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The Effects of Deficit Irrigation and Irrigation Interval on Yield and above ground Biomass of Haricot Bean (*Phaseolus vulgaris L.*) at Adami Tullu, Oromia, Ethiopia.

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Abstract

This study assessed the response of haricot bean to deficit irrigation and irrigation intervals (II) at Adami Tullu, Oromia, Ethiopia using a factorial experiment. The treatments were comprised of factorial combinations of two factors: four levels of water application (100%ETc, 85%ETc, 70%ETc, and 50%ETc) and three IIs (3 days, 5 days and 7 days). The experiment was replicated three times and the treatments were placed in each block in a randomized manner. Analyses of Variance (ANOVA) was used to analyze the results of the study and it showed highly significant ($P < 0.05$) differences among values of yield, above ground biomass and wateruse efficiency (WUE) under the considered treatments. The highest yield was obtained under 100%ETc with 3 days II; the lowest yield was obtained under 50%ETc with 7 days II. In terms of crop and field wateruse efficiencies (CWUE and FWUE, respectively), 50%ETc with 3 days II gave the highest CWUE and FWUE values (0.54kg/m^3 and 0.38kg/m^3, respectively). The lowest values of CWUE and FWUE were obtained under100%ETc with 7 days II (0.32kg/m^3 and 0.26kg/m^3, respectively). In general, 85%ETc with 5 days II could be recommended in the study area for optimum production under water scarce condition.

Key words: Deficit irrigation, Irrigation interval, Haricot bean

1. Introduction

Ethiopia is an agrarian nation; rain fed agriculture provides a livelihood for over 80% of its population and is responsible for about 90 % of its exports (Abate, 1994). By accounting for 50% of the GDP, 85% of the foreign exchange earnings and supporting, although insufficiently, 85% of the workforce, agriculture is vital to the economy of Ethiopia. However, rainfall has been decreasing in many parts of Ethiopia as a result of climate change. Climate related factors that result in the decrease in rain fed agricultural production include extended drought periods, decline in groundwater levels and erratic nature of precipitation (Chengot et al., 2021). For this reason, the rain fed agricultural production is not enough to secure food self-sufficiency (Awulachewet al., 2007). In addition, limited water resources availability and the increase in water demand for industrial and other domestic uses in Ethiopia have caused reduction in the quantity and quality of agricultural wateruse in some areas (Osman et al., 2002).

According to the World Bank (2006), most parts of Ethiopia fall under arid and semi-arid regions. These areas receive small amounts of rainfall, out of which about 70% of the rain fall takes place in the months of June, July and August. In such areas, water scarcity is known to seriously affect agricultural production (Abdelkhalik et al, 2019). The World Bank (2006) also added that production of food in a reliable and sustainable manner is almost impossible as a result of political constraints, rising production costs, groundwater scarcities, the erratic nature of rainfall resulting in less water being available for agriculture. Frequently, crop failure occurs for the reason that the availability of water is not enough at some critical growth stages of a crop. As a result, there has been not enough production of food in Ethiopia to fulfill the needs of rapidly increasing population size (Koohafkan and Stewart, 2008).

The Central Rift Valley of Ethiopia is one of the water scarce places in the country. However, it is also a place where there has been rapid expansion of irrigated agriculture mainly for the production of market-oriented crops (Kamara et al., 2002), resulting in further water scarcity. In this area, water scarcity has resulted in competition of water among domestic, private investors, farmers and industries, which in turn, has resulted in conflicts among users.

One of the crops which is grown in the Central Rift Valley of Ethiopia is haricot bean. The production of haricot bean is usually under rain fed conditions and, as a result, inadequate rainfall has limited its production (Acosta-Gallegos and Domingo, 2009). In this regard, irrigation contributes to improving production and, thus, achieving food security and guarantying well established agricultural growth. However, as stated by Mannocchi and Mecarelli (1994), plants need to be provided with the amount of water they require for their proper growth and development.

Water scarcity has increased the interest in improving agricultural water productivity in various parts of the world (Abdelkhalik et al., 2019). In the context of improving water productivity, deficit irrigation (DI), as defined by Kirda (2002), which is a water management method in which less water than the irrigation water requirement is applied to plants either during a particular growth stage or throughout the whole growing season with accepting some level of yield reduction without any severe damage to the plant and, with the objective of saving water, has been implemented. Particularly in regions where there is water shortage, deficit irrigation has become a very crucial way to achieve higher water use efficiency and reduce cost of water. Reduced yield as the effect of deficit irrigation, particularly under water shortage condition, may be compensated by increased production by irrigating other areas (Kirda, 2002). Proper irrigation interval is also used to utilize scarce water resources efficiently and effectively by applying the required amount of water when it is needed (Mofoke et al., 2002).

Nonetheless, Mofoke et al. (2002) reported that irrigation scheduling is done based on farmers' experience, not based on scientific facts. Therefore, optimum deficit irrigation and irrigation interval needs to be determined to reduce the challenges stated above as, when deficit irrigation is properly practiced, it increases quality of crop yield, protein content, and sugar content; reduces crop cycle length, grain size and etc (Du et al., 2015). Yield reduction is little when compared with the profit gained by using the saved water to irrigate additional crop land (Kirda, 2002). In addition, studying the effect of applying regulated deficit irrigation and irrigation interval of a crop is of paramount importance to achieve higher wateruse efficiency (Shammout et al., 2018). Moreover, understanding the yield response factor of a crop with deficit irrigation and irrigation interval throughout the growth season is important for proper scheduling of limited water supply and for better crop management practices related to soil moisture. This study was, therefore, initiated to investigate the effects of irrigation levels and irrigation intervals, and determine the optimum deficit irrigation level as means of dealing with water scarcity at Adami Tullu District of the Central Rift Valley of Ethiopia using haricot bean as a test crop. This particular crop was selected as it is one of the most widely grown crops in the study area for its economic importance (Ferris and Kaganzi, 2008). The finding of this study is expected to improve agricultural practice of farmers to use water efficiently which in turn increase productivity and farm return.

2. Material and Methods

2.1 Description of the study area

This experimental study was carried out at the Experimental Site of Adami Tullu Agricultural Research Centre (ATARC) in the dry months of 2018 and 2019 (two seasons). ATARC is located in the Central Rift Valley of Ethiopia, particularly in Adami Tullu-Jido Kombolcha District. The site extends between Latitude of 7˚ 37'-7˚ 41' N and Longitude of 38˚ 32'-39˚ 04' E geographical coordinates (Figure 1). The site is located at a mean altitude of 1650 m above sea level. It receives a mean annual rainfall of 760.9 mm and it has annual mean minimum and maximum temperature values of 12.6˚C and 27˚C, respectively.

Results of the analyses of soil samples collected from the experimental site showed that the soil type of the study area is loam sand. The bulk density was found to be 1.35 g/cm^3 for the first 30 cm (0-30 cm) depth of soil and it was found to be 1.36 g/cm^3 for the depth of 30 cm-60 cm. Soil moisture content at field capacity of the soil was 11.2% and 12.2% on weight basis for 0-30cm and 30-60cm, respectively. Soil moisture content at permanent wilting point was 3.4% and 3.45% on weight basis for 0-30cm and 30-60cm, respectively. The total available water (mm/m) values determined for these depth were found to be 102.3 and 119.3, respectively.

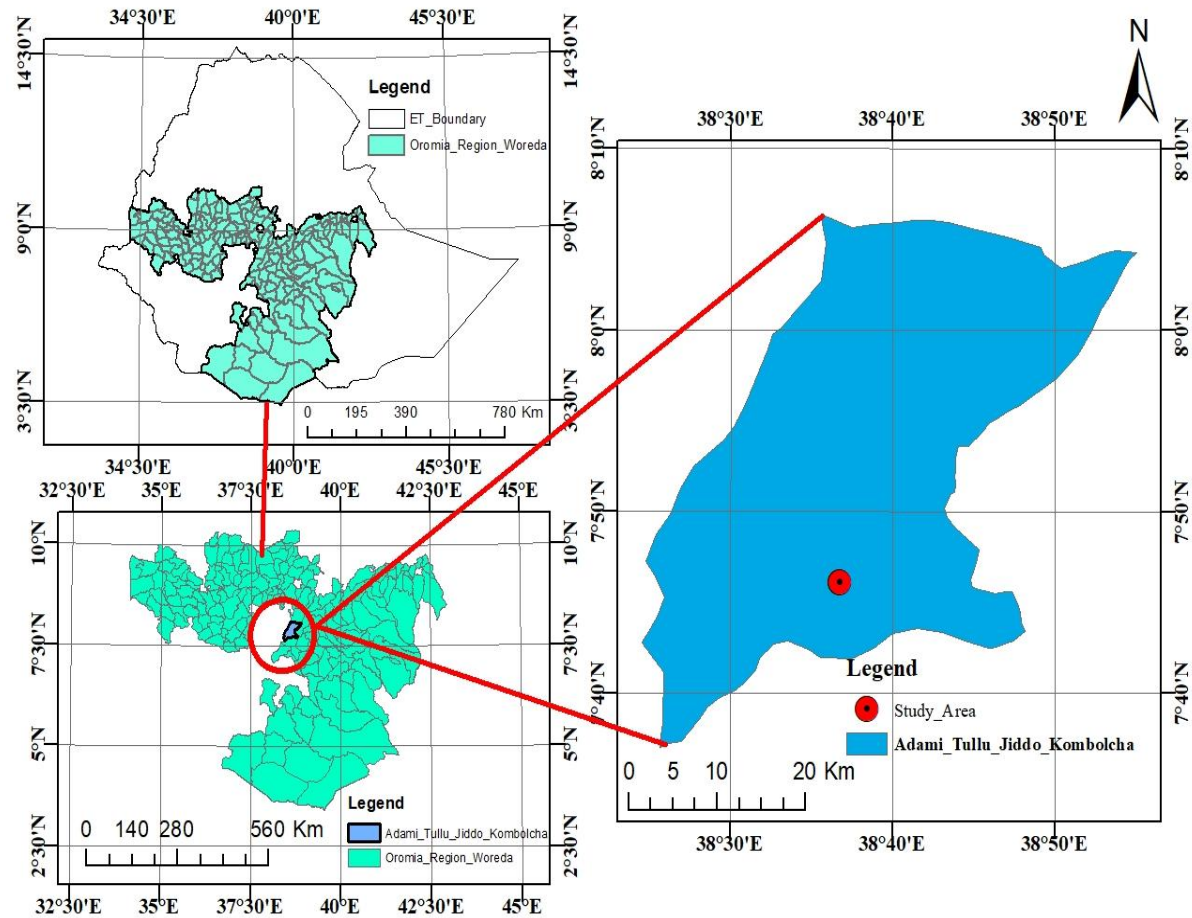

Figure 1. Location map of study area

2.2 Data collection and analyses

2.2.1 Experimental design and treatments

The treatments in this study were comprised of factorial combinations of two factors (II and IL) and the design was randomized complete block design. The treatments were four levels of water application (100% ETc, 85%ETc, 70%ETc, and 50%ETc) with three irrigation intervals (3 day, 5 day and 7 day) and they were replicated three times to reduce error. Thus, in total, there were 36 plots with the size of each plot being 2m×4m. The total experimental area was 525m^2 (35mx15m). A distance of 1m and 1.5 m was left between plots and blocks, respectively. There is no standard value for irrigation level and irrigation interval and different researchers use different values. The design of the irrigation levels used in this study were in line with Furgassa (2015) and also, the irrigation intervals used in this study were in line with Amin (2014). The treatments are presented as follows:

T1: five day irrigation interval with 100%ETc

T2: five day irrigation interval with 85%ETc

T3: five day irrigation interval with 70%ETc

T4: five day irrigation interval with 50%ETc

T5: seven day irrigation interval with 100%ETc

T6: seven day irrigation interval with 85%ETc

T7: seven day irrigation interval with 70%ETc

T8: seven day irrigation interval with 50%ETc

T9: three day irrigation interval with 100%ETc

T10: three day irrigation interval with 85%ETc

T11: three day irrigation interval with 70%ETc

T12: three day irrigation interval with 50%ETc

The field lay out and the locations of the treatments are presented in Figure 2. R_1, R_2 and R_3 represent replications 1, 2 and 3, respectively.

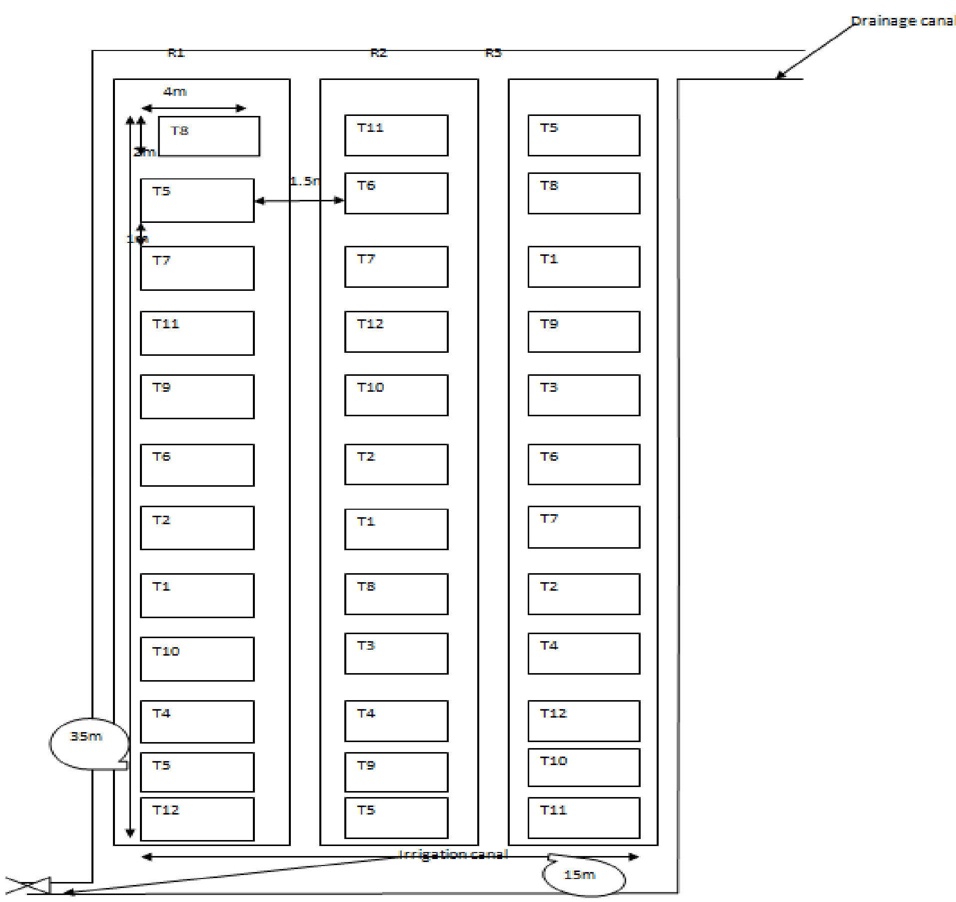

Figure 2. Field layout and locations of treatments

2.2.2 Determination crop and irrigation water requirements

Appropriate climatic data of years 1981-2017 were collected from Adami Tullu Agricultural Research Center Meteorological Station to compute monthly ETo by using the CROPWAT model (Version 8.0). The model determines ETo based on the following equation (Allen et al., 1998):

$$\boldsymbol{ETo} = \frac{\mathbf{0.408}\Delta(\boldsymbol{Rn}-\boldsymbol{G})+^{\gamma}\left(\frac{\mathbf{900}}{\boldsymbol{T}+\mathbf{273}}\right)\boldsymbol{U2}(\boldsymbol{es}-\boldsymbol{ea})}{\Delta+^{\gamma}[\mathbf{1}+\mathbf{0.34}\boldsymbol{U2}]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots1$$

,where ETo is reference evapotranspiration(mm/day), Rn is net radiation at the crop surface(MJm^2/day), G is soil heat flux density(MJm^2/day), T is mean daily temperature at 2m height(˚C), U_2 is wind speed at 2 m height(m/s), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa),e_s-e_a is saturation vapour pressure deficit (kPa), Δ is saturation slope of vapour pressure curves(kPa˚C^{-1}) and $^{\gamma}$ is psychrometric constant(kPa˚C^{-1}).

The crop water requirement (CWR) of haricot bean was then determined by multiplying the reference evapotranspiration (ETo) values by crop coefficient (Kc) values of haricot bean at various growth stages. Allen et al. (1998) reported that the value of Kc for haricot bean was 0.4 at initial stage, 1.15 at mid stage and 0.35 at the end stage.

These values were also used to determine the gross irrigation water amounts (GI) for the various irrigation intervals considered in this study. The gross water requirement was calculated by considering a field application efficiency value of 70%.

2.2.3 Assessing the effects of Irrigation levels and irrigation intervals on yield and yield components

In order to see the effects of various levels of irrigation and irrigation interval on the yield and yield components of the test crop, the CWR and GI under the considered deficit levels (irrigation levels, i.e, 85%ETc, 70%ETc and 50%ETc) were determined from the 100%ETc value and the values were further manipulated to determine corresponding amounts for various irrigation intervals (3 days, 5 days and 7 days). Then, as performance indicators, the following crop parameters were collected under each treatment and were further analyzed: Days to 50% flowering and days to maturity, plant height, leaf area, number of pods per plant, number of seeds per pod, above ground dry biomass, pod width, pod length and number of leaves per plant. Data were taken from ten plants from each plot excluding the border rows.

Days to 50% flowering were determined by counting days from planting up to 50% flowering. Days to maturity were determined by counting days from planting up to when the pod color changed to yellow. Plant height was measured from the base of the plant to the apical bud of plant in centimeters. The total leaf area was determined by measuring the maximum length and width of trifoliate leaves and by multiplying these values by a correction factor of 0.6 derived from the actual leaf area determined by employing the use of a leaf area meter. Then, Leaf Area Index (LAI) for each plot was calculated by multiplying the leaf area values by the plant density (250000plants/ha) based on the following equation:

$$LIA = LeafArea(m^2 / plant) * PlantDensity(Plant / ha) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Pod number per plant were counted from ten plants from each plot; then mean values were recorded as number of pods per plant. Number of seeds per pod were counted from ten randomly selected plants and mean values were determined and recorded as number of seeds per pod. Above ground dry biomass was computed from ten randomly selected plants by cutting above ground biomass and drying at 70˚c for 24 hrs in an over dry, and then measuring the dry biomass. Then harvest index (HI) was calculated as the ratio of grain yield to the above ground dry biomass as given in the following equation:

$$HI = \frac{GrainYield(Kg)}{AGDB(Kg)} * 100 \quad \ldots\ldots 3$$

Pod width was determined by measuring pods from ten plants from each plot by using ruler in cm and then mean values were recorded as pod width. Similarly, pod length was measured from the pods of the ten plants used for determining pod width. Then, mean values were determined and recorded. Number of leaves per plant were counted from ten plants from each plot and, then, mean values were recorded. One thousand seed weight and yield were determined considering seeds collected from central rows, excluding border rows. One thousand numbers of seeds were counted from each plot and weighted. The yield obtained from each plot was then expressed as kilogram per hectare (kg/ha).

The wateruse efficiency was calculated by dividing harvested yield (kg) per unit volume of water used (m^3). Crop wateruse efficiency (CWE, kg/m^3) was calculated as the amount of marketable yield (kg/ha) obtained per unit volume of seasonal ETc (m^3/ha) as presented in Equation 4. Field wateruse efficiency (FWE, kg m^{-3}) under every treatment was determined by the amount of marketable yield (kg ha^{-1}) obtained per unit amount of seasonal irrigation water applied (SIWA, m^3/ha) as presented in Equation 5 (Heydari, 2014).

$$\boldsymbol{CWE = \frac{Y}{ETc}} \quad \ldots\ldots 4$$

$$\boldsymbol{FWE = \frac{Y}{I}} \quad \ldots\ldots 5$$

, where Y is the economical yield (kg ha^{-1}), ETc is the seasonal crop evapotranspiration (mm), and I is the amount of irrigation water applied (gross irrigation) (mm).

The yield response factor (K_y), which is a function of relative yield decrease and relative evapotranspiration of irrigation deficit level, is determined as a function of four parameters (Ya, Ym, ETa and ETm) as determined by Stewart et al. (1977) as presented in Eq. 6:

$$1 - \frac{Ya}{Ym} = Ky\left(1 - \frac{ETa}{ETm}\right) \quad \ldots\ldots 6$$

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

The value of K_y depends on crop species, irrigation method and management, and crop growth stage when deficit evapotranspiration occurs.

2.2.4 Statistical analysis

All the data that were collected from the experimental plots were subjected to analysis of variances (ANOVA) using the SAS computer software (Version 9.2) and the Least Significant Difference (LSD) test at $P < 0.05$ level of significance was used to compare treatment means.

3. Results and Discussion

3.1. Results of crop water requirement.

The values of the reference evapotranspiration of the study are determined for various months and the data used to determine it are presented in Table 1.

Table 1. The reference evapotranspiration of the study area

Month	T_{min} (˚C)	T_{max} (˚C)	Humidity (%)	Wind speed (km/day)	Sunshine (hr)	Radiation (MJ/m/day)	ETo (mm/day)
Jan.	10.9	28.3	52	431	9	21.1	6.17
Feb.	12	29.4	50	428	9	22.3	6.68
Mar.	13	30.3	51	394	9	23.3	6.82
Apr.	14.1	29.7	58	375	8	21.8	6.13
May	14.8	29.2	61	411	8	21.2	5.94
Jun.	14.8	28	63	566	8	20.7	6.03
Jul.	14.7	25	70	545	6	17.9	4.72
Aug.	14.5	25.1	71	440	6	18.4	4.52
Sep.	13.3	26.4	69	296	7	20.1	4.64
Oct.	11.2	28.1	56	340	8	21	5.66
Nov.	10.2	28	51	433	9	21.3	6.26
Dec.	9.8	27.4	52	456	9	20.7	6.06
Mean	12.8	27.9	59	426	8	20.8	5.8

As can be seen from this table, the maximum ETo occur in March was found to be 6.82mm/day and the minimum ETo occur in August was found to be 4.52mm/day.

The crop water requirement (CWR) and the gross irrigation water amounts (GI) for the various irrigation intervals considered in this study were then determined following proper steps and procedures. The values of ETo, Kc, CWR, and GI corresponding to 7 days irrigation intervals during the period of growing season are presented in Table 2 as illustration.

Table 2. Crop water requirement and gross irrigation values for 7 days irrigation interval during the period of growing season.

Date	ETo (mm/day)	Crop Kc	CWR (mm/day)	CWR (mm/7day)	GI (mm/day)	GI (mm/7day)
18-Feb	6.68	0.4	2.67	18.70	3.82	26.72
25-Feb	6.68	0.4	2.67	18.70	3.82	26.72

4-Mar	6.76	0.45	3.04	21.29	4.35	30.42
11-Mar	6.82	0.52	3.55	24.82	5.07	35.46
18-Mar	6.82	0.78	5.32	37.24	7.60	53.20
25-Mar	6.82	1	6.82	47.74	9.74	68.20
1-Apr	6.13	1.11	6.80	47.63	9.72	68.04
8-Apr	6.13	1.22	7.48	52.35	10.68	74.79
15-Apr	6.13	1.22	7.48	52.35	10.68	74.79
22-Apr	6.13	1.22	7.48	52.35	10.68	74.79
29-Apr	6.13	1.22	7.48	52.35	10.68	74.79
6-May	5.97	1.13	6.75	47.22	9.64	67.46
13-May	5.94	0.95	5.64	39.50	8.06	56.43
20-May	5.94	0.72	4.28	29.94	6.11	42.77
24-May	5.94	0.41	2.44	17.05	3.48	24.35

3.2. Effect of deficit irrigation and irrigation interval on yield and yield components

Mean values of days to 50% flowering (DF), days to maturity DM), plant height (PH), number of pod/plant (NP/P), number of seed/pod (NS/P), crop water use efficiency (CWE), field wateruse efficiency (FWE) and standard error (SE) under the various levels of irrigation and irrigation intervals are presented in Table 3. In addition, number of leaf per plant (NL/P), thousand seed weight/treatment (1000SW/T), yield (YLD), above ground dry biomass (AGDB), pod width (PW), pod length (PL), leaf area index (LAI), harvest index (HI) and standard error (SE) under the various levels of irrigation and irrigation intervals are presented in Table 4. The letters attached to the values presented in both tables represent significant differences. The ANOVA tables could not be provided in this document due to the large amount of space they take.

Table 3. Some yield and yield components under various irrigation intervals and irrigation levels

Treatment		DF	DM	PH	NP/P	NS/P	CWE	FWE
II	IL	(days)	(days)	(cm)	(number)	(number)	(kg/m^3)	(kg/m^3)
3 day	100% ETc	64.33a	97a	43.3a	28.2a	6.9a	0.42cd	0.29cd
	85% ETc	60bc	95.33bc	41.63ab	24.27bc	6.6ab	0.44bc	0.31bc
	70% ETc	55e	94cd	40.47bc	22.67bcd	6.33abc	0.44bc	0.31bc
	50% ETc	52.67f	93de	39.03cd	19.27e	5.97bc	0.54a	0.38a
5 day	100% ETc	63.67a	95.67ab	41.43ab	25.67ab	6.6ab	0.34ef	0.24ef
	85% ETc	59c	94cd	40.43bc	23.33bcd	6.33abc	0.38de	0.26de
	70% ETc	54.33e	93de	39.1cd	21de	6bc	0.43bc	0.3bc
	50% ETc	51.33fg	91.33fg	37.3de	13.47f	5.63cd	0.47b	0.33b
7 day	100% ETc	61b	94cd	40.23bc	23.4bcd	6.53ab	0.32f	0.23f
	85% ETc	57d	92.33ef	38.1d	21.27cde	6.03bc	0.34ef	0.24ef

	70% ETc	52.33fg	91.67efg	37.73dde	18.4e	5.8bc	0.36ef	0.31bc
	50% ETc	51g	91.33fg	36.1e	12.97f	4.80d	0.46bc	0.32bc
SE		0.67	0.69	0.93	1.57	0.42	0.23	0.16
LSD		1.40	1.44	1.94	3.26	0.86	0.47	0.33

*Means followed by the same letter are not significantly different at ($p < 0.05$)

3.2.1. Effects on days to 50% flowering and days to maturity

As can be seen in Table 3, the irrigation levels and intervals exhibited significant differences in terms of days to 50% flowering and days to maturity at ($P<0.001$). The maximum days to 50% flowering (64.33 days) and days to maturity (97 days) were recorded under 100%ETc with 3 days irrigation interval. As opposed to these, the minimum days to flowering (51 days) were observed under 50% ETC and 7 days intervals, while the minimum days to maturity (91.33) was recorded under 50%ETc, but under both 5 days and 7 days irrigation interval. The results with regards to DF and DM are in similar to the results obtained in the study by Ahmed et al. (2008) on faba bean crop. As the authors stated, this is because plants try to deal with unfavorable stress conditions by shortening their life days earlier than those under normal soil moisture conditions. In addition, Kalima (2013) reported that 100 % ETc water regime showed the longest days to fifty percent flowering, while the 50 % ETc water stress regime had the shortest days to fifty percent flowering for haricot bean. As also stated in Al-Suhaibani (2009), these results indicate that soil water stress leads to a considerable decrease in the number of days to flowering and maturity. In addition, the results with regards to irrigation intervals are consistent with the results reported by Bashari (2004), which stated that long irrigation interval reduces time to maturity. The interaction effect of irrigation levels and irrigation intervals on days to 50% flowering and maturity were found to be insignificant ($P<0.05$).

Table 4. Additional yield and yield components under various irrigation intervals (IIs) and irrigation levels (ILs).

Treatment II	IL	1000SW/T (g)	YLD (kg/ha)	AGDB (kg/ha)	PW (cm)	PL (cm)	NL/P	LAI	HI (%)
3 day	100% ETc	142.7a	2202.4a	4400a	0.91a	9.79a	102.9a	11.91a	43.3a
	85% ETc	135.87bc	1964.3b	3497.6bc	0.79bc	9.67ab	91.9b	9.74b	41.63ab
	70% ETc	133.43cd	1642.9cde	2373.8d	0.74c	9.24bcd	83.9cde	8.41de	40.47bc
	50% ETc	131.3de	1434.5efg	2040.5de	0.73c	8.32f	76.6fg	6.98fg	39.03cd
5 day	100% ETc	137.37b	1821.4bc	3726.2b	0.85ab	9.62ab	90.3bc	9.71bc	41.43ab
	85% ETc	134.57bcd	1696.4cd	3473.8bc	0.78bc	9.39abc	85.5bcd	8.48cde	40.43bc
	70% ETc	129.73e	1589.3de	2133.3de	0.73c	8.83def	78.1efg	6.59gh	39.1cd
	50% ETc	124.1f	1250gh	1557.1ef	0.713c	8.38f	68.6h	5.64hi	37.3de
7 day	100% ETc	135.87bc	1702.4cd	3223.8bc	0.80bc	9.39abc	87.4bcd	9.07bcd	40.23bc
	85% ETc	132.47cde	1523.8def	2992.9c	0.76bc	8.98cde	83.2def	7.91def	38.1d
	70% ETc	117.2g	1327.4fgh	1835.7def	0.73c	8.63ef	75.5g	6.59gh	37.73de
	50% ETc	109.1h	1220.2h	1331f	0.71c	8.3f	65.43h	5.64hi	36.1e
SE		1.78	100.66	284.31	0.05	0.26	3.31	0.61	0.93

LSD	3.70	208.75	589.62	0.11	0.54	6.86	1.26	1.94

*Means followed by the same letter are not significantly different at ($p < 0.05$)

3.2.2. Effects on plant height (PH)

The irrigation levels and irrigation intervals resulted in significantly different values of plant height ($P<0.001$). The maximum plant height (43.3 cm) was recorded under 100%ETc with 3 days irrigation interval, while the minimum PH value (36.1 cm) was observed under 50%ETc with 7 days irrigation interval (Table 3). The interaction between the irrigation interval and irrigation treatments was not significant on plant height in this study similar to what was reported in Elsafi (2003).

3.2.3. Effects on number of pods per plant (NP/P) and number of seeds per pod (NS/P)

The values of NP/P and NS/P under the various ILs and IIs were found to be significantly different from each other ($P<0.001$) (Table 3). The maximum NP/P and NS/P (28.2 and 6.9, respectively) were recorded under treatment 100%ETc with 3 days II, while the smallest corresponding values (12.97 and 4.8, respectively) were observed under treatment 50%ETc with 7 days II. These results are in agreement with Metwally (2011), which indicated that the higher irrigation water depth applied the higher the vegetative parameters developed. Also, Ambachew (2011) reported that average number of seeds per pod was significantly influenced by different levels of irrigation water application throughout and at different growth stages of mung bean. Not significant differences were observed due to the interaction effect of irrigation level and irrigation interval in number of pod per plant at ($P < 0.05$). A similar result was observed in the study by Elsafi (2003), where the interaction between water quantity and irrigation interval was insignificant for black cumin on NP/P and NS/P.

3.2.4. Effects on crop and field wateruse efficiencies

The highest values of Crop Wateruse Efficiency (CWE) and Field wateruse Efficiency (FEW) were obtained at 50%ETc irrigation level under 3 days irrigation interval with values of 0.54 and 0.38kg/m^3, respectively, while the lowest value of CWE and FWE were obtained at 7 day irrigation interval under 100%ETc with values of 0.32 and 0.23 kg/m^3, respectively. These values show that deficit irrigation increased the wateruse efficiency of the study crop. This result is consistent with the results of Webber et al. (2008) and Geerts and Raes (2009). As presented in Table 3, the various irrigation levels and irrigation intervals showed significant effect in crop wateruse efficiency and field wateruse efficiency of haricot bean at ($P<0.001$). However, the combined effect (interaction) of irrigation level and irrigation interval did not show significant effect on crop water use efficiency and field wateruse efficiency even at ($P < 0.05$).

3.2.5 Effects on Thousand Seed Weight per treatment (1000SW/T)

The largest 1000SE/T (142.7 g) was observed under 100%ETc with 3 days irrigation interval and the lowest 1000SW/T (109.1 g) was observed under 50%ETc with 7 days irrigation interval. The ANOVA analyzed carried out on the values of 1000SW/T under the considered IIs and ILs (depicted in Table 4) were found to be significantly different ($P<0.001$). In addition, the interaction of irrigation intervals and irrigation levels were found to have significant affect the weight of 1000-seeds at ($P<0.001$). These results are similar to the results obtained in the study by Ambachew (2011), which reported that the weight of thousand seeds was significantly influenced by the different levels of irrigation water application for mung bean.

3.2.6. Effects on yield and above ground dry biomass (AGDB)

Significant differences in were observed among the yield under various irrigation levels and irrigation intervals at ($P<0.001$) (Table 4). The highest yield (2202.4 kg/ha) was recorded under 100%ETc irrigation levels with 3 days irrigation interval, while 50%ETc with 7 days irrigation interval resulted in the lowest yield (1220.2 kg/ha). These results are similar to the results obtained by Ramirez-Vallejo and Kelly (1998), which reported that the yield of beans decreased due to water shortage even though it was for a brief period. Haricot bean is a sensitive plant to high moisture stress levels that substantial influence on haricot bean yield and its component (Ndimbo et al., 2015). The interaction of irrigation level and irrigation interval did not have significant effect on the yield of haricot bean even at ($P < 0.05$).

The values of the yield response factor of haricot bean (Ky) were computed using determined values of actual crop water (ETa), maximum potential crop water (ETm), actual crop yield (Ya) and maximum potential crop yield (Ym). The Ky values ranged from 0.42-0.7. As stated in Kirda et al. (1999), Ky values of field crops ranges from 0.2 to 1.15. Thus, the values in this study are acceptable. Ky is less than 1 means that the crop is considered as more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced wateruse (Smith and Steduto, 2020 This indicates that sensitivity growth period of haricot bean for water deficit is low in Adami Tullu.

Furthermore, as presented in Table 4, the largest AGDB (4400 kg/ha) was observed under 100ETc IL with 3 days II and the smallest AGDB (1331 kg/ha) was observed under 50%ETC IL with 7 days II. The results of ANOVA sowed that the AGDB results under the considered IL and II were found to be significantly different ($P<0.001$). However, the interaction effect of irrigation level and irrigation interval was insignificant ($P<0.05$).

3.2.7. Effects on pod width (PW), pod length (PL) and harvest index (HI)

The values of PW, PL and HI are presented in Table 4. As can be seen from the table, the largest values of these variables were observed under IL of 100%ETc with 3 days II (0.91 cm, 9.79 cm and 43.3%, respectively). The smallest values of these variables were measured under IL of 50%ETc with 7 days II (0.71 cm, 8.3 cm and 36.1%, respectively). ANOVA showed that the results of these variables under the various ILs and IIs were found to be statistically significant ($P<0.001$). However, the interaction of IL and II did not have significant effect on the values of the variable ($P<0.05$).

3.2.8. Effects on NL/P and LAI

As presented in Table 4, the maximum mean number of leaves per plant (NL/P) (and the leaf area index (LAI) values (102.9 and 11.91, respectively) were observed under 100%ETc Il with 3 days II and the smallest corresponding values (65.4 and 5.64, respectively) were observed under 50%ETc IL with 7 days II. The values of these variables presented in the table were found to be significantly different ($P<0.001$). Similar results were observed in the studies by Gwathmey et al.

(1992), El-Oksh et al. (1993), Nimir (2002) and Al-Moshileh (2007), which reported that watering intervals and levels had significant effect on number of leaves and leaf area index of haricot bean. However, the interaction of IL and II did not have significant effect on the values of the variable (P<0.05).

4. Conclusion

Based on the results of the study it can be concluded that the maximum yield and aboveground biomass was observed under 100%ETc and 3 days irrigation interval. In addition, a significant decrease in the crop yield and above ground biomass of haricot beans was observed when the amount of irrigation water applied is reduced. Moreover, in water scarcity areas, among all the treatments, 85%ETc irrigation level with 5 day irrigation interval was found to be efficient in conserving significant irrigation water and reduce number of irrigation.

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