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Effect of Optimal Irrigation Scheduling on Yield and Water Productivity of Haricot Bean (Phaseolus vulgaris L.) at Melkassa, Central Rift Valley of Ethiopia

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Abstract

Water is one of the most critical inputs for obtaining maximum production of crops. Each crop has its own water requirement and maintains its own tolerance limits within which the moisture variations don't affect crop yields. Therefore, the moisture availability in the root zone of the crop could be maintained within the crop tolerance limits by adopting proper water management practices and improve water productivity in irrigated agriculture. Hence, the objective of this study was to determine the optimal soil moisture depletion level for improving production and water productivity of irrigated haricot bean (Awash Melka). Field experiment was conducted at Melkassa Agricultural Research Center, Ethiopia during growing season 2016 and 2017 with furrow irrigation system and five irrigation treatments replicated three times in a randomized complete block design. Irrigation treatments: 60%, 80%, 100% (when 45% of total water available was depleted), 120% and 140% ASMDL. Obtained results revealed that, the average seasonal water requirements value of 450-480 mm depth. The result revealed that there was no significant ($p>0.05$) difference in grain yield and water productivity among treatments. Therefore, as much as the total water applied is the same it is better to use higher depletion level for irrigation scheduling to have a wider irrigation interval for better agronomic management.

Keywords: Allowable soil moisture depletion, Awash Melka, Grain Yield, Haricot Bean, Irrigation Schedule, Water Productivity
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INTRODUCTION

Water is one of the most critical inputs for obtaining the maximum production of crops. Each crop has its own water requirement and maintains its own tolerance limits within which the moisture variations don't affect crop yields (MOA, 2011). Therefore, the moisture availability in the root zone of the crop could be maintained within the crop tolerance limits by adopting proper water management practices and improve water use efficiency in irrigated agriculture. Different crops differ in their consumptive use of water, sensitivity to water stress, water extraction capacity and optimum water regime. A crop having a higher consumptive use rate utilizes the soil water quickly and requires more frequent replenishment of soil water. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to the transpiration demand and the crop begins to experience stress. According to ICDC (2017), Irrigation scheduling ensures that water is applied according to crop requirements and is consistently available to the plant. Proper irrigation scheduling will improve profitability by: maximizing crop yield and quality; decreasing water lost through deep percolation and runoff; optimizing pumping costs; and improving water use efficiency. As the crop grows and extracts water from the soil to satisfy its ETc requirement, the stored soil water is gradually depleted. In general, the net irrigation requirement is the amount of water required to refill the root zone soil water content back up to field capacity. This amount, which is the difference between field capacity and current soil water level, corresponds to the soil water deficit (Andales et al., 2015). The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water, $RAW = p * TAW$. The fraction p is a function of the evaporation power of the atmosphere (Allen et al., 1998). At low rates of ETc, p-values are higher than at higher values of ETc. Crops like vegetables require a higher level of water to be maintained in the soil need frequent irrigations than crops like wheat, barley, maize, sorghum and finger millet, which require relatively less frequent irrigations.

Improved irrigation methods are the controlled application of the right amount of water at the desired time, which leads to reduce the range of variation of the moisture content in the root zone and reducing stress on the plants. Increasing water productivity is particularly important where water is scarce compared with other resources involved in production (Drechsel *et al*., 2015). Hence, irrigation scheduling is important for developing best management practices for irrigated areas (Ali *et al*., 2011). There is considerable scope for improving the water use efficiency of crops by proper irrigation scheduling which is governed by crop evapotranspiration (Tyagi *et al*., 2000). In Ethiopia, although irrigation has long been practiced at different farm levels, there is no efficient and well-managed irrigation water practice in different parts of the country until now. This implies that there are very few or no information regarding the appropriate management of irrigation water and crop management practices for the rapidly expanding irrigation farms in the country.

Haricot bean (*Phaseolus vulgaris L.*) is an annual pulse crop, widely cultivated throughout the world (Graham & Ranalli, 1997), particularly in Ethiopia; it is a highly valuable cash crop (Turuko & Mohammed, 2014). This crop can also help for phytoremediation of the irrigated and non-irrigated soils by fixation and accumulation of Nitrogen at the root zone (Dhatonde & Nalamwar 1996). The central rift valley of Ethiopia contributes about 60% of haricot bean production in the country. However, unreliable and poor distribution of rain is one of the major causes of the low yield of haricot bean in this area (IAR, 1990). Nowadays, farmers are opting for the production of this crop under irrigation. However, limited information is available in the technical literature on the optimum level of irrigation water in the study area. Haricot bean is a crop commodity that well-established in Ethiopian agriculture. From the export of white seeded beans, Ethiopia on average obtains about $16 million USD, out of which Awash Melka, the famous exportable variety used in this study, contributes the major portion (MARC, 2001).

Climate variability has become more threatening to food security and the sustainable development of any nation. Besides, increasing progress of agro-industrial, climate is changing (Lykhovyd, 2018) and about 66% of the total areas of Ethiopia fall within the arid and semi-arid climatic zone of the country (MoA, 1998). Nevertheless, agriculture, which is highly sensitive to climate variability, is the driver of the country's economy as it accounts for half of GDP and 80% of employment (MoARD, 2007). The dependence of Ethiopia on agriculture makes the economy extremely vulnerable to the risks associated with climate variability. Hence, the improvement of efficient irrigation water utilization is essential to carry out irrigation in water-scarce areas for different crops to determine the optimum depletion level and increasing yield both per cultivated land and per irrigation water used in area. Therefore, this study was undertaken with the objective of developing optimal depletion level of irrigation application and water productivity for haricot bean.

MATERIALS AND METHODS

General description of the study area

The study was conducted at Melkassa Agricultural Research Center, Central Rift Valley of Ethiopia in two consecutive years 2016 and 2017. It is geographically located between the latitude of $8^{0}24'$ to $8^{0}26'$ N, the longitude of $39^{0}19'$ to $39^{0}19'$ E and the mean altitude of the area is 1550 m.a.s.l. The climate of the area is characterized as semi-arid with a uni-modal low and erratic rainfall pattern with annual average of 824.9 mm. About 67.4% of the total rainfall of the area occurs from June to September. The mean maximum temperature varies from 26.3 to 31.0 ^{0}C while the mean minimum temperature varies from 10.4 to 16.4 ^{0}C. The climate water balance shows that there is a need for irrigation water for almost the year-round except for the months from mid of June to September (Figure 1).

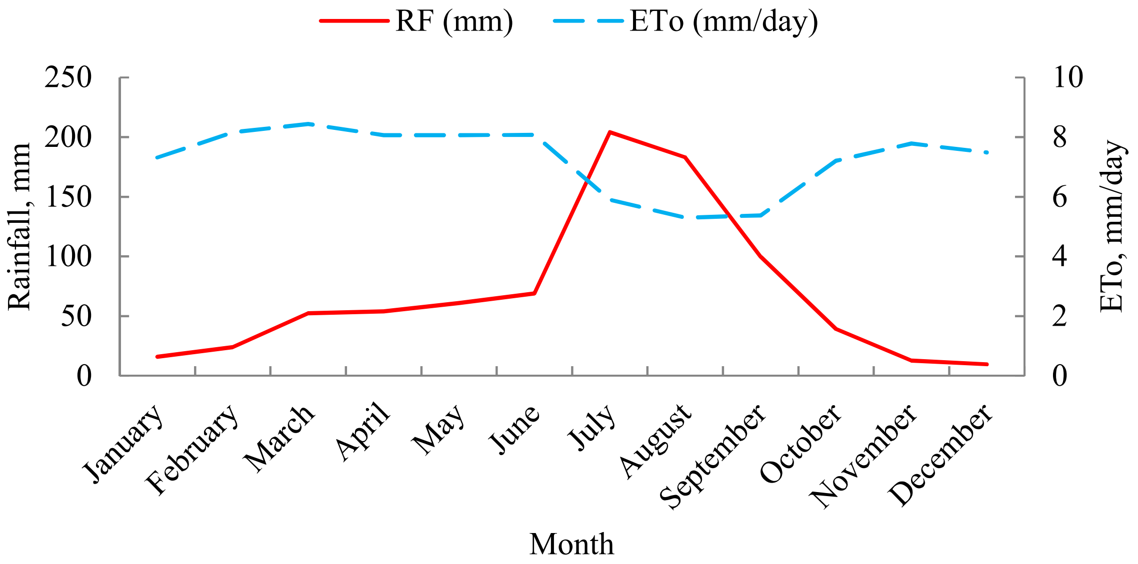

Figure 1: Long-term monthly climatic water balance of the study area

Experimental Design and Treatment Combinations

The experiment was set as a single factor experiment in randomized complete block design in three replications.

The experiment included five levels of soil water depletion levels (SMDL) as treatments and the five level of SMDL are (60%, 80%, 100% (FAO recommended ASMDL), 120% and 140% FAO recommended ASMDL). Treatments set up were done by decreasing and increasing 0, 20 and 40% recommended depletion. FAO recommended allowable soil moisture depletion level of Beans is 45% and the other treatments were calculated based on this allowable soil moisture depletion level value (Allen *et al.*, 1998).

Table 1: Treatment combinations and description

Treatments	P (%)	Description
T1	27	60% of ASMDL (-40%)
T2	36	80% of ASMDL (-20%)
T3	45	ASMDL* (control) (0%)
T4	54	120% of ASMDL (+20%)
T5	63	140% of ASMD (+40%)

P (depletion levels), and ASMDL (allowable soil moisture depletion level)

Experimental procedure and management practice

Haricot Bean *(Phaseolus vulgaris L.), Awash Melka* variety were planted in February of each experimental year. The plot size was 3.6 m wide and 5 m long with 0.6 m furrow spacing and 0.1 m plant spacing. All agronomic practices were kept normal and performed at the appropriate time. After two common irrigations were applied for all plots uniformly without considering the variation of the treatment to enhance better establishment experimental treatments were imposed to plant.

Crop water requirement and Irrigation management

Depth of irrigation water applied was computed using the CROPWAT model version 8.0 (FAO, 2009) based on the actual daily climatic data collected at Melkassa Agricultural Research Center, Agro-meteorological Service Department. Calculations of irrigation requirements and scheduling utilize inputs of climatic, crop and soil data, as well as irrigation and precipitation data, thus simulations are based on daily water balance (Allen *et al.*, 1998). Daily climatic data (maximum and minimum temperatures, humidity, wind speed and actual sunshine hours) and geographical information (coordinates and altitude of the location) are used by CROPWAT to calculate ETo according to the FAO Penman-Montieth equation (Allen *et al.*, 1998) using equation 1.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \ldots\ldots\ldots\ldots\ldots..\ldots\ldots..(1)$$

Where ET_O -reference evapotranspiration (mm/day), R_n -net radiation at the crop surface (MJ/m^2/day), G -soil heat flux density (MJ/m^2/day), T -mean daily air temperature at 2 m height (^{0}C), u_2 -wind speed at 2 m height (m/s), e_s -saturation vapour pressure (kPa), e_a -actual vapour pressure (kPa), e_s - e_a -saturation vapour pressure deficit (kPa), Δ -slope vapour pressure curve (kPa/^{0}C) and γ -psychrometric constant (kPa/^{0}C)

Crop evapotranspiration was calculated from reference evapotranspiration and crop coefficient value over a given period, such as physiological growth stage or whole season using equation 2

ETc = ETo x Kc ………………………………………………… (2)

Where ETc is crop evapotranspiration (mm/day), Kc is crop coefficient (dimension less), and ETo is reference evapotranspiration (mm/day).

The amount of water applied at each irrigation interval was determined following the respective depletion level of each treatment. Determination of net irrigation water requirement was done based on the water holding capacity of the soil from depletion level to field capacity in the effective root depth for each treatment based on equation 3.

In = (FC-PWP)*P*ρ_d*Rd- Pe ……………………………………… (3)

Where:- I_n: net irrigation water requirement (mm), FC: Mass base moisture content at field capacity (decimal), PWP: Mass base moisture content at permanent wilting point (decimal), P: Allowable soil moisture depletion level for wheat (decimal), ρ_d: Soil bulk density (g/cc), R_d: Root depth (mm) and P_e: Effective rainfall (mm)

The effective rainfall can be calculated from the expression (FAO, 2009):

$$Pe = 0.6\,P - 10 \quad \text{if Pmonth} \leq 70 \text{ mm/month}, \qquad (4)$$

$$\text{Or } Pe = 0.8\,P - 24 \quad \text{if Pmonth} > 70 \text{ mm/month} \qquad (5)$$

Irrigation water was conveyed to the experimental plots through an open channel using Parshall flume (3-inch throat width) to measure total applied water (Kandiah, 1981). The predetermined amount of water for each application was added for each treatment. The gross irrigation requirement was computed by adopting a field application efficiency of 60%. The result is in line with the study reported by FAO (2002) that stated as average ranges vary from 50 to 70% and a more common value is 60% application efficiency. The time required to deliver the desired depth of water into each plot was calculated using equation 6 given by Michael (2008). Time is then recorded with a stopwatch to deliver the estimated amount of water applied to each plot.

$$t = \frac{I_g \times A}{60 \times q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where: Ig = gross depth of water applied (mm), t = application time (min), A = plot area, q= flow rate (l/s) at specific Parshall flume head and 60 (sixty) is unit adjusting figure.

Data collection

From the total of five plating rows, the interior three sampling rows were harvested. Data on plant height, above-ground biomass and other relevant agronomic parameters were recorded from five randomly selected plants from three middle rows of each experimental plot and these plants were tagged for subsequent measurement.

Water Productivity

Water productivity (WP) was estimated as a ratio of yield to the total ETc through the growing season and it was calculated using equation 7 (Molden *et al*., 2010).

$$WP = \frac{Ya}{ETa} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where WP is water productivity (kg/m^3), Ya is crop yield (kg/ha) and ETa is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data Analysis

The collected data were statistically analyzed using the statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean separation using the least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

RESULTS AND DISCUSSIONS

According to the USDA soil textural classification, the particle size distribution of the experimental site revealed that the soil textural class is clay loam soil which is suitable for onion. The average weighted bulk density of the experimental site was 1.1 g/cm^3. Average moisture content on weight base at FC (1/3 bar) and PWP (15 bar) were 32.3% and 17.7%, respectively. Volumetric TAW was 163.6 mm/m as presented and summarized in Table 2.

Table 2: Soil physical and chemical properties of the experimental site

Soil property	Particle size distribution			Textural class	Bulk density (g/cm3)	FC (Vol %)	PWP (Vol %)	TAW (mm/m)	pH	ECe (dS/m)	ECw (dS/m)	OM (%)
	Sand (%)	Silt (%)	Clay (%)									
Average	34.5	29.7	35.8	Clay loam	1.12	32.3	17.7	163.6	7.5	0.2	0.38	2.3

Source: MARC Laboratory

The analysis of the experimental field soil showed that the value of average pH is near to neutral 7.5. The soil has an average electrical conductivity of 0.2 dS/m through soil profile which is below the threshold value for yield reduction, i.e. 1.2 dS/m (Smith *et al*, 2011). The percentage of the organic matter content of the soil was 2.3. The analysis of applied irrigation water showed that the value of 7.51 and ECw value of 0.38 dS/m was obtained (Table 2). According to Bryan *et al. (*2007), the irrigation water is classified in terms of pH value found that slight to moderate in the study area.

Effect of Depletion Levels on Haricot bean production and Water Productivity

The results of haricot bean total grain yield and water productivity during the two years were presented in Table 3. Analysis of variance revealed that haricot bean grain yield and water productivity were not significantly (p<0.05) influenced by different levels of soil moisture depletion levels. The results of haricot bean in both 2016 and 2017, even though numerically higher yields were observed with 120 % of ASMDL than with the other treatments, but all treatments were not statistically different. Similar results were observed for these treatments in water productivity for the two years of study. The results imply that haricot bean prefers longer intervals between irrigations but deeper depths of irrigation. The result is in line with Muktar and Yigezu (2016) who reported that increasing the soil moisture depletion level over the recommended ASMDL the grain yield and crop water use efficiency of maize could be improved. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas.

Table 3: Effect of irrigation depletion levels on haricot bean production and water productivity during two (2016 and 2017) years of the study.

Treatments	2016 year		2017 year	
	YIELD(t/ha)	WP (kg/m3)	YIELD (t/ha)	WP (kg/m3)
60% of ASMDL	2.75	0.61	2.93	0.61
80% of ASMDL	2.69	0.60	2.63	0.55
ASMDL	3.06	0.68	3.07	0.64
120 % of ASMDL	3.33	0.74	3.56	0.74
140 % of ASMDL)	3.19	0.71	2.13	0.44
CV (%)	10.49	10.73	21.13	21.15
LSD0.05	NS	NS	NS	NS

NS; Non significant

Response of Irrigation scheduling on Haricot bean

Total rainfall amounts for the two growing seasons were 147.8 mm and 89.8 mm in 2016 and 2017, respectively. The average cumulative crop evapotranspiration amounts from the treatments during 2016 and 2017 were 449.7 mm and 480.7 mm, respectively. The average amounts of irrigation water use during the growing season from the treatments in 2016 and 2017 were 301.9 mm and 390.9 mm, respectively. The 2017 growing season was warmer than 2016 with mean crop evapotranspiration of 480.7 mm in 2017, which is higher than the mean maximum crop evapotranspiration of 449.7 mm in 2016. Mean ETo recorded also shows that during the growing season were 5.87 mm/day in 2016 and 6.27 mm/day in 2017. The obtained values of seasonal water demand of 450 - 480 mm could be also in terms of maximum yield and optimum utilization of irrigation water. Similar results reported by Doorenbos and Kassam (1979) for bean crops ranged as 300-500 mm depending on climate.

Table 4: Irrigation water applied, effective rainfall and total seasonal water demand during study

Treatments	2016 year			2017 year		
	Irrigation water applied, mm	Effective rainfall, mm	total seasonal water demand	Irrigation water applied, mm	Effective rainfall, Mm	total seasonal water demand
60% ASMDL	303.0	147.8	450.8	390.5	89.8	480.3
80% ASMDL	300.5		448.3	388.4		478.2
100% ASMDL	302.2		450.0	389.9		479.7
120% ASMDL	302.2		450.0	391.3		481.1
140% ASMDL	301.5		449.3	394.3		484.1

Higher rainfall received during 2016, resulted in small irrigation amounts applied than in 2017 (Table 4). The result indicated that amount and distribution of precipitation seriously affected the irrigation schedule of haricot bean in the study area in the two years differently. Therefore, the irrigation schedule of haricot bean has to be adjusted to the actual climatic conditions of each year, mostly to the amount and distribution of precipitation that affects the depth of irrigation to be applied. The results in line with Pejic et al. (2011) emphasized that amount and distribution of precipitation seriously affected the soil water regime and irrigation schedule. Thus it enables to apply the right the amount of water to be applied at the root zone. A similar conclusion with Ketema et al. (2019) who concluded that supplying the right amount of crop water requirement is essential for healthy plants and potential production and results of crop water requirement depend on crop variety, climate, location, and growing seasons.

The following figure 2 shows that maximum and minimum values and relation of haricot bean grain yield and water productivity with different depletion levels of irrigation which is not statistically significant ($p<0.05$). Even though, the results showed statistically no significant difference among treatments, at treatment 140% ASMDL yield penalty as well as reduction of water productivity occur than other treatments. Thus it's better to irrigate haricot bean (Awash melka) at 55% of depletion level (p~55%) for Melkassa agro climatic condition and similar areas having the same agro climatic condition. Thus during irrigation water application, the availability of experimentally determined local depletion level is important for proper irrigation scheduling and efficient agricultural water management resulted in crop productivity, water productivity, crop quality, profit and sustainable use of irrigated land and also used for design of scheme and planning of different crop production with available water.

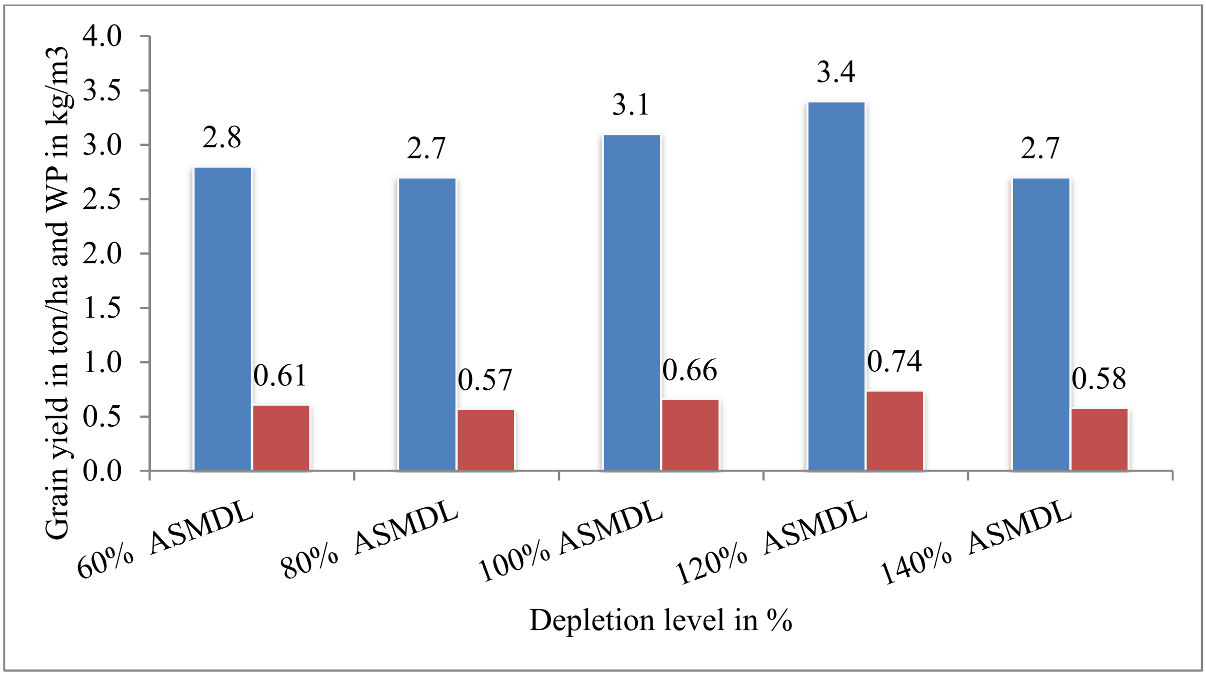

Figure 2: Relation of haricot bean grain yield and water productivity with depletion levels

The over year analysis of variance showed that the effect of allowable soil moisture depletion level on haricot bean grain yield, total above-ground biomass, plant height, pod number and water productivity had no significant difference as treated by the different depletion levels (Table 5). Similar result obtained by Tesfaye et al. (2017) who reported higher water productivity at higher soil moisture depletions on irrigated lemongrass at 60% of the total available water and also improves the herbal and oil yields of lemongrass.

Table 5: Effect of irrigation depletion levels on haricot bean grain yield, yield parameters and water productivity for overall two years of the study

Treatments	Yield (ton/ha)	Total above ground biomass (ton/ha)	Plant height, cm	Pod No.	Water Productivity (Kg/m^3)
60% ASMDL	2.8	3.9	67.6	25	0.61
80% ASMDL	2.7	4.3	73.0	26	0.57
100% ASMDL	3.1	4.2	50.6	25	0.66
120% ASMDL	3.4	4.3	69.1	26	0.74
140% ASMDL	2.7	3.9	66.4	23	0.58
CV (%)	16.4	11.2	6.5	13.5	10.56
LSD$_{0.05}$	NS	NS	NS	NS	NS

NS; Non significant

The result also shows that the principal objectives of irrigation water management that are to make the most effective use of water coupled with higher crop yields and to prevent waste of water and to save it for further use to irrigate new areas by applying the right amount of water required at right time. This result is in line with Ketema et al. (2019) who say efficient use of water for irrigated agriculture is fundamental for agricultural production that improves crop water productivity, especially in arid and semi-arid areas.

In general, the result showed that farmers can irrigate haricot bean at different intervals without significant yield loss. However, it's better to irrigate at 120% and 140% ASMDL at large interval to minimize competition for water; give time for maintenance of pumps and field operation such as weeding, hoeing and canal maintenance. In irrigation practice, only a percentage of TAW is allowed to be depleted because plants start to experience water stress even before soil water is depleted down to PWP. Therefore, a management allowed depletion (ASMDL, %) of the TAW must be specified which is also suggested by Andales et al. (2015)

CONCLUSIONS

Two season field experiments were conducted at Melkassa ARC in Ethiopia to determine the effect of optimal irrigation scheduling on yield and water productivity of haricot bean *(Phaseolus vulgaris L.*). The experiment was designed based on ± 40% of FAO recommended ASMDL (45%) five-treatment combinations replicated three times in RCBD under furrow irrigation method.

The results of the study revealed that optimum water amount and irrigation scheduling determined. Irrigating haricot bean at the different depletion level within ± 40% ASMDL didn't affect the yield and water productivity of haricot bean. Therefore, the use of higher depletion levels like 120% and 140% ASMDL will be more efficient for irrigation water management and from the result it is better to use 120% ASMDL (p~55%) to be profited than 140% ASMDL because it produce higher yield and water productivity than 140% ASMDL. The obtained values of seasonal water demand of 450 - 480 mm could be also used as a good platform for haricot bean growers in the area in terms of maximum yield and optimum utilization of irrigation water. Thus closely keeping available water within crop needs throughout the cropping season improves yields and water productivity.

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