Response of onion (Allium CepaL.) to soil moisture stress condition at different growth stages in the central Highland Vertisols Areas of Ethiopia.

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ABSTRACT

Improving water use efficiency is an important strategy for addressing future water scarcity. Therefore, enhancing agricultural water productivity is a critical response since agriculture is the main consumer of global fresh water. The main objective of this study was to identify sensitive growth stages of onion to soil moisture stress, to determine the critical time for irrigation water application and water use efficiency for onion. The field experiment was conducted for three consecutive seasons (2015 – 2017) at main station of Debre Zeit Agricultural Research Center. Fifteen treatments were used. It is arranged by stressing application of the crop water requirement during irrigation event with combinations of four growth stages of onion. All treatments were laid out in randomized complete block design with three replications for each treatment. The result revealed that onion bulb yield and water use efficiency were significantly affected at $p< 0.05$ by depriving irrigation water at growth stages among the all treatments. The highest bulb yield (23.8 t/ha) was observed from no stress (control) treatment and followed by stressing at initial (22.7 t/ ha) and at maturity stage (21.6 t/ha) with no statistical difference with control. However, the lowest yield was recorded at stressing all stages of the crop growth period except development (6.7 t/ha). There was also a significant differences of water use efficiency (WUE) detected among the treatments. However, the highest WUE (13.84 kg/m^3) had been recorded at stressing all stages except initial. Under irrigated onion production, the mid-stage should be regularly monitored as it significantly affects the yield of onion. Besides, in the areas where

irrigation water is limited, limiting the amount of water applied during development and maturity sage is the best solution to enhance water productivity without significantly reducing the bulb yield of irrigated onion.
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Keywords: Critical stages; Crop response; Moisture stress; Treatments; Yield

1. INTRODUCTION

Irrigated agriculture is the major consumer of available fresh water worldwide and its consumption is estimated at 70% of the existing freshwater supplies. Besides, there is a general perception that agriculture water use is often wasteful and highly inefficient (Hsiao et al., 2007). However, irrigation agriculture, covering only 17% of the world cultivated area, provides 40 to 45% of the world food and fiber supply (Evans and Sadler, 2008).

Ethiopia has a favorable climate, comparatively abundant land and labor as well as reasonably good water resources, which created ample opportunities for horticulture and floriculture production. The agro-ecological factors of the country give the chances of all-year-round production capability. The country has 125 billion cubic meter surface water, 2.6-13 billion cubic meter ground water, 12 river basins, 18 natural lakes including the Rift Valley lakes and a potential of 5.3 million hectares irrigable land (Awulachew et al., 2010). 80-90 percent of these resources are located in the west and south-west of the country where close to 40 percent of the Ethiopian population lives.

Furthermore, 10-20 percent of these resources are located in the east and central part of the country.

However, the production of sustainable and reliable food supply is becoming hard to realize because of temporal and spatial imbalance in the distribution of rainfall. This often resulted in non-availability of water at some critical periods causing crop failure. To combat these natural phenomena, it needs shifting from the traditional rain-fed agriculture to efficient irrigation agricultural practices. Under conditions of scarce water supply and drought, deficit irrigation practice is economically more profitable than maximizing yield and unit of water use (Molden*et al*., 2010). However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by growth stage, species and cultivars. Identifying growth stages of particular crops under local conditions of climate and soil fertility allows irrigation scheduling for maximum crop yield and most efficient use of scarce water resource. Therefore, in areas with water shortage, it is important to see what level of stress at specific growth stages of major irrigated crops result in high water use efficiency (Upchurch et al., 2005, Evans and Sadler, 2008). This enables irrigators to know not only a critical growth stage but also help to identify the optimum magnitude of stress to be imposed.

Onion (*Allium cepa L.*) is one of the most important vegetable crops worldwide. The Ethiopian upper Awash Valley region is an area of great economic importance to the national food security and foreign exchange earnings of the country through production of export crops. The bulk of onion produced in the county comes from this region where cultivation is mainly carried out using irrigation. However, with the increase in the use of irrigated land by state and private farms, there will be more pressure on the consumption of available water, which will lead to scarcity of irrigation water, and sensitivity of onion crop to moisture stress during the most important stages, and hampering of onion yield. Besides; there were very limited studies available on the application of deficit irrigation practices for onion production in Awash Valley and there is no adequate knowledge of yield response to soil moisture stress at different growth stages.

Therefore, considering the scarcity of irrigation water in the region and the sensitivity of onion crop to moisture stress, this research was aimed to identify the specific growth stages of onion crop at which it becomes sensitive to water stress and determine crop water productivity under deficit irrigation practice.

2. MATERIALS AND METHODS

2.1. Description of study area

The study was conducted at Debre Zeit Agricultural Research Center, located in the central highlands of Ethiopia. Its geographical location extends from 08°45’51” (8.760) Northern latitude to 39°00’29” (39.010) Eastern longitude. It has low relief difference with altitude ranging from 1610 to 1908 meters above the mean sea level. The soil at the experimental site is heavy clay in texture with the field capacity and permanent wilting point of 35% and 19%, respectively. The area receives an annual mean rainfall of around 810.3 mm with the medium annual variability. Seasonal variations and atmospheric pressure systems contribute to the creation of three distinct seasons in Ethiopia: Kiremt (June to September), Bega (October to February) and Belg (March to May). The Kiremt is the main rainy season and Belg is the short-lasting season while the dry season is the attribute of Bega (Selshi and Zanke, 2004). Belg in the study area receives quite small rainfall to support crop production whereas Kiremt is known by long rainy season. About 76 % of the total rainfall of the area is attributed to Kiremt or wet season, about 15% to Belg and the rest to Bega or dry season which needs full irrigation in the area. The mean maximum temperature varies from 23.7 to 27.7^{o}C while mean minimum temperature varies from 7.4 to 12.10C (Table-1). However; maximum and minimum reference Evapotranspiration (ETo) was recorded as 4.9 and 3.3 mm/day in May and July months, respectively (Table-2).

Table 1. The climate data of 42 years (1975 – 2017) for the study area.

Month	T max (^{O}C)	T min (^{O}C)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour (hrs)	Solar radiation ($MJ/M^2/day$)
January	25.2	8.9	63.0	1.3	9.8	22.0
February	26.3	10.2	46.4	1.4	8.5	21.4
March	27.0	11.3	46.4	1.5	8.1	21.8
April	27.1	11.9	47.7	1.5	7.1	20.4
May	27.7	11.6	46.5	1.6	8.6	22.2
June	26.4	11.4	54.9	1.0	6.3	18.4
July	23.7	12.1	66.4	0.9	4.9	16.4
August	23.9	12.1	67.8	0.9	5.5	17.7
September	24.1	11.5	63.3	0.8	6.7	19.6
October	25.0	9.5	49.9	1.4	8.6	21.7
November	24.6	8.0	47.0	1.3	9.3	21.4
December	24.8	7.42	46.9	1.4	9.4	20.9
Average	**25.5**	**10.5**	**53.9**	**1.2**	**7.7**	**20.3**

Table 2. Mean Monthly rain fall, effective rainfall and ETo values of study area.

Month	**Season**	**Rainfall (mm)**	**Effective Rainfall (mm)**	**ETo (mm/day)**
January	Bega	9.4	0.0	4.0
February		24.8	4.9	4.4
March	Belg	31.5	8.9	4.7
April		44.2	16.5	4.6
May		41.3	14.8	4.9
June	Kiremt	88.9	47.1	3.9
July		235.1	164.1	3.3
August		208.2	142.6	3.5
September		83.6	42.9	3.7

Month	Season	Rainfall (mm)	Effective Rainfall (mm)	ETo (mm/day)
October		25.9	5.5	4.3
November	Bega	7.4	0.0	4.1
December		1.0	0.0	4.0
Average		**810.3**	**447.3**	**4.1**

2.2. Treatments and Experimental design

A field experiment was executed in three seasons of the years 2015 to 2017. This experiment was laid out in randomized complete design (RCBD) with three replications. The treatments in Table 3 showed fifteen soil moisture stress levels including check with growth stages and its combinations.

According to Allen et al. (1998) the initial stage runs from planting date to approximately 10% ground cover. The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops including onion occurs at the bulb initiation. The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, and leaf drop. The late season stage runs from the start of maturity to harvest or full senescence.

Table 3. Treatments combination

No.	Treatments
1	Irrigate all growth stages (Check)
2	Irrigate all stages except initial stage
3	Irrigate all stages except development stage
4	Irrigate all stages except mid-season stage
5	Irrigate all stages except maturity stage
6	Irrigate all stages except initial and development stages
7	Irrigate all stages except initial and mid-season stage
8	Irrigate all stages except initial and maturity stages
9	Irrigate all stages except development and mid-season stages
10	Irrigate all stages except development and maturity stages
11	Irrigate all stages except mid-season and maturity stages
12	Irrigate only at maturity stage
13	Irrigate only mid-season stage
14	Irrigate only development stage
15	Irrigate only initial stage

2.2.1. Experimental procedure and management practice

Nafis variety of onion (*Allium cepa L.)* seedlings was transplanted to individual plots with 3m x 3m area consisting of five ridges. Then it was planted on both sides of the ridges with 20cm furrow and 10cm plant spacing. Onion seedlings transplanted to experimental field were received two common irrigations to ensure better plant establishment. One-time application of Di-ammonium phosphate (DAP) at transplanting only and a split application of urea at transplanting and 10 days after transplanting were done by hand placement at a rate of 200 kg/ha and 100 kg/ha, respectively (Olani and Fikre, 2010). All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and two light irrigations for establishment.

2.2.2. Irrigation and water management

The depth of irrigation was estimated using CROPWAT 8 model from daily climate data. Irrigation scheduling was done based on soil water depletion and replenishment. CropWAT8 model was used to set each growth stages. Initial stage should be 18days after planting (25th Nov. to 7th Dec.), Development stage 46 days after planting (13th Dec. to Jan. 4th), Mid stage 87 days after planting (12th Jan. to Feb. 14th). Finally, maturity stage 22 days after planting (13th Dec. to Jan. 4th). The gross irrigation water applied annually for each growth stage was 81.9mm, 151.9mm, 250.5mm, and 49.2mm, respectively.

Irrigation water was delivered to the experimental plots through an open channel. The amount of water applied to the plots was measured using Parshall flume (3-inch throat width) (Kandiah, 1981). Predetermined amount of water for irrigation events was applied for each treatment. The gross irrigation requirement was computed by adopting a field application efficiency of 60%. As stated by Bakker et al. (1999), application efficiencies of furrow irrigation normally vary between 45 and 60% (Bakker et al., 1999). Time is then recorded with a stopwatch to estimate the amount of water applied to each plot. Accordingly, the time required to deliver the desired depth of water into each plot was calculated using the following equation:

$$t = (Ig \times A)/(60 \times q)\text{-- (1)}$$

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.

2.2.3. Data collection

From the total of five plating rows, the interior three sampling rows were harvested. The data collected included onion yield and yield parameters like plant height.

2.2.4. 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 the equation suggested by Zwart and Bastiaanssen (2004).

$$\text{WUE (kg}/m^3\text{)} = \text{MBY } (\tfrac{kg}{ha}) \text{ / Irrigation water used } (m^3/\text{ha})\text{---- (2)}$$

Where, WUE is Water Use Efficiency (kg/m^3), MBY is marketable bulb yield harvested (kg/ha) and ET is the net irrigation water used though out the growing period (m^3/ha).

2.2.4. Yield Response Factor

The yield response factor (Ky) of maize was estimated using the equation formulated by Doorenbos and Kassam (1979) as:

$$(1 - Ya/Ym) = Ky\ (1 - ETa/ETm) \text{ --------------------------- } (3)$$

Where, Ya is an actual yield (kg/ha), Ym is a maximum yield (kg/ha), ETa is an actual evapotranspiration (mm), ETm is a maximum evapotranspiration (mm), and Ky is a yield response factor.

2.2.5 Data Analysis

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

3. RESULTS AND DISCUSSION

3.1. Effect of Soil Moisture Stress on Onion Bulb Yield and Water Productivity

3.1.1. Onion Bulb Yield

The means across years indicated the presence of moisture stress at different onion growth stages had a significant effect at $p<0.05$ on marketable bulb yield. The result revealed that the maximum bulb yield of 23.8 t/ha was obtained from irrigating all growth stage (control) though statistically no significant difference with stressed either at initial or maturity. The minimum bulb yield of 8.1 t/ha was obtained from treatment with moisture stress at three stages (Initial, development and mid-season). Stressing onion at mid-stage results in lowering bulb yield compared with the other stages, (Table 3).

3.1.2. Crop Water Use Efficiency

Moisture stress at different growth stages has a significant ($p<0.05$) influence on water use efficiency of irrigated onion. The maximum onion water use efficiency was obtained from irrigating only at initial stage (13.84 kg/m^3) and development stage. However, the minimum efficiency was obtained from irrigating at all growth stages (6.64 kg/m^3). Yensew and Tilahun (2009) indicated that application of irrigation water by reducing the amount of water per irrigation results in a decline of grain yield, increase in irrigated area and high water use efficiency. The minimum water was due to the imposed moisture stress at all seasons followed by stress at initial, development and mid-seasons. The study revealed that irrigating onion only at initial stage and development stage resulted in higher water productivity as shown in Table 4.

Table 4. *Bulb yield and water productivity analysis*

No.	Treatments	Bulb Diameter (cm)	Bulb yield (t/ha)	WUE (kg/m^3)
1	Irrigate All Growth Stages	6.4^{ab}	23.8^{a}	6.64^{f}
2	Irrigate All Stages Except Initial Stage	5.9^{abc}	22.7^{a}	8.78^{cdef}
3	Irrigate All Stages Except Development	5.8^{abc}	16.8^{bc}	7.15^{ef}

No.	Treatments	Bulb Diameter (cm)	Bulb yield (t/ha)	WUE (kg/m^3)
4	Irrigate All Stages Except Mid-Season Stage	6.6[a]	11.5[ef]	9.08[cdef]
5	Irrigate All Stages Except Maturity	6.8[a]	21.6[a]	8.81[cdef]
6	Irrigate All Stages Except Initial & Development	5.5[abc]	15.1[cd]	9.47[bcde]
7	Irrigate All Stages Except Initial & Mid-Season	5.9[abc]	13.3[ed]	8.48[cdef]
8	Irrigate All Stages Except Initial & Maturity	6.5[ab]	17.5[b]	9.10[cdef]
9	Irrigate All Stages Except Development & Mid-Season	4.7[c]	10.7[f]	9.75[bcd]
10	Irrigate All Stages Except Development & Maturity	5.0[c]	12.2[ef]	7.28[def]
11	Irrigate All Stages Except Mid-Season And Maturity	4.9[c]	10.6[f]	10.07[bc]
12	Irrigate Only At Maturity Stage	5.2[bc]	8.1[gh]	11.67[ab]
13	Irrigate Only Mid-Season Stage	5.6[ab]	10.4[gf]	10.03[bc]
14	Irrigate Only Development Stage	4.9[c]	9.9[gf]	13.00[a]
15	Irrigate Only Initial Stage	5.3[bc]	6.7[h]	13.84[a]
	R^2	**0.55**	**0.96**	**0.75**
	CV (%)	**13.8**	**9.8**	**15.7**
	LSD0.05	**1.3**	**2.3**	**2.5**

**Means followed by the same letters in a column are not significantly different from each other at a 5% probability level; CV: coefficient of variation; LSD: least significant difference.*

4. CONCLUSIONS

The result of this study revealed that stressing onion at early and late growth stages enhance water use efficiency of the crop without significantly reducing the yield under climatic condition of Debre Zeit. Stressing onion at development and mid-season crop growth stage while irrigating at the rest of growth stages may lead to wastage of water and decrease of water productivity. To improve onion productivity both in irrigated and rain-fed agriculture, application of irrigation water to enhance the soil moisture at mid-season growth stage is vital. However, combined moisture stress at development and mid-season stage critically influences the yield and water use efficiency. Thus, water use efficiency is lower for well-irrigated onion and inferior especially when moisture stress takes place at development and mid-season stages. Likewise stress at mid-stage has great influence on water use efficiency with every combination. Therefore, it can be concluded that the critical sensitive stages for onion crop at mid-stage. Moreover, to enhance the water use efficiency without affecting the bulb yield, onion could be irrigated after stressing at the initial stage and late season stage.

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