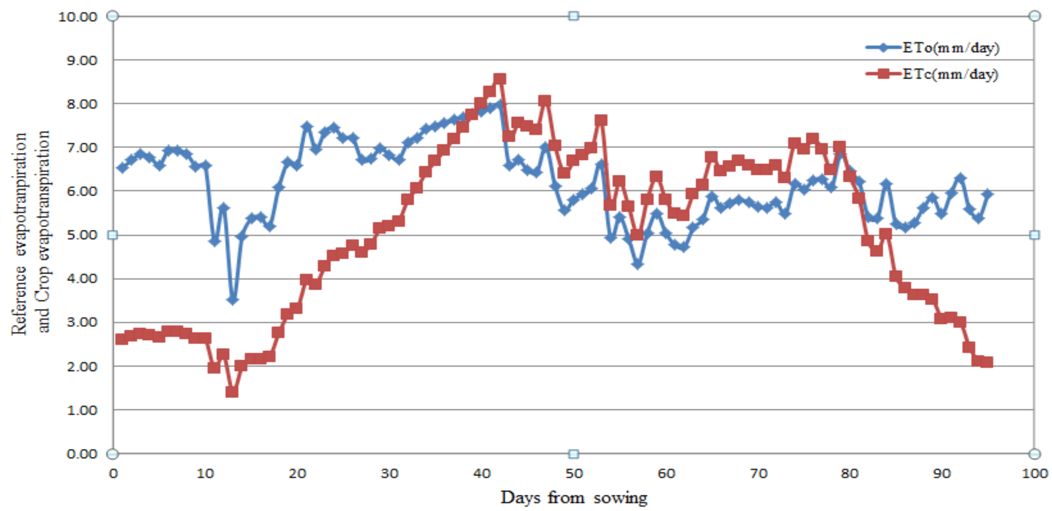



**Fig.3** Effect of different levels of water stress on plant height

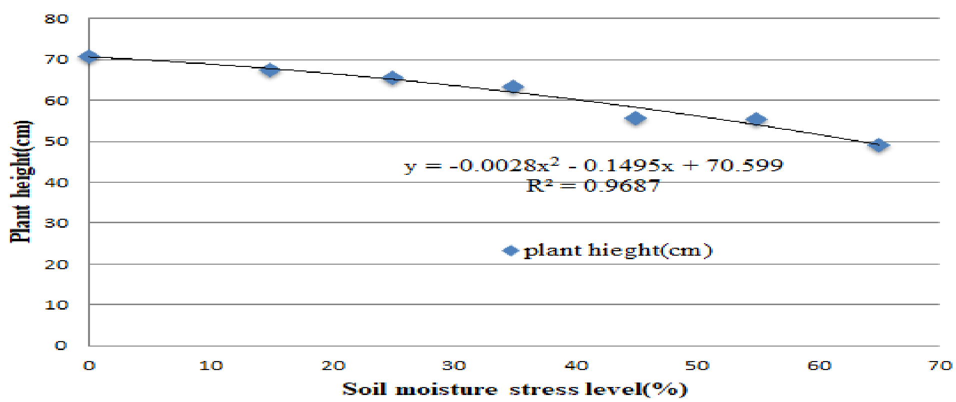
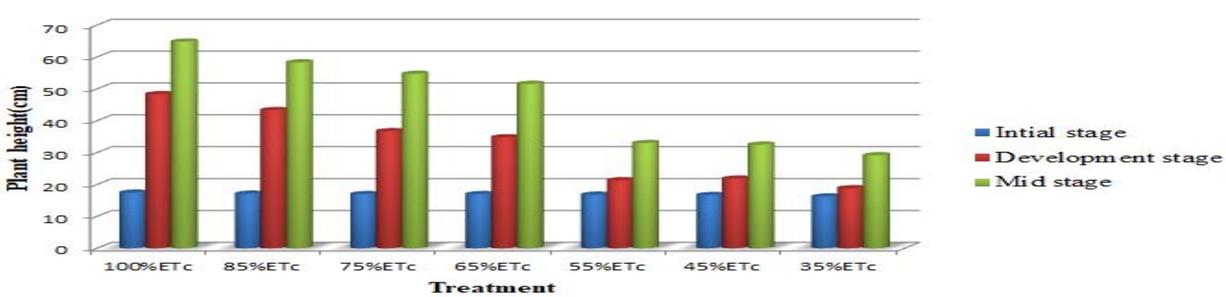



**Fig.4** Influence of irrigation level on plant height at different growth stage




## Leaf area and leaf area index

Leaf area of common bean significantly affected ($p<0.05$) due to influence of irrigation level. Maximum and minimum leaf area of (22.3cm$^2$) and (18.6cm$^2$) was obtained at 100% ETc and 35% ETc respectively. On the other hand, leaf area of 21.4cm$^2$ was recorded from 75% ETc treatment which is not significant from control treatment (85 and 100%ETc). Leaf area index was highly significantly ($p<0.001$) influenced by different moisture stress levels. Values of (3.1, 2.9 and 2.8) were obtained from 100, 85 and 75% ETc respectively and similar with each other's from analysis of variance (Table 5). 35%ETc resulting in lower means (1.9) of LAI when compared to the treatment without water deficit. The reduction of irrigation water amount from 100% ETc to 35% ETc showed decreasing gradient of leaf area and leaf area index (Table 4).

The previous research (Tesfaye *et al.*, 2011) reported that individual leaf area of chickpea reduced with increasing moisture stress. Subbarao *et al.*, (1995) revealed that under water deficit conditions plants reduced their leaf area as drought tolerance mechanism. Jose *et al.*, (2016) evaluated the effect of water deficit in the LAI characteristic of common bean, and found that LAI decreases with moisture stresses.

Drought stress decreased common bean leaf area, root, shoot and total dry weight of common beans (Mayek *et al.*, 2002). Similarly Admasu *et al.*, (2019) showed maize crop stressed by 15, 25 and 35% crop water requirement had relatively a good leaf area and leaf area index which is in line with the current study.

## Crop Yield Response Factor (Ky)

Crop yield response factor is the quantitative estimate used to establish the relationship between evapotranspiration deficits and yield depression (Greaves et. al., 2017). The current study showed that Ky value increased as irrigation level decreased (Table 6). The highest Ky was 0.53 attained at 35% ETc whereas, the lowest Ky was 0.27 observed at 85% Etc. Yield response factor was gradually increased, as the moisture stress level increased, decreasing trend of yield response factor ($K_y$) showed the decrease in yield as a function of evapotranspiration.

According to FAO (2002), yield response factor of different crops and different stress condition varies from 0.20 for tolerant crops to 1.15 for sensitive crops. According to Lovelli (2007); Kirda *et al.*, (1999) yield response factor(ky) with a value lower than one shows a good tolerance to water deficit regimes with little production decrements and a substantial stability in water use efficiency.

Soil moisture stresses are among rapidly increasing constraints to agricultural production particularly common bean crop. This study aimed at determining irrigation level under soil moisture stress condition and investigates the effect of soil moisture stress on common bean growth components under limited water resource condition.

The result of the study showed that moisture stress affects common bean phenology in which day to different physiology was varied. Reducing irrigation water from 100% ETc to 35% ETc leads to earlier flowering and maturity of common bean. Similarly, plant height and relative leaf water was significantly reduced. Those treatments received 85%ETc and 75% ETcof its crop water requirement had relatively good relative leaf water content as compared to the rest stressed treatments. Whereas, treatment received 35% of its crop water requirement revealed the minimum relative leaf water content at the same growing stage which was not statistically different with treatment received 45% of its crop water requirement.

Plant height reduced from 70.58 cm to 48.95 due to reduction of irrigation water from 100% ETc to 35% ETc. Yield response factor was gradually increased, as the moisture stress level increased, from 0.27 to 0.53.decreaseng trend of yield response factor (Ky) showed the decrease in yield as a function of the evapotranspiration.

## Declaration

## Author Contributions

Addisu Asefa developed proposal and conducted the research experiment, analysis the data, write the conducted research

## Conflicts of Interest

The author declares no conflict of interest.

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## Availability of data and material

All data generated and analyzed during this study are included in this manuscript.

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