Response of Onion (*Allium cepa L.)* 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, critical time for irrigation water application and to determine 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, preventing not to apply the crop water requirement during irrigation with combinations of four growth stages of onion were used. 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 different growth stages among the treatments. The highest bulb yield was observed from no stress (23.8 t/ha) followed by stressing at initial (22.7 t/ha) & stressing at maturity stage (21.6 t/ha) with no statistical difference while 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) has 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 scenario to enhance water use efficiency without significantly reducing the bulb yield of irrigated onion.

Keywords: Critical stages, Yield, Moisture stress, Crop response and Treatments.

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, covering only 17% of the world cultivated area, irrigation agriculture 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) and about 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 and 10-20 percent of these resources are located in the east and central part where most of the population has settled.

However, the production of sustainable and reliable food supply is becoming almost impossible due to temporal and spatial imbalance in the distribution of rainfall. This often-brought non-availability of water at some critical periods causing crop failure. To combat these natural phenomena, it needs shifting from the traditional rainfed agriculture to efficient irrigation agricultural practices. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gain by 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, as irrigated land under vegetables and other irrigated crops by state and private farms is increasing in the area, the pressure on the available water is increasing leading to scarcity of irrigation water and sensitivity of onion crop to moisture stress during the most important stages hampering yield of onion. Besides; there were very limited studies available on the application of deficit irrigation practices for onion production in Awash Valley area 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 the plant is sensitive to water stress and also to determine crop water productivity under deficit irrigation practice.

Materials and Methods

Description of study area

The study was conducted at Debre Zeit Agricultural Research Center, located in the central highlands of Ethiopia. Its geographical extent ranges between 3 / 0 0, 3)21 I . 4 -4 . 4) , b)D 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 seaon while the dry season is attributed to 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 falls in Kiremt or wet season, about 15% in Belg and the rest is in Bega or dry season which needs full irrigation in the area. The mean maximum temperature varies from 23.7 to 27.7°C while mean minimum temperature varies from 7.4 to 12.1°C (Table-1). However; maximum and minimum reference Evapo-transpiration (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 (°C)	T min (°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	Rainfall (mm)	Effective Rainfall (mm)	ETo (mm/day)	Season
January	9.4	0.0	4.0	Bega
February	24.8	4.9	4.4	
March	31.5	8.9	4.7	Belg
April	44.2	16.5	4.6	
May	41.3	14.8	4.9	
June	88.9	47.1	3.9	Kiremt
July	235.1	164.1	3.3	
August	208.2	142.6	3.5	
September	83.6	42.9	3.7	
October	25.9	5.5	4.3	Bega
November	7.4	0.0	4.1	
December	1.0	0.0	4.0	
Average	**810.3**	**447.3**	**4.1**	

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 block design (RCBD) with three replications. The treatments which are presented in Table 3 consisted of fifteen soil moisture stress levels and a check which imposed at four growth stages.

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, leaf drop for onion. 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

Experimental procedure and management practice

Nafis variety of onion (Allium cepa L.) seedlings were transplanted on individual plots with 3mx3m area consisting of five ridges and planted on both sides of the ridges with furrow and plant spacing of 20 & 10cm, respectively. 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.

Irrigation water management

Depth of irrigation water applied was estimated using CROPWAT 8 model from daily climate data. Irrigation scheduling was done based on soil water depletion and replenishment. The planting and harvesting date was 25th of November and 9th of March respectively. Using CropWAT8 model, Initial stage 15days after planting (25th Nov. to 9th Dec.), Development stage 45 days after planting (10th Dec. to 8th Jan.), Mid stage 85 days after planting (9th Jan. to Feb. 18th), and Maturity stage 105 days after planting (Feb 19th. to Mar. 9th). The gross irrigation water applied annually for each growth stage was 81.9mm, 151.9mm, 250.5mm, and 49.2mm respectively.

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). 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%. As stated by Bakker et al. (1999), furrow irrigation application efficiencies normally vary between 45 and 60% (Bakker et al., 1999). Time is then recorded with a stop watch 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 equation:

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

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.

Data collection

From the total of five planting rows the interior three sampling rows were harvested. Data on pepper yield and yield parameter like plant height was collected.

Water use efficiency

Water use efficiency (WUE) was estimated as a ratio of yield to the total ETc through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$\mathbf{WUE}\ (\mathbf{kg/m^3}) = \mathrm{MBY}\ (\mathrm{kg/ha})\ /\ \mathrm{ETc}\ (\mathrm{m^3/ha}) \text{ ------------------- } (2)$$

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

Yield Response Factor

The yield response factor (Ky) of maize was estimated using the following equation which is formulated by Doorenbos and Kassam (1979).

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

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

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 employed to compare the differences among the treatments mean.

Results and Discussion

Effect of Soil Moisture Stress on Onion Bulb Yield and Water Use Efficiency

Onion Bulb Yield

The result of over years means indicated moisture stress at different onion growth stages had a significant effect ($p<0.05$) on marketable bulb yield. This revealed that the maximum bulb yield of 23.8 t/ha was obtained from irrigating all growth stage (control) and also statistically no significant difference with the treatment 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 result in lowering bulb yield compared with the other stages (Table 3).

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 initial stage (13.84 kg/m^3) and followed by irrigate only at development stage but the minimum was obtained from irrigating all four 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 highwater use efficiency. The minimum water was due to the imposed moisture stress at all season followed by stress at initial, development and mid-season. The study revealed that irrigating onion at only at initial stage and irrigate only at development stage resulted in higher water use efficiency as shown in Table 4.

Table 4. Bulb yield and water use efficiency 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}
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.

Conclusion and Recommendation

Based on the result gained on response of onion to moisture stress condition at some growth stages enhance water use efficiency of onion without significantly reducing the yield under climatic condition of Debre Zeit. Stressing onion at development and mid-season crop growth stage while irrigating the rest of growth stages may lead to wastage of water. To enhance onion crop productivity both in irrigated and rain-fed agriculture, application of irrigation water to enhance the soil moisture at mid-season growth stage is vital where supplementary irrigation from available water source is possible. However, combined moisture stress at development and mid-season stage critically influenced the yield and water use efficiency. Generally, water use efficiency is lower for well irrigated onion and inferior especially when moisture stress takes place consecutively on 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 are mid stage and combined development and initial stages. Moreover, to enhance the water use efficiency without affecting the bulb yield, onion could be irrigated after stressing at the initial stage and also stressing at late season stage.

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References

Awulachew SB, Merrey D, Van Koopen B, and Kamara A. 2010. Roles, Constraints and Opportunities of Small-Scale Irrigation and Water Harvesting in Ethiopian agricultural Development: Assessment of Existing Situation. ILRI workshop; 2010 March 14-16; Addis Ababa, Ethiopia: International Water Management Institute (IWMI).

Bhagyawant RG, Gorantiwar SD and Dahiwalkar SD. 2015. Effect of Deficit Irrigation on Crop Growth, Yield and Quality of Onion under Surface Irrigation. American-Eurasian J. Agric. & Environ. Sci., 15 (8): 1672-1678

Bakker DM, Raine SR and MJ Robertson, 1999. A preliminary Investigation of Alternate Furrow Irrigation for Sugar Cane Production. [http://www.usq.edu.au/users/raine/index fiels/ASSCT 97](http://www.usq.edu.au/users/raine/index%20fiels/ASSCT97). Bakkeret al., pdf.

Bekele S, Tilahun K. 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia.Agric Water Manage. 89:148 152.

Chen S, Zhen-jiang Z, Mathias N and Tian-tian H. 2015. Tomato yield and water use efficiency-coupling effects between growth stage specific soil water deficits. Acta Agriculturae Scandinavica, Section B-Soil & Plant Science 65(5):460-469.

Evans RG and Sadler EJ. 2008. Methods and technologies to improve efficiency of water use. Water Resources Res. 44:1-15.

Fabeiro Cortés, C Martín de Santa Olalla, F López Urrea R. 2003. Production of garlic (Allium sativum L.) under controlled deficit irrigation conditions in a semi-arid climate. Agricultural Water Management, 59, 155 167.

Hsiao TC, Steduto P, Fereres E. 2007. A systematic and quantitative approach to improve water use efficiency in agriculture. Irrigation Science, 25, 209-231.

Kandiah A. 1981. Guide for measurement of irrigation water using Parshall flumes and siphons: Technical bulletin No 1. Addis Ababa, Ethiopia. p. 2.

Mermoud A, Tamini TD and Yacouba H. - 0) D a aa b water balance components of an onion crop in a semi- <b R Management 77(1-3): 282 293.

Molden D, Oweis T, Steduto P, Bindraban P, Hanjra MA, Kijne J. 2010. Improving agricultural water productivity: Between optimism and caution. Agric. Water Manag. 97, 528 553.

J AE b -Padilla A, L´opez R. 2004. Production and quality of the onion crop (Allium cepa L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate <b R H b 13 , 522 89,

Olani Nikus and Fikre Mulugeta. 2010. Onion seed production techniques. A Manual for Extension Agents and Seed Producers. FAO-Crop diversification and marketing development project. FAO, Rome, Italy.

Valipour M. 2014. Pressure on renewable water resources by irrigation to 2060. Acta Advances in Agricultural Sciences 2(8):23-42.

Zwart SJ and Bastiaanssen WGM. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize, Agricultural Water Management,69(2),115-133.