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Evaluating the Effects of Deficit Irrigation on Yield and Water Productivity of Furrow Irrigated Onion (*Allium cepa* L.) in Ambo, Western Ethiopia

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Abstract

The objective of this study was, to evaluate the effects of deficit irrigation on yield and water productivity (WP) of onion crop grown under Ambo condition. Field experiment was conducted at Ambo Agricultural Research Center in Ethiopia. The treatments consisted of nine different treatments replicated three times arranged in RCBD. The experiment involved two categories of deficit with different timings: 1) skipping of irrigation during one particular phenological stage and application of 75% ETc during the rest of the growing stages and 2) no watering during specific phenological stage and watering with 50% ETc during the remaining stages. Amount of water applied was monitored using standard Parshall flume. The highest total onion yield (46.7t/ha) was obtained from full irrigated treatment, which was not statically different from treatments that were not irrigated during initial growth stage and irrigated with 75% ETc during the rest of phenological stages (T2) and treatment with no irrigation during bulb maturity stage and irrigated with 75% ETc otherwise (T5) ($P<0.05$). The second category of treatment (irrigation with 50% ETc) resulted high water saving and yield reduction which may not be attractive for producers. WP varied from 7.7 kg/m^3 for control and 14.9 kg/m^3 for the 50% stressed and not irrigated during maturity stage. T2 and T5 produced WP values of 10.8 and 13.1 kg/m^3 respectively. From resources conservation point of view, maximum water productivity may be of interest, which could be obtained under sever deficit irrigation. However, such consequences on yield may not be tolerable from producers view point. The recommended depth of irrigation would be 75% ETc during development, bulb formation, maturity stages and skipping during initial growth stage. Skipping irrigation during maturity stages and irrigating with 75% ETc otherwise has more water saving and WP enhancement potential with tolerable level of yield reduction.

Keywords: Onion; Deficit irrigation; Phenological stages; Yield; WP

Introduction

Food production in many parts of Ethiopia is challenged by inadequate and unreliable supply of water. The fact that the country's water use in general and agricultural water in particular is inefficient increases the water demand in all water use sectors [1]. Although modern irrigation development has short history in the country, the development trend of its undesirable consequences such as soil salinity, sodicity and groundwater rise is becoming areas of concern [2,3]. Nowadays small-scale irrigation is increasingly used at household level to produce high value crops such as vegetables for marketing and own consumption. Onion (*Allium cepa* L.) is considered as the most important vegetable crops grown on small scale in Ethiopia. The area under onion production is increasing from time to time mainly due to its high profitability per unit area and easy of production and the expansion of small scale irrigation [4]. Onion is a shallow-rooted crop that requires frequent and adequate irrigation to achieve good yield [5]. The crop is believed to cover 95% of vegetables and fruits produced and consumed in the country [6]. Its production is entirely limited to small-holder farmers both under irrigation and rain-fed.

Irrigation is the major input to vegetable crops production like onion. It is a shallow rooted crop that requires light and frequent irrigation to avoid water stress [7]. The level of crop's response to water application depends on the crop phenological stages [8-10]. The knowledge of the sensitivity of onion to a certain level of water stress and the consequences on yield as a result is important for on-farm irrigation management and scheduling of irrigation. This enables saving of water during less water stress sensitivity growing stages and fully meeting the water requirement of the crop during high sensitivity stages. Through such practices significant water savings can be achieved for a variety of crops by deliberately stressing the crop to a certain profitable level [11]. Such irrigation management technique is widely known as deficit irrigation. With increasing scarcity of water in many areas, deficit irrigation is found to be a vital strategy to save water and hence enhance water use efficiency by maintaining satisfactory yield.

In principle maximum yield is obtained when the crop water requirements are fully met. However, deficit irrigation in one or more of the growing stage of the crop would lead to a certain level of yield reduction based on sensitivity of the crop to water stress. Hence, the expectation of practicing deficit irrigation strategy is that the gains from increased water use efficiency and use of saved water to irrigate extended areas would offset the yield reduction as a result of imposed water stress. Nevertheless, deficit irrigation practice requires accurate information regarding growth stage specific water stress tolerance level of crops under consideration [12].

The objective of this study was to determine the effect of deficit irrigation on yield and water use efficiency of onion crop grown under Ambo condition in Ethiopia [13].

Materials and Methods

Description of the study area

The experiment was carried out at Ambo agricultural Research Center, West Shoa Zone in Oromia Regional. The Research Center is located at about 115 km west of Addis Ababa, at an altitude of 2225 masl. It is

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located at 08°57"N latitude and 37°52"E longitude (Figure 1). The area has a warm humid climate with mean monthly minimum, maximum temperatures and average total annual rainfall of about 10.3°C, 26.4°C and 1036 mm respectively. The area is characterized as more or less constantly high potential evapotranspiration rate of 102 mm/month.

Experimental design

The experiment was laid out in RCBD with three replications. A seed of the Bombay Red onion was transplanted to field plots on 24th December 2016. More number of seedlings than required for transplanting was raised and vigorous, strong and healthy ones were selected. The experimental field was ploughed using tractor, levelled and made ready for planting. The plot size was 1.5 m × 3 m=4.5 m^2 area. The distance between blocks, plots, rows and plants were 3 m, 1.5 m, 0.30 m and 0.10 m, respectively. One plot has got five furrows and planting rows. Each row accommodated about 30 plants. The experimental design and treatment descriptions are presented in Table 1.

Irrigation water application

Definition of the level of deficit irrigation to be imposed requires the knowledge of crop water demand to fully meet its water requirements. The daily water requirement of onion crop was estimated using CROPWAT model version 8 and meteorological data from the nearby station [14]. The level of deficit applied was then calculated for each growing stage based on experimental design given in Table 1. The water for irrigation was pumped from Huluka river and stored in a tank and was brought to the experimental field by gravity flow that run adjacent to experimental plots. Water is then directed to smaller supply channels that feed the furrows. Through careful opening and closure of channel banks, the water was supplied into furrows up to their storage capacity. Water applications for full irrigation treatments were based on the estimated (mean) crop water requirement calculated over the entire growing season.

Monitoring of irrigation water was done using a 3 inch standard Parshall flume which was installed near the up-stream of the experimental field to measure irrigation water applied to individual plots. An average discharge was diverted into the experimental field from a tertiary canal. This discharge was allowed to flow into one plot at a time. With the aid of a calculator and a stopwatch, the flow into each plot and the time required to apply the desired depth of water was immediately calculated as soon as water was guided into the plot. Water was discharged into the plot and each furrow for the calibrated time. Immediately after the desired depth is applied to a given plot, the discharge was cut-off by closing the channel banks to stop water from entering the plots.

Crop data collection

The Crop data was collected from the middle rows in order to avoid border effects. The plants were picked randomly carefully from middle three rows by avoiding one plant from starting and ending of three middle rows. Data related to yield and yield components were recorded. These data include among others:

Bulb weight (single onion bulb weighed): The mean of weights of the bulb for each onion bulb taken randomly from plot.

Marketable yield (kg/ha): is healthy and non-diseased average to large sized Bombay Red onion bulbs were recorded from central three harvestable rows.

Unmarketable onion (kg/ha): is split, decayed, diseased and under sized bulbs.

Total bulb yield (kg/ha): is the sum of marketable and unmarketable bulb yields.

Total biomass yield (kg/ha): this was determined by summation of all above and underground biomass weights of sample plants.

Soil sampling and analysis

The soil samples were taken from top soil to the depth of 60 cm in 20 cm interval. The sub-samples were mixed thoroughly, dried at room temperature, ground and sieved through a 2 mm screen for analysis

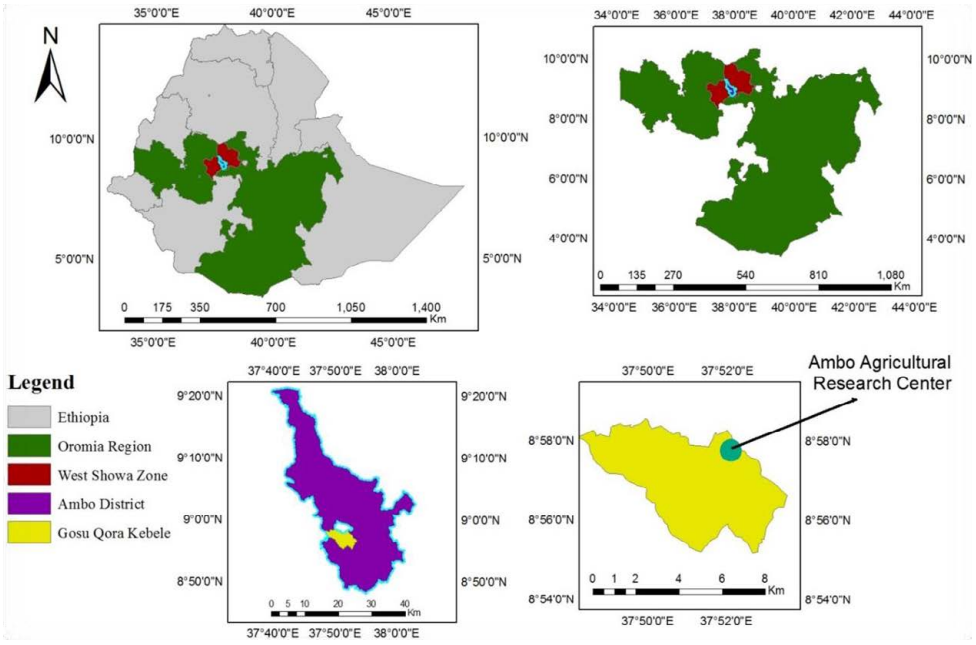

Figure 1: Location map of the study area.

Treatment	Growth stages				Description
	G1	G2	G3	G4	
Control					
1111 (T1)	1	1	1	1	Full irrigation at all growth stages- 100%ETc
75% ETc and no irrigation at one growth stage					
0111 (T2)	0	1	1	1	No irrigation during G1 and 75%ETc watering during G2, G3 and G4
1011 (T3)	1	0	1	1	No watering during G2 and 75%ETc watering during G1, G3 and G4
1101 (T4)	1	1	0	1	No watering during G3 and 75%ETc watering during G1, G2 and G4
0110 (T5)	1	1	1	0	No watering during G4 and 75%ETc watering during G1, G2 and G3
50% ETc and no irrigation at one growth stage					
0111 (T6)	0	1	1	1	No watering during G1and 50%ETc watering during G2, G3 and G4
1011 (T7)	1	0	1	1	No watering during G2 and 50%ETc watering during G1, G3 and G4
1101 (T8)	1	1	0	1	No watering during G3 and 50%ETc watering during G1, G2 and G4
1110 (T9)	1	1	1	0	No watering during G4 and 50%ETc watering during G1, G2 and G3

Table 1: Experimental design and description of irrigation level treatments.

Depth (cm)	FC (%)	PWP (%)	Bulk density (gm/cm^3)	Clay (%)	Silt (%)	Sand (%)	Textural class	TAW (mm)
0-20	40.45	21.53	1.09	66.1	18.1	15.9	Clay	41.2
20-40	35.63	17.73	1.12	66.9	17.1	16.0	Clay	40.1
40-60	29.73	17.70	1.13	68.3	14.4	17.3	Clay	27.2
Total available water in effective root zone of 60 cm								108.5

Table 2: Characteristics of the upper (0-60 cm) soil layer of the experimental site.

of physical properties. Soil textural analysis was done using disturbed soil samples which were collected from representative location of the field and textural class was determined by using pipette method in laboratory.

The bulk density was determined using undisturbed soil samples which were collected from three depths (0-20 cm, 20-30 cm and 30-60 cm), oven dried for 24 h at 105°C and weighed for determination of dry weight. The bulk density was then calculated as:

$$\rho_b = \frac{W_d}{V_T} \quad (1)$$

Where, W_d=weight of dry soil and V_T is total sample volume.

Determination of soil moisture parameter is important for monitoring of irrigation. Soil moisture at field capacity (FC) and permanent wilting point (PWP) were determined. For this purpose, soil samples were collected from three depths described above and sun dried, crushed and soaked in water for one day (24 h). Pressure plate apparatus and pressure membrane apparatus were used for determination of moisture content at FC and PWP. For this, a suction of -1/3 bar and -15 bar were exerted for FC and PWP, respectively.

Total available water (TAW), theoretically plant available water was determined as:

$$TAW=1000\ (\theta_{FC}-\theta_{PWP})\ Z_r \quad (2)$$

Where, TAW is the total available soil water content (mm), θ_{FC} is soil moisture content at field capacity (cm^3/cm^3), θ_{PWP} is soil moisture content at field permanent wilting point (cm^3/cm^3), Z_r is crop rooting depth (m).

Data analysis

Water productivity: Crop water productivity (WP) simply refers to the ration of output (example, crop yield or economic return) to water input during production. This mean the output may be expressed either as physical production in kilograms per unit area or economic return in dollars per unit area. The water input is the amount of water applied to the cropped area per season. In this study crop water productivity was estimated as the ratio of onion bulb yield to the total irrigation depth applied to during the season. It is expressed as:

$$WP = \frac{Y}{W} \quad (3)$$

Where, Y is onion bulb yield (kg/ha) and W is irrigation depth applied during the season (m^3/ha).

Statistical analysis: All necessary data collected were managed properly using SAS computer package version 8.2. When the treatments effect was found significant, mean difference was tested using LSD test at P=0.05.

Results and Discussions

Soil of the experimental site

The soil characteristics of the experimental site are presented in Table 2. The top soil layer of the study site is characterized as clay in texture. The bulk density is 1.1 g/cm^3 over the effective root zone of onion crop.

The total available water which is the amount of water that a crop can theoretically extract from its root zone is about 109 mm over 60 cm soil depths.

Amount of water applied

Water requirement of onion was determined from climate data measured at the nearby station using CROPWAT model. Gross irrigation depth was estimated considering field irrigation application efficiency of 60% (Table 3). Accordingly, irrigation depths applied to each treatment plots are presented in Table 3. There was no rainfall contribution during the entire growing period. As a result the net irrigation demand was equal to the crop water requirement (IR=ETc) as determined by evaporative demand of the atmosphere and crop growth stage specific crop coefficient. The seasonal crop water requirement was 362 mm. Hence, the gross irrigation depth applied to the full irrigated plot (control) was 603 mm. The remaining treatment plots received gross irrigation depths proportional to the intended levels of deficit (50% ETc and 75% ETc). It has to be noted that all treatments were

Growth stage	Irrigation Dates	ETC=IR (mm/ period)	T1 (Control)	75%ETC, zero watering otherwise				50%ETC, zero watering otherwise			
				T2	T3	T4	T5	T6	T7	T8	T9
Initial	24-Dec	11.2	11.2	0	8.4	8.4	8.4	0	5.6	5.6	5.6
	27-Dec	12.2	12.2	0	9.1	9.1	9.1	0	6.1	6.1	6.1
	02-Jan	13.2	13.2	0	9.9	9.9	9.9	0	6.6	6.6	6.6
	05-Jan	15.3	15.3	0	11.5	11.5	11.5	0	7.7	7.7	7.7
	08-Jan	16.5	16.5	0	12.4	12.4	12.4	0	8.3	8.3	8.3
Development	12-Jan	23.3	23.3	17.5	0	17.5	17.5	11.7	0	11.7	11.7
	15-Jan	24.5	24.5	18.4	0	18.4	18.4	12.3	0	12.3	12.3
	19-Jan	25.2	25.2	18.9	0	18.9	18.9	12.6	0	12.6	12.6
	23-Jan	24.5	24.5	18.4	0	18.4	18.4	12.3	0	12.3	12.3
	27-Jan	25.2	25.2	18.9	0	18.9	18.9	12.6	0	12.6	12.6
Bulb formation	03-Feb	25.2	25.2	18.9	18.9	0	18.9	12.6	12.6	0	12.6
	08-Feb	25.2	25.2	18.9	18.9	0	18.9	12.6	12.6	0	12.6
	13-Feb	31.5	31.5	23.6	23.6	0	23.6	15.8	15.8	0	15.8
	18-Feb	31.5	31.5	23.6	23.6	0	23.6	15.8	15.8	0	15.8
	23-Feb	31.5	31.5	23.6	23.6	0	23.6	15.8	15.8	0	15.8
	28-Feb	31.5	31.5	23.6	23.6	0	23.6	15.8	15.8	0	15.8
	02-Mar	31.7	31.7	23.8	23.8	0	23.8	15.8	15.8	0	15.8
Maturity	08-Mar	31.7	31.7	23.8	23.8	23.8	0	15.8	15.8	15.8	0
	14-Mar	31.7	31.7	23.8	23.8	23.8	0	15.8	15.8	15.8	0
	20-Mar	30.8	30.8	23.1	23.1	23.1	0	15.4	15.4	15.4	0
	26-Mar	30.8	30.8	23.1	23.1	23.1	0	15.4	15.4	15.4	0
	02-Apr	30.8	30.8	23.1	23.1	23.1	0	15.4	15.4	15.4	0
	08-Apr	30.8	30.8	23.1	23.1	23.1	0	15.4	15.4	15.4	0
	10-Apr	17.5	17.5	13.1	13.1	13.1	0	8.8	8.8	8.8	0
Total		603.3	603.3	401.2	360.4	296.5	299.4	267.7	240.5	197.8	200.0

Table 3: Gross irrigation depth applied (mm) per irrigation event and treatment in 2016/2017 (60% irrigation efficiency).

Yield components	T1	T2	T3	T4	T5	T6	T7	T8	T9
Total Biomass (t/ha)	67.3^{a}	$63.4^{a,b}$	44.1^{c}	38.4^{d}	59.0^{b}	46.1^{c}	$42.6^{c,d}$	33.0^{e}	45.6^{c}
Bulb weight (gm)	79.7^{a}	71.7^{b}	$67.7^{b,c}$	61.7^{d}	70.7^{b}	68.3^{b}	61.3^{d}	56.7^{e}	$63.3^{c,b}$
Marketable yield (t/ha)	42.6^{a}	39.1^{a}	33.3^{b}	$26.9^{c,d}$	35.0^{a}	28.4^{c}	$23.7^{d,e}$	20.9^{f}	$25.3^{d,c}$
Unmarketable yield (t/ha)	4.1^{e}	4.1^{e}	$4.2^{d,e}$	$4.4^{c,d}$	4.1^{e}	$4.4^{c,d}$	$4.5^{b,c}$	4.6^{b}	$4.4^{c,d}$
Total yield (t/ha)	46.7^{a}	43.2^{a}	37.5^{b}	$31.3^{c,d}$	39.1^{a}	32.8^{c}	$28.2^{d,e}$	$25.5^{e,f}$	$29.7^{c,d}$

^{a,b,c,d,e,f}Mean value followed by the same letters does not differ significantly at $p<0.05$ probability level, which mean that if the mean value of two yield components have the same letter there is no significant difference among them.

Table 4: Yield and yield components of onion crop.

subjected to a certain level of water deficit except the control.

Treatments (T2-T5) that were received no irrigation during one phenological growth and watered with 75% ETc obtained total depth of water that range from 401 to 299 mm. On the other hand treatments that were irrigated with 50% ETc during three growth stages and deprived of irrigation during one growth stage (T6-T9) received total water depth ranging from 268-200 mm. Considering failure of rainfall during the season, this low irrigation depth coupled with no irrigation during specific growth stage has affected crop growth and yield performances. Like any other crops, onion crop require relatively large amount of water during mid (bulb formation) stage [15]. This is why the total amount of water applied to plots that were not irrigated during bulb formation and maturity stages are comparably less. Although such scheduling can bring about considerable water saving, the practice may be discouraged by the extreme yield reduction which may not be tolerable.

Crop yield components as affected by deficit irrigation

The analysis of variance indicated that yield of onion was significantly ($P<0.05$) affected by timing and depth of water application in all treatments (Table 4).

Total biomass: Analysis of variance revealed that total biomass production was significantly ($P<0.05$) affected by variation in water application depth and timing (Table 4). The total biomass of onion, which is the sum of all above and underground biomass, was highly influenced by interaction of zero watering and deficit irrigation levels. Maximum biomass was obtained from fully irrigated treatment. However, T2 and T5 have also produced high biomass yield next to T1. Low biomass yields were obtained from treatments watered with 50% ETc deprived of irrigation during bulb formation stage. This result on biomass yield of onion is in agreement with the result of Subedi et al. [16] who found that total biomass of onion was significantly reduced at low irrigation level. Similarly, Kumar et al. [17] found that irrigation affects the total onion yield, yield components and morphological characteristics of onion bulbs.

Total onion yield: The highest marketable, unmarketable and total onion yields were obtained from the control treatment (T1) which is also not significantly different from that of T2 and T5. The later treatments were not irrigated during initial and maturity stages respectively and irrigated with 75% ETC during the rest of the growing periods. The yield reduction incurred by T2 and T5 as a result are 7.5 and 16.3% in relation to T1 (control). In effect, the water saved under both treatments was 34 and 51% respectively. This represents huge

amount of water that can be used to develop additional area or be released for other uses. Treatments with high yield also produced heavy bulb yields. The heaviest bulb weight of about 80 g was obtained from treatment 1 (the control) followed by T2 and T5.

Treatments (T6-T9) that involve no irrigation during one phenological stage and 50% ETc (50% stress) irrigation during the rest of the stage are characterized by poor performance in all yield components. Low marketable onion yields were obtained from treatments irrigated with 50% ETc. It is obvious that these treatments are already deficit irrigated and moreover not irrigated in one of their growing stages. The yield reduction as a consequence of this ranged from 30-45.4% (Table 5).

As it can be seen from Table 6, timing and depth of irrigation application considerably affect the total bulb yield of onion. The effect is relatively high during development and bulb formation stage and low during initial and bulb maturity stage. No watering during bulb formation stage had the consequence of reducing yield by 33 and 45% under 75% ETc and 50% ETc irrigated treatments respectively (Table 6). Whereas skipping irrigation during bulb maturity stage, resulted to yield reduction of about 16 and 36% respectively. On the other hand saving water during initial growth stage had only little effect on yield reduction. However, as the water demand at this stage is low, the amount of expected water saving is also low. The water saving potentials of T4 and T5 were almost same (51%). However, the later treatment which was not irrigated during maturity stage has incurred lower yield reduction (16.3%). Similar evaluation can be made between treatments T6, T7, T8 and T9 which were not irrigated during particular growth stage and irrigation with 50% ETc during the rest of the growth stages. Relatively low yield reduction of about 30% was observed under T6 followed by 36% under T9. These treatments were subjected to zero irrigation during initial and maturity stages respectively. Failure to irrigate during development and bulb formation stages under all circumstances had the consequence of high yield reduction. Although the water saving potential of irrigating with 50% ETc throughout the growing period with zero irrigation in one growth stage is high, the yield reduction varied from 30-45.4%. Such extreme water saving practices that lead to extreme yield reduction may not be attractive for producers and hence, not recommended.

Water productivity

As per the definition given in eqn. (3), water productivity can be improved either by enhancing the yield (nominator) or reducing the water application (denominator). From the stand point of resources conservation it is important to save as much water as the consequence on economic return is acceptable. It means producing more with less water. However, from the farmers' viewpoint, the target of irrigation is not water productivity per se, but improving net income, avoiding risk of crop failure, and ensuring sustainability of agricultural production [18].

As can be seen from Table 6, the water productivity ranged from 7.7 kg/m^3 under full irrigation treatment and 14.9 kg/m^3 under 50% stressed plot. WP varied from 10.4 to 13.1 kg/m under treatments which are not irrigated during one growth stage and irrigated with 75% ETc (25% stressed) during the rest of the growth stages. These results are comparable with the findings of others researches done in Ethiopia [8,9].

Although the 50% stressed plots seem to result highest WP due to high water savings, the yield reduction is also high. Such trade-off, higher water productivity for lower yield, should be carefully interpreted. Acceptable level of water saving and hence WP is the highest value level that can be achieved without significant reduction in yield. As summarized [19], attaining higher yields with increased WP is only economical when the increased gains in crop yield are not offset by increased costs of other inputs. Consequently, the intention of deficit irrigation is to improve yield and WP by efficiently managing agricultural water.

Figure 2 shows yield-water relation of onion at the research site.

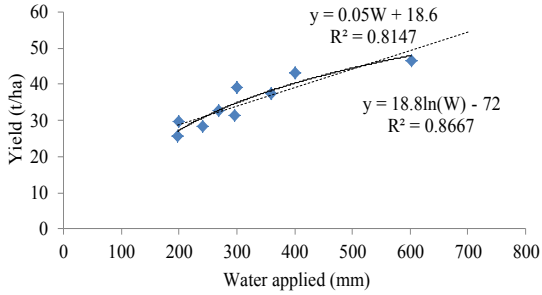

Figure 2: Yield versus total water applied.

Irrigated with %ETc during the rest of the stages	Yield (t/ha) when zero watering at				Average yield (t/ha)
	Initial	development	Bulb formation	Bulb maturity	
75%ETc	43.2	37.5	31.3	39.1	37.8
50%ETc	32.8	28.2	25.5	29.7	29.1
Control (100%ETc)					46.7

Table 5: Total bulb yield as affected by timing and depth of irrigation.

Treatments	Irrigation (m^3/ha)	Total yield (kg/ha)	CWP (kg/m^3)	Water saved (m^3/ha)	Water saved (%)	Yield reduction (%)
T1	6039	46700	7.7	0.0	0.0	0.0
T2	4012	43200	10.8	2027	33.6	7.5
T3	3604	37500	10.4	2435	40.3	19.7
T4	2965	31300	10.6	3074	50.9	33.0
T5	2994	39100	13.1	3045	50.4	16.3
T6	2677	32800	12.3	3362	55.7	29.8
T7	2405	28200	11.7	3634	60.2	39.6
T8	1978	25500	12.9	4061	67.2	45.4
T9	2000	29700	14.9	4039	66.9	36.4

Table 6: Crop water productivity (CWP) and amount of water saved.

Such relations are important for efficient irrigation water management and economic appraisal. The relationship can be fit to both linear and natural logarithmic functions. The later function showed better relationship with R^2 of 0.91. The implication is that with increasing application of water the onion yield increases. However, increasing water application depth beyond optimum level will not result in increased rate of onion yield.

Summary and Conclusions

A one season field experiment was conducted at Ambo Agricultural research Station in Ethiopia to evaluate the yield and water productivity effects of deficit irrigation on onion. The experiment was designed as nine-treatment combinations replicated three times under RCBD. The experiment involved two categories of deficit with different timings: 1) skipping of irrigation during one particular phenological stage and application of 75% ETc during the rest of the growing stages and 2) no watering during specific phenological stage and watering with 50% ETc during the remaining stages. To see the effects of these treatments control plots with 100% ETc (full irrigation) were considered. Amount of water applied was monitored using standard Parshall flume.

The results indicated that treatment with full irrigation application has demonstrated the highest performances in all considered yield components (total biomass, total yield, marketable yield, unmarketable yield and bulk weight). Treatments that were not irrigated during initial and bulb maturity stage and irrigated with 75% ETc during the rest of the growth stages produced total yield that is not significantly different from the control. The yield reduction was about 7.5 and 16% respectively. However treatment category that were irrigated with 50% ETc during three growth stages and not irrigated during one phenological stages incurred large yield losses.

Water productivity is directly related to either enhancing production or reducing water consumption. The WP values in this experiment ranged from 7.7 to 14.9 kg/m^3. The highest WP was obtained under the treatment which was irrigated with 50% ETc during the first three phenological stages and not irrigated during maturity stage. The water saving and yield reduction as a result was 67 and 36.4%, respectively. The least WP was obtained from the control (full irrigated plot). It is important to note that, except the control, all watering events involved 25% water stress (75% ETc irrigation) or 50% stress (50% ETc irrigation). The later treatment combined with no watering during one growth stage represented too much stress especially during bulk formation stage. The consequence is high yield reduction that ranged from 30-45.4%. Even if water saving and WP enhancement potential of such practices are high, the level of yield reductions are intolerably high.

Irrigating onion with 75% ETc during development, bulb formation, maturity stages and skipping irrigation during initial stages resulted the least yield reduction with 33.6% water saving. The success of this practice, however, depends upon well establishment of the seedlings before the treatments commence. The crop was found to be sensitive to water stress during bulb formation and early bulb maturity stages. As the water demand during these stages is high, stressing during these growth stages was found to result high water saving and WP. However, the high yield reduction makes this option of imposing the crop to water stress during bulb formation stage unattractive.

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