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Irrigation scheduling and water use efficiency for onion production in Kulumsa, Arsi Zone, Ethiopia

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The response of onion to irrigation regime was evaluated at Kulumsa Agricultural Research Center, Arsi zone, Ethiopia, for 3 consecutive years from 2015/16 to 2017/18. Five treatments based on the level of soil moisture depletion (60%, 80%, 100%, 120%, and 140% of Available Soil Moisture Depletion Level (ASMDL)) were evaluated on yield, yield components, and water productivity of onion. The experiment was arranged in a randomized complete block design with 3 replications. Results demonstrated that irrigating onion at soil moisture depletion levels from 60 to 140% of the FAO recommendation significantly influenced the biomass yield, but had no significant effect on plant height, bulb diameter, bulb yield, and water productivity of onion. Higher bulb yield, biomass yield, and water productivity of 29,926 kg ha-1, 8,770 kg ha-1 and 5.34 kg m-3, respectively were attained at 80% of ASMDL. The general tendency demonstrated that the bulb yield and water productivity of onion decreased with increasing soil moisture depletion level from 80 to 140% of ASMDL. Irrigating onion at 120% ASMDL provided the highest economic return of 89.23 birr per every unit birr investment on labor for irrigation. Given the enhanced economic return, prolonged irrigation frequency, and non-significant yield and water productivity of onion compared to 80% of ASMDL, irrigating onion at 120% of ASMDL has been recommended for the study area and other areas with similar agro-ecologies for irrigated onion production.

Keywords: Onion bulb yield, irrigation scheduling, onion, soil moisture depletion and water productivity.

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INTRODUCTION

Water is essential for crop production, and the best use of the available water must be made for efficient crop production and higher yields. This requires a proper understanding of the effect of rainfall-irrigation on crop growth and yield under different growing conditions (FAO, 1986). Irrigation can be defined as the replenishment of soil water storage in the plant root zone through methods other than natural precipitation. Irrigation is seen to have found its roots in the history of mankind since the earliest beginning. It helps to reduce the uncertainties, particularly the climatic uncertainties in agricultural practices. The practice of irrigation consists of when and how much to irrigate.

Crop water requirement (CWR) encompasses the total amount of water used in evapotranspiration. FAO (1992) defined crop water requirement as 'the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment'. The irrigation water requirement represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and water to compensate for the non-uniformity of water application. For the calculations of the CWR, the crop coefficient approach is used (Allen et al., 1998).

The onion (Allium cepa L.) crop belongs to the plant family of Alliaceae and is one of the earliest vegetable crops grown. The use of onion is worldwide among all nationalities and cultures. It is available in most markets of the world throughout the entire seasons of the year. Onion is used widely in Ethiopia and many parts of the world for flavoring and seasoning foods, as a vegetable, and for medication. Thus, onion forms an essential part of the daily diet, creating year round demand.

Irrigation scheduling is directly related to profitable onion production and sustainable agricultural practices.

Research at the Oregon State University Malheur Experiment Station has demonstrated that onion yield and grade are very closely related to irrigation practices, especially the criterion used to schedule irrigations. Careful attention to irrigation scheduling can help assure high onion yields, better bulb storability, and better internal quality. The onion needs frequent irrigation to maintain high soil moisture (Shock et al., 1998). Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Al-Jamal et al., 1999; Hedge, 1986; Olalla et al., 1994; Vučić, 1976). If a shortage of readily available soil water is eliminated and the technological and biological characteristics of the crop are taken into account, it is possible to achieve high and stable yields of irrigated onion, at the level of 40 t ha-1 or higher (Halim and Ener, 2001; Kanton et al., 2003; Meranzova and Babrikov, 2002; Pejić et al., 2008). Therefore, the objective of this study was to evaluate the response of onion to irrigation regime (when and how much to irrigate) and to determine the crop water productivity.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Kulumsa Agricultural Research Center, Tiyo district of Arsi Zone Oromia regional state, Ethiopia. The study area lies between 8°00'59'' N latitude, 39°09'25'' E longitude and situated at an elevation of 2200 m. a.s.l. It is characterized by uni-modal rainfall pattern with a mean annual rainfall of 809 mm. The study area had minimum and maximum air temperatures of 9.9°C and 23.1°C, respectively. The soil is characterized by a clay loam texture. The experimental site had a field capacity and wilting point of 33.6 and 21.8%, respectively. Thus, the total available water content of the studied soil was about 11.8% while its bulk density was 1.25 g cm-1. The climatic data of the study area is summarized in Table 1.

Table 1: Long-term climatic data of Kulumsa (1979-2009)

Month	RF (mm)	Max T (°C)	Min T (°C)	RH (%)	WS (m s-1)	SS (hr)	ETo (mm)
January	17.09	23.36	8.21	56.49	4.96	8.18	191.36
February	37.66	24.37	9.35	52.89	5.23	8.35	173.18
March	79.53	25.07	10.33	50.73	4.36	7.65	182.63
April	84.15	24.41	11.50	58.35	4.18	7.23	161.08
May	88.13	24.80	11.16	57.26	4.74	7.28	179.89
June	87.04	23.50	10.64	80.58	4.71	6.53	133.03
July	124.22	21.16	10.64	76.41	4.84	4.94	128.55
August	131.07	20.94	10.38	77.37	3.87	4.96	105.58
September	97.86	21.51	9.94	75.38	2.87	5.57	99.01
October	42.09	22.75	10.17	60.91	4.98	7.65	192.32
November	10.16	22.56	8.70	53.98	5.71	8.75	198.98
December	10.15	22.53	7.71	54.23	6.11	9.00	179.27
Total	809.15						1924.87
Average		23.08	9.90	62.88	4.71	7.17	

Note: RF, Max T., Min T., RH, WS, SS, and ETo are rainfall, maximum temperature, minimum temperature, relative humidity, wind speed, and reference evapotranspiration, respectively

Table 2: Climatic data of Kulumsa area during cropping season (2015/16-2016/17)

Year	Month	Rainfall (mm)	Effective RF (mm)	RH (%)	Sun Shine Hour (hr)	Tmax (OC)	Tmin (OC)	Wind Speed (m/s)
2015	November	28.40	7.04	58.33	8.04	23.68	12.15	2.20
	December	0.30	-9.82	62.06	7.56	23.12	11.43	2.16
2016	January	20.90	2.54	64.58	8.89	24.73	11.95	1.44
	February	1.90	-8.86	52.21	7.03	26.47	11.30	2.17
	November	12.20	-2.68	56.65	7.51	23.52	11.20	1.76
	December	0.00	-10.00	55.39	8.96	22.60	10.42	2.35
2017	January	0.00	-10.00	44.57	8.94	24.08	9.14	2.39
	February	29.10	7.46	60.86	6.98	24.67	10.70	1.58

Note: RF, T max., T min., and RH are rainfall, maximum temperature, minimum temperature and relative humidity respectively.

Effective Rainfall (peff) is calculated by Dastane N.G., 1974 empirical equation for design purpose at 80% probability of exceedance as follows:

$P_{eff} = 0.6^* P_{Total} - 10$ for $P_{Total} < 70$ mm (1)
Peff = 0.8 * PTotal - 24 for PTotal > 70 mm

Experimental design and management practices

The seed of an improved variety of onion (Bombe Red) was initially grown in the nursery. The seedlings were transplanted to the experimental plots and well-watered to have suitable growth and favorable plant stand. The experimental plot size was 4.0 m wide and 4.50 m long. The spacing between ridges was 0.40m. The seedlings were planted in both sides of each row, which held the spacing of 0.20 m between two lines within a row, and 0.10 m between plants along each planting line. The onion was fertilized with the recommended rate of nitrogen (113 kg N ha-1) and phosphorous (49 kg P ha-1) from di-ammonium phosphate and urea, respectively. All doses of P and half of N were applied in a band as basal along rows during transplanting, while the remaining half of N was side dressed at the flowering stage.

The furrow method was used to supply irrigation to each plot. The amount of irrigation water applied to each furrow was measured using a 2-inch partial flume. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT 8.0 software (Smith, 1992). Crop water requirement was also calculated using CROPWAT 8.0 computer program based on the FAO Penman-Monteith method (Allen et al., 1998). Soil water content was monitored using the gravimetric method of soil moisture content determination. Soil samples were taken from the representative locations within rows of each plot just before irrigation and 24 hours after irrigation to check whether the residual moisture content approached to manageable allowable depilation and field capacity levels, respectively. All agronomic practices were carried out uniformly to the entire plots as per the recommendation set for onion.

This experiment was conducted for 3 consecutive years from 2015/16 to 2017/18 during the non-rainy season. The irrigation treatments included 5 levels of soil water depletions depending on the FAO guideline. Irrigation scheduling was based on the percentage depletion level of available soil water content in the root zone. The treatments were Available Soil Moisture Depletion Level (ASMDL) at 60%, 80%, 100%, 120% and 140%. The experimental treatments were laid out in a randomized complete block design with 3 replications. The treatment description is summarized in Table 2.

Table 3: Treatment setting for the field experiment

No	Treatment	Description
T1	ASMDL1	60% of ASMDL
T2	ASMDL2	80% of ASMDL
T3	ASMDL3	ASMDL*
T4	ASMDL4	120% of ASMDL
T5	ASMDL5	140% of ASMDL

*ASMDL is available soil moisture depletion level according to FAO (33) (Doorenbos and Kassam, 1979).

With the aid of the CROPWAT software, the crop water requirement of onion was calculated for the 4 growth stages. The input data were historic (1979–2009) monthly climatic data as obtained from the meteorological station located in the center, where the study was carried out; soil physical properties such as texture, field capacity, permanent wilting point, available water content and infiltration capacity of the soils; and crop specific information. The crop information included type, growth stages and their respective periods, effective rooting depth and days to maturity.

Data collection and analysis

The collected (computed) data on yield and yield components of onion included plant height, bulb diameter, bulb yield, biomass yield and water productivity. Water productivity in response to the irrigating at different soil moisture depletion levels was quantified from equation 1. Water productivity was computed as a ratio of total bulb yield to the total water applied (Bos, 1985).

$$\text{Water productivity}\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{\text{Total bulb yield (kg)}}{\text{Crop water use (m}^3\text{)}} \quad (2)$$

Economic analysis

Economic analysis was conducted to evaluate the comparative advantages of irrigating at different soil moisture depletion levels for onion production following the procedure of partial budget analysis set by CIMMYT (1988). The cost that varied during the period of this study was the expense incurred for labor to irrigate experimental plots. The other costs are considered fixed since they hold similar among the experimental treatments. The value of variable cost (VC) was calculated based on the farm gate price of labor. The gross field benefit (GFB) was calculated by multiplying the selling price of the bulb yield of onion. The net benefit (NB) was calculated by subtracting the VC from GFB. The marginal rate of return (MRR) was calculated as the ratio of marginal NB and marginal VC of onion production. The bulb yield of onion was adjusted downwards by 10% before calculation to represent the actual yield that can be attained based on the farmers' practices. The treatments were listed in increasing order of VC. One treatment was discarded from further consideration through dominance analysis due to the greater variable cost, but lower net benefit. The marginal rate of return (MRR) was calculated for the remaining 4 treatments. The acceptable MRR considered declaring profitability in this study was greater than or equal to 100%.

Data analysis

The collected data were analyzed using the statistical analysis system (SAS) software version 9.0 (SAS, 2002) with the General Linear Model (GLM) procedure. When differences existed among treatments, means separation was carried out using the least significant difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Marketable bulb yield

Irrigating onion at different soil moisture depletion levels did not significantly affect the bulb yield of onion (Table 3). The trend, however, demonstrated that the bulb yield of onion decreased as the depletion level increased from 80 (p = 0.24) to 140% (p = 0.42) of ASMDL. This could be confirmed by the relatively higher bulb yield (29,270 kg ha^{-1}) in the 80% of ASMDL treatment compared to the lowest bulb yield (23,730 kg ha^{-1}) attained in the 140% of ASMDL treatment (Table 3). Increasing the level of irrigation water from 80 (p = 0.24) to 100 (p = 0.30), 120 (p = 0.36) and 140% (p = 0.42) of ASMDL decreased the bulb yield of onion by 4, 7 and 21%, respectively (Table 3). Though relatively higher bulb yield was attained from irrigating onion at 80% of ASMDL, it increased the irrigation frequency and incurred more cost of labor for the insignificant marginal return. Given the non-significant differences among treatments, irrigating onion at 120% of ASMDL under the study area condition can be promoted to be practiced by farmers since it did not have significant yield reduction, but prolong the irrigation interval (frequency) with tolerable decline in water productivity. Despite the longer irrigation interval in comparison with other treatments, it significantly reduced the associated labor cost and increased the economic return to farmers.

In agreement with the results of this study, Haile et al. (2019) reported non-significant effects on the total yield of onion in their experimental sites in response to the application of different irrigation intervals. This finding is also in line with the FAO guideline, which recommends a 60% depletion level for the production of grass species (FAO, 1998). The soil gets dried beyond 60% of the total available water of the crop demand. Thus, a shortage of water supply imposes stress on the crop during the growing season due to photosynthetic interruption. This, consequently, leads to a significant reduction in yield as more than 90% of the biomass production is due to photosynthetic activity (Makino, 2011).

Abdelkhalik et al. (2019), Peji et al. (2011) and Yemane et al. (2019), however, reported significant differences among treatment means with different levels of manageable allowable depletion for the bulb yield of onion. Triggering irrigation at moisture depletion levels of

≤ 40 % (AWC) produced the higher fruit yields of tomato with the optimum yields obtained between -10 kPa and -30 kPa, which represented 20 to 24% depletion in AWC (Felix, 2012). Hartz et al. (2005) indicated that tomato can tolerate depletion of 20-30% of available soil moisture in the active root zone with no yield loss.

Biomass yield

The treatments were significantly ($p<0.05$) different from each other in terms of biomass yield. The highest biomass yield of onion, 8,770 kg ha^{-1}, was recorded from the 80% of ASMDL treatment, and was significantly different from all other treatments except for plots irrigated at 60% and 100% of ASMDL (Table 3). The lowest biomass yield of 6,500 kg ha^{-1} was obtained from the treatment with 140% of ASMDL (Table 3). In agreement with the results of this study, Abdelkhalik et al. (2019) reported inferior biomass production in onion due to water restrictions with the greatest values corresponding to full irrigation and moderate deficit irrigation. Narang et al. (2000) also found that the yield of all wheat cultivars studied decreased with increasing levels of soil moisture depletion.

Plant height

Irrigating onion based on the soil moisture depletion levels did not significantly affect the plant height under the study area condition (Table 3). This could be attributed to the onion plants' adaptation to the water stressed conditions (60 and 80% ASMDL). Plants respond to water stress by closing their stomata as an adaptation mechanism to slow down water loss through transpiration (Siyal et al., 2016; Zhang et al., 1987). Thus, the gas exchange within the leaf is limited, consequently, photosynthesis and growth are slowed down to the extent that does not significantly retard plant growth (Currah and Proctor, 1990). In line with the current results, Yemane et al. (2019) and Abdelkhalik et al. (2019) also reported that irrigation scheduling that encompassed water stress did not significantly reduce the plant height of onion as compare to the optimal irrigation.

Bulb diameter

Onion bulb diameter was not significantly ($p>0.05$) affected by irrigating at different soil moisture depletion levels. The current result was in agreement with Enciso et al. (2019), who reported that irrigation method and water level did not significantly affect the small, medium and colossal onion sizes. Haile et al. (2019) and Yemane et al. (2019) also reported non-significant bulb diameter in response to different irrigation intervals for their experimental sites. Shock et al. (1998) and Kruse et al. (1987), however, obtained higher jumbo size and colossal yields with wetter treatments.

Table 4: Influence of irrigation scheduling on yield and yield components of onion at Kulumsa during 2016/17 and 2017/18 cropping season

Treatments	Plant height (cm)	Bulb diameter (cm)	Bulb yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	WP (kg m^{-3})
60% of ASMDL	50.8	5.98	27,570	7,750^{ab}	5.03
80% of ASMDL	52.3	5.78	29,929	8,770^{a}	5.34
100% of ASMDL	50.7	5.95	28,850	8,390^{a}	5.27
120% of ASMDL	51.8	5.90	27,740	7,010^{b}	5.06
140% of ASMDL	48.9	6.18	23,730	6,500^{b}	4.33
Mean	**50.9**	**6.0**	**27565**	**7685**	**5.01**
$LSD_{0.05}$	**ns**	**ns**	**ns**	**13.8**	**ns**
CV (%)	**6.0**	**7.7**	**21.9**	**18.7**	**21.86**

Note: *WP is water productivity*

Water productivity

Irrigating onion at different depletion levels did not bring a significant influence on water productivity (WP) (Table 3). The tendency of changes in WP with irrigation at different depletion levels followed a similar way to the bulb yield. The relatively higher WP of 5.34 kg m^{-3} was observed when onion was irrigated after 80% of the ASMDL in the soil depleted (Table 3). However, the WP recorded irrigating after 80% of the ASMDL ($p = 0.24$) was extracted by plants from the root zone of the soil was not statistically different from all other treatments. Similar to the changes followed by bulb yield of onion, the WP tended to decrease as the level of depletion increased from 80 ($p = 0.24$) to 100 ($p = 0.30$), 120 ($p = 0.36$) and 140% ($p = 0.42$) of ASMDL. Although the differences among treatment means were insignificant, increasing the depletion level from 80 to 100, 120 and 140% of ASMDL reduced the WP by 1, 5 and 19%, respectively (Table 3) inferring the loss of irrigation water without additional benefit in bulb yield of onion. Given the lower reduction in WP and bulb yield when irrigating onion at 120% compared to the 80% of ASMDL, promotion of the 120% ASMDL is encouraged among farmers to be practiced for optimum onion production.

Improving WP is getting an increasing concern among scientists, and efforts have been underway through different irrigation practices to enhance crop yield per unit of irrigation water used. Determination of optimum soil moisture depletion level for the targeted crops and irrigating when the identified levels have been reached improved water productivity. The results obtained in this experiment were within the recommended ASMDL of FAO 33 (Doorenbos and Kassam, 1979) for onion production. In agreement with the results if this study, Peji et al. (2019) reported the highest irrigation water use efficiency of 281 kg ha^{-1} mm^{-1} with irrigating onion when 30% of available soil water in the root zone was consumed. Similarly, Yemane et al. (2019) stated the highest water productivity of 5.81kgm^{-3} from the FAO recommended available soil moisture depletion level followed by +20% FAO recommended ASMDL in onion production.

Economic analysis

Except for irrigating onion at 60% of ASMDL, all other irrigations at different soil moisture depletion levels for onion production at Kulumsa site were found profitable (Table 4) because they gave a MRR in excess of 100%. The maximum benefit of 89.23 birr for every birr investment in labor was attained from irrigating onion at 120% of ASMDL followed by irrigating at 100% of ASMDL, which gave 23.98 birr return for every birr investment (Table 4). Irrigating onion at 80% of ASMDL also provided an equivalent economic return of 23.28 birr for every birr investment (Table 4).

Table 5: Economic analysis based on mean values for onion production using different levels of soil moisture depletion at Kulumsa

Treatments	Adjusted tuber yield (kg ha^{-1})	Total cost that vary (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal rate of return
140% of ASMDL	21,357	8,000.00	419,140.00	
120% of ASMDL	24,966	8,800.00	490,520.00	89.23
100% of ASMDL	25,965	9,600.00	509,700.00	23.98
80% of ASMDL	26,936	10,400.00	528,322.00	23.28
60% of ASMDL	24,813	12,000.00	484,260.00	D

CONCLUSION AND RECOMMENDATIONS

Results revealed that irrigating onion at soil moisture depletion level from 60 to 140% of the FAO recommendation had no significant effect on plant height, bulb diameter, bulb yield, and water productivity of onion. The effect on biomass yield, however, was significant. Relatively higher bulb yield, biomass yield and water productivity of 29,926 kg ha^{-1}, 8,770 kg ha^{-1} and 5.34 kg m^{-1}, respectively were obtained from irrigating at 80% of ASMDL. The general trend demonstrated that as the level of soil moisture depletion increased from 80 to 140% of ASMDL, the bulb yield and water productivity of onion decreased. Economic analysis result exhibited that irrigating onion at 120% of ASMDL provided the highest economic return of 89.23 birr for every unit birr investment on labor for irrigation. Given the non significant bulb yield and water productivity reduction compared to the 80% of ASMDL, and higher economic return, irrigating onion at 120% of ASMDL has been recommended for farmers in the study area and other similar agro-ecologies for irrigated onion production.

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