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Effect of Deficit Irrigation at Different Growth Stages on Onion (*Allium Cepa* L.) Production and Water Productivity at Melkassa, Central Rift Valley of Ethiopia

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Improving water use efficiency is one important strategy for addressing future water scarcity, which is driven particularly by increasing human population. Enhancing agricultural water productivity is a critical response as it is by far the main consumer of global fresh water. A field experiment was conducted at Melkassa Agricultural Research Center during the off-rain season to investigate the sensitivity of onion (Nafis variety) yield and water productivity to deficit irrigation at different growth stages. The experiment was carried out in randomized complete block design with fifteen treatments and three replications. The treatments were set as: one stage deficit of 25% and 50% at development and mid growth stages; two stage deficits of 25% and 50% at two consecutive stages from initial to maturity; three stage deficits of 25% and 50% at three stages with either development or mid stage in a combination; and control. Crop water use was estimated using soil moisture depletion method. The result showed that the different deficit irrigation had significant ($p< 0.01$) impact on bulb yield. The control treatment gave the highest bulb yield of 40.38 t/ha with no significant difference from 25% deficit treatments except the deficit at bulb formation stage. Crop water productivity (kg/m^3) was the highest with no deficit irrigation at the bulb formation stage with 25% deficit at other stages, and the yield response factor (Ky) was higher when half deficit occurred at same stage. The result revealed that onion bulb yield was most sensitive to water deficit that occurred at bulb formation stage. This result can guide irrigation scheduling to achieve optimal onion bulb production under water scarce condition.

Keywords: Deficit Irrigation, Growth Stage, Onion, Water productivity, Yield Response Factor (Ky)

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INTRODUCTION

The ever increasing world population and the demand for additional water supply by industrial, municipal and agricultural sectors exert a lot of pressure on renewable water resources (Valipour, 2014). The Growing competition for water from domestic and industrial sectors is likely to reduce its availability for irrigation. Thus, the need to meet the growing demand for food will require increased crop production from less and less water.

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 receives an apparently adequate rainfall for crop production if one considers countrywide average annual rainfall which is about 850 mm. 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 period causing crop failure. To combat these natural phenomena it needs shifting to efficient irrigation agriculture practices.

Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gain by maximizing water use efficiency. The term water use efficiency (WUE) is used to describe the relation between crop yield and water use (Oweis and Zhang, 1998; Zhang *et al*., 1998). Increasing the amount of water used by the plant or increasing the yield of the plant can change water use efficiency. In this context, deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Mermoud *et al*., 2005). 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. Deficit irrigation strategies would require an accurate assessment of growth stage-specific stress tolerances for vegetable crops (Upchurch *et al., 2005)* and optimal water management supported by advanced irrigation systems; i.e., able to promptly cope with crop water requirements at sensitive phenological stages (Evans and Sadler, 2008).

Onion (*Allium cepa L.*) is one of the most important vegetable crops worldwide. The Ethiopian Central Rift 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 shortage of water during the most important stages hampering yield of onion.

Water is the main limiting factor for production of many crops including onion in the arid and semiarid regions. When water resources are scarce, deficit irrigation is one way of maximizing water use efficiency (Bekele and Tilahun, 2007). Many investigations have been carried out worldwide regarding the effects of deficit irrigation on yield of mainly horticultural crops (Fabeiro *et al*., 2003; Olalla *et al*., 2004; Chen *et al*, 2015). However, deficit irrigation of onion distributed over the whole growing season might not always result in increasing crop water productivity (Bekele and Tilahun, 2007; Bhagyawant *et al*., 2015a). This can be due to variation in sensitivity of the different phonological stages to water stress.

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 specificgrowthstagesof onion crop at whichtheplantissensitivetowaterstress and also to determine crop water productivity under deficit irrigation practice.

MATERIALS AND METHODS

Description of the Experimental Site

The field experiment was conducted at Melkassa Agricultural Research Center in the central rift valley of Ethiopia, on clay loam soil during the dry period of2015/16. The long term mean annual rainfall and potential evapotranspiration in the area is 818 and 2567 mm, respectively. However, about 67% of the total rainfall of the area falls mainly from June to September with its peak in the month of July.

Experimental Setup

The experiment was carried out in Randomized Complete Block Design (RCBD) with three replications and fifteen treatments. The treatments were made by varying the deficit irrigation levels through the growing stages (Table 1). The crop growing season was divided into four major growth stages: initial (I), development (D), bulb formation (B), and maturity (M) with 20, 30, 30 and 15 days period, respectively (Allen*et al*., 1998). The treatments were: one treatment with full irrigation throughout the growing season (control), seven treatments with half irrigation requirement (50% deficit) at D, B, DB, ID, BM, IDM and IBM, and another seven treatments with three quarter of irrigation requirement (25% deficit) at D, B, DB, ID, BM, IDM and IBM.

Crop Management

Nafis, an early maturing and high yielding variety of onion (*Allium cepa L.*), seed was sown on well-prepared

Table 1. Treatments setting of the experiment

Treatments	ETc percentage at each growth stage*				Deficit level At different stage*
	I	D	B	M	
T1	100	100	100	100	Control
T2	100	75	100	100	25% at D stage
T3	100	100	75	100	25% at B stage
T4	100	50	100	100	50% at D
T5	100	100	50	100	50% at B
T6	75	75	100	100	25% at I and D
T7	100	75	75	100	25% at D and B
T8	100	100	75	75	25% at B and M
T9	50	50	100	100	50% at I and D
T10	100	50	50	100	50% at D and B
T11	100	100	50	50	50% at B and M
T12	75	75	100	75	25% at I, D and M
T13	75	100	75	75	25% at I, B and M
T14	50	50	100	50	50% at I, D and M
T15	50	100	50	50	50% at I, B and M

*Stage: I = Initial, D = Developmental, B = Bulb formation, M = Maturity

seedbed of 1 m x 5 m at seed rate of 80 grams per bed on September 10, 2015. The seedling management practice was made as per the recommendation for the area until seedlings reached stage of transplanting. The seedlings were then transplanted on 25 October 2015 on well prepared experimental plots on both sides of a ridge at row and plant spacing of 20and 5 cm, respectively.

Each experimental plot had 3.0 m length and 3.6 m width. Onion seedling transplanted to experimental field was received two common irrigations to ensure better plant establishment. One-time application of DAP at transplanting only and split application of Urea at transplanting and 10 days after transplanting was done by hand placement at a rate of 200 kg/ha and 100 kg/ha, respectively (Olani and Fikre, 2010). The chemicals Selecron (3 liter/ha) and Redomil Gold (3 liter/ha) were used, to safeguard the crop against harmful insects and fungus, respectively.

Crop Water Requirement and Irrigation Scheduling

Soil moisture depletion method was used for irrigation scheduling. The soil moisture levels were monitored using Neutron probe and gravimetric method. Accordingly, net irrigation depth applied to the treatments was presented in Table 2. Net irrigation depth applied at each growth stage for all treatments (mm)
. Treatment T1 was set as a control and was not subjected to water stress, hence its consumptive water use was considered to be equal to the maximum crop water requirement ETm. Thus, the seasonal water demand of the control was 403.3 mm. 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). In this experimental setup, pre-determined volume of water was appliedwith precise measurement, and furrows were short and end-diked. Hence, there was no run-off loss and the only loss would be deep percolation which was expected to be not much in a deficit irrigation practice. Therefore, a higher value of application efficiency (60%) wasadopted. Adopting this value of application efficiency, the gross seasonal irrigation requirement for treatment T1 (control) was 672.2 mm. All the other treatments received proportional amount of gross irrigation to the anticipated stress levels (Table 2). The irrigation water applied to the plots was measured using a 3 inch Parshall flume installed just at the upper stream of the experimental field.

Water productivity

Crop water productivity is the yield harvested in kilogram per total water used. In the case of this experiment, crop water productivity (WP) was expressed as the ratio of bulb yield to the amount of water depleted by the crop and refilled. Mathematically it was determined using the following equation as described by Michael (2008).

$$WP = \frac{Y}{I}$$

Where, WP = water productivity (kg/mm), Y = onion bulb yield (kg/ha) and I = net irrigation depth applied for each treatment (mm/ha).

Table 2. Net irrigation depth applied at each growth stage for all treatments (mm)

Treatment	Growth stage				Total
	I	D	B	M	
T1	49.9	120.4	164.3	68.7	403.3
T2	49.9	90.5	164.3	68.7	373.4
T3	49.9	120.4	123.3	68.7	362.2
T4	49.9	60.2	164.3	68.7	343.1
T5	49.9	120.4	82.2	68.7	321.2
T6	37.2	90.5	164.3	68.7	360.7
T7	49.9	90.5	123.3	68.7	332.4
T8	49.9	120.4	123.3	51.7	345.3
T9	24.8	60.2	164.3	68.7	318.0
T10	49.9	60.2	82.2	68.7	261.0
T11	49.9	120.4	82.2	34.4	286.9
T12	37.2	120.4	123.3	51.7	332.6
T13	37.2	90.5	164.3	51.7	343.7
T14	24.8	60.2	164.3	34.4	283.7
T15	24.8	120.4	82.2	34.4	261.8

I = Initial, D = Developmental, B = Bulb formation, M = Maturity

Yield Response Factor

Yield response factor which links relative yield decrease to relative evapotranspiration deficit was determined following equation stated by Stewart *et al*. (1977).

$$1-\frac{Y_a}{Y_m}=K_y\left[1-\frac{ET_a}{ET_m}\right]$$

Where, K_y = yield response factor, Ya = actual onion bulb yield (kg/ha), Ym = maximum onion bulb yield obtained from the control (kg/ha), ETa = actual evapotranspiration/ net irrigation depth applied to each treatment (mm) and ETm =maximum evapotranspiration/ net irrigation depth applied to the control (mm)

Data Analysis

The collected data were subjected to statistical analysis of variance using SAS software version 9.0 for windows. Whenever treatment effects were found significant, treatment means were compared using the least significant difference (LSD) method (Steel *et al.*, 1997).

RESULT AND DISCUSSIONS

Soil Characterization of the Experimental Site

Soil physical and chemical characteristics were determined at Melkassa Agricultural Research Center laboratory and the results are presented in Table 3.

Yield Response of Onion to Deficit Irrigation

Deficit irrigation in combination with growth stages has significantly influenced the marketable bulb yield of onion production (Figure 1). The highest bulb yield was recorded in plants, which did not experience anywater deficit. Maximum and minimum bulb yields obtained were 40.38 and 20.82 t/ha from T1 and T10 with the maximum and minimum water applications respectively. The 25% Etc water deficit applied at the bulb formation stage and the 50% ETc deficit applied at any stageaffected bulb yield with significant differencefrom the control ($P < 0.01$). Moreover, 25% deficit at bulb formation stage and 50% deficit at developmental stage statistically equally affected bulb yield.

When the deficit level increased from 25 to 50%, the reduction in yield increased from 1 to 15% and from 13 to 36% for developmental and bulb formation stages, respectively.This shows that water deficit at the bulb formation stage reduced bulb yield considerably, while the plant which experienced 25% water deficit at any of the combination of the other three growth stages gave comparative yield with the fully irrigated one. This could be due to the highest yield response factor of the bulb formation stage than the other stages (Doorenbos and Kassam, 1979). Besides, stress at coupled developmental and bulb formation stage highly affected bulb yield than any other combinations of stages.The probable reason for having good yield from plants under deficit irrigation could be that the mild water stress might have induced plants to extend their root system deep to extract soilmoisture and help in uniform distribution of roots. Similar study also revealed that stressing the crop during initial and late season stage of the growing season does

Table 3. Soil physical and chemical properties of the study site

Physical properties								
Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	FC (vol %)	PWP (vol %)	TAW (mm/m)	Bulk density g/cm^3
0-15	34.1	32.1	33.8	Clay loam	34.4	19.5	163.4	1.1
16-30	35.0	31.2	33.8	Clay loam	33.4	18.4	165.0	1.1
31-45	34.3	29.0	36.7	Clay loam	31.5	16.7	163.7	1.1
46-60	34.5	26.5	39.0	Clay loam	29.5	16.2	162.3	1.2

Chemical properties		
pH	ECe(ds/m)	OM (%|)
7.5	0.2	2.3

Note. FC = field capacity, PWP = wilting point, TAW = Total available water holding capacity (FC-WP), ECe = Electrical conductivity of the soil, OM = Organic matter content

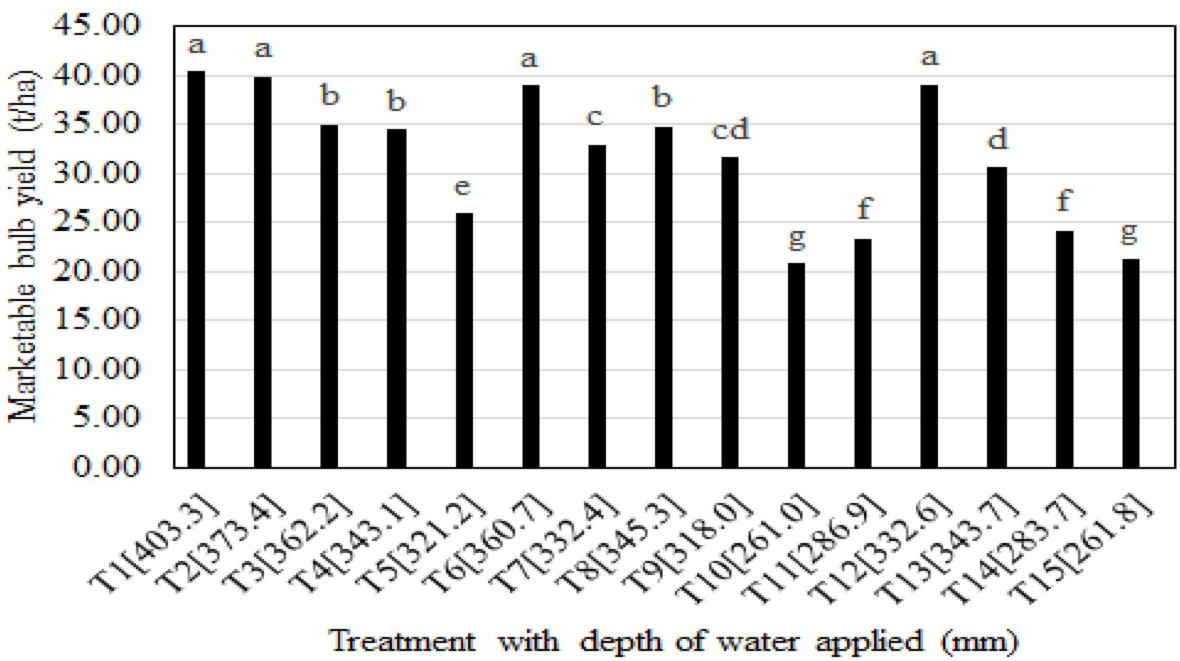

Figure 1. Bulb yield as affected by deficit irrigation treatments

not affect crop yield significantly (Bazza and Tayaa, 1999).

Moreover, treatment T10 (received 50% ETc at both developmental and bulb formation stage) produced the lowest yield (20.82 t/ha) followed by T15 (received 50% ETc throughout the growth period except the developmental stage) 21.31 t/ha. This is in agreement with the finding of Bhagyawantv *et al*. (2015b) who reported that onion yields are higher with less water stress and reduce with increase in water stress level.

Water Productivity

Water productivity (WP) result showed variation among treatments (Table 4). The differences in water usebetween the treatments can be attributed to differing amounts of water stress imposed by theirrigation treatments.Applying 75% of the full irrigation throughout the whole growing season except bulb formation stage (T12) resulted in the highest water productivity (11.74 kg/m^3). While the lowest was obtained when the bulb formation stage was stressed by half ETc (T5). Higher water productivities were obtained from treatments

Table 4. Marketable bulb yield, WP and relative water saved as influenced by treatments

Treatments	Marketable bulb yield ton/ha	WP kg/m^3	Relative water saved (%)	Relative yield reduction (%)	Yield response factor (Ky)	Net additional yield from saved water (ton)	WP increment (%)
T1	40.38[a]	10.01[c]	0.00	0.00	-	0.00	0.00
T2	39.85[a]	10.67[b]	7.41	1.35	0.18	2.66	6.57
T3	35.00[b]	9.66[cd]	10.19	13.49	1.31	(1.41)	(3.40)
T4	34.50[b]	10.06[c]	14.93	14.76	0.98	0.17	0.50
T5	25.93[e]	8.07[f]	20.36	36.31	1.76	(7.82)	(19.29)
T6	39.00[a]	10.81[b]	10.56	3.49	0.32	3.22	7.97
T7	32.90[c]	9.90[c]	17.58	18.79	1.05	(0.47)	(1.07)
T8	34.78[b]	10.07[c]	14.38	14.06	0.97	0.24	0.67
T9	31.67[cd]	9.96[c]	21.15	21.87	1.02	(0.23)	(0.47)
T10	20.82[g]	7.98[f]	35.28	49.16	1.37	(8.21)	(20.25)
T11	23.35[f]	8.14[f]	28.86	42.80	1.46	(7.56)	(18.63)
T12	39.05[a]	11.74[a]	17.53	3.34	0.19	6.97	17.26
T13	30.60[d]	8.90[e]	14.78	24.59	1.64	(4.48)	(11.03)
T14	24.19[f]	8.53[de]	29.66	40.70	1.35	(6.00)	(14.77)
T15	21.31[g]	8.14[g]	35.09	47.90	1.35	(7.55)	(18.59)
CV	2.75	2.69	-	-		-	
LSD(0.05)	1.45	0.43	-	-		-	
SE	0.50	0.15	-	-		-	

stressed by 25% than 50%. This shows that the crop was more effective in using the applied water for yield production at 25% deficit than 50% deficit. Moreover, water productivity obtained from T2, T4, T6, T8 and T12 was higher than the control by 6.6, 0.5, 8.0, 8.7 and 17.3%, respectively. This suggests that increasing the area irrigated with the water saved would compensate for the yield loss due to deficit irrigation for these treatments. Accordingly, by using treatment T12, it is possible to compensate the yield reduction due to deficit application and obtain additional 6.97 ton of onion bulb with the saved water on 0.2 ha additional land. In addition, T2, T4, T6 and T8 could compensate for the yield reduction occurred and result in additional yield (2.66, 0.17, 3.22 and 0.24 ton) with the saved 7.41, 14.93, 10.56 and 14.38% of water, respectively. Although there were other treatments with greater percent of saved water, only treatments with higher WP than the control (water saving percentage greater than corresponding yield reduction percentage) could compensate for the yield reduction. This indicates that it was not only the difference in deficit level which resulted in higher WP but also the stage of application was the main determinant factor (Englsih*et al*., 1990). A similar study revealed that stage wise deficit irrigation application is better option of water saving than deficit irrigation distributed throughout the growth season (Patel and Rajput, 2013).

The relationship between bulb yield, WP and irrigation amount demonstrate that higher WP was achieved at a water supply level that is lower than the control (maximum water), which gave maximum bulb yield. Thus, the most productive use of water was reached with about 332.60 mm of irrigation depth and the minimum was at 321.2 mm. Therefore, aiming for maximum bulb yield under limited water resources is not economical. Similarly, Yalew (2007) investigated that although yield increment is generally accompanied with an increase in the total water use, higher WP was recorded withthe deficit application.

Yield Response Factor (ky)

The magnitude of Ky value indicates the sensitivity of the irrigation protocol for water deficit and subsequent yield decreases. The highest Ky was obtained from T5 (50% deficit at bulb formation only) and the lowest was 0.14from T2, followed by 0.17 and 0.27 obtained from T12 and T6 respectively (Figure 2). Deficit irrigation of 25% applied at any stage other than the bulb formation stage did not result in visible bulb yield reduction, while deficit application at bulb formation stage caused pronounced yield reduction. The result showed that only those treatments with a lower crop yield response factor (Ky< 1.0) can generate significant savings in irrigation water through deficit irrigation (Kirda, 2002).

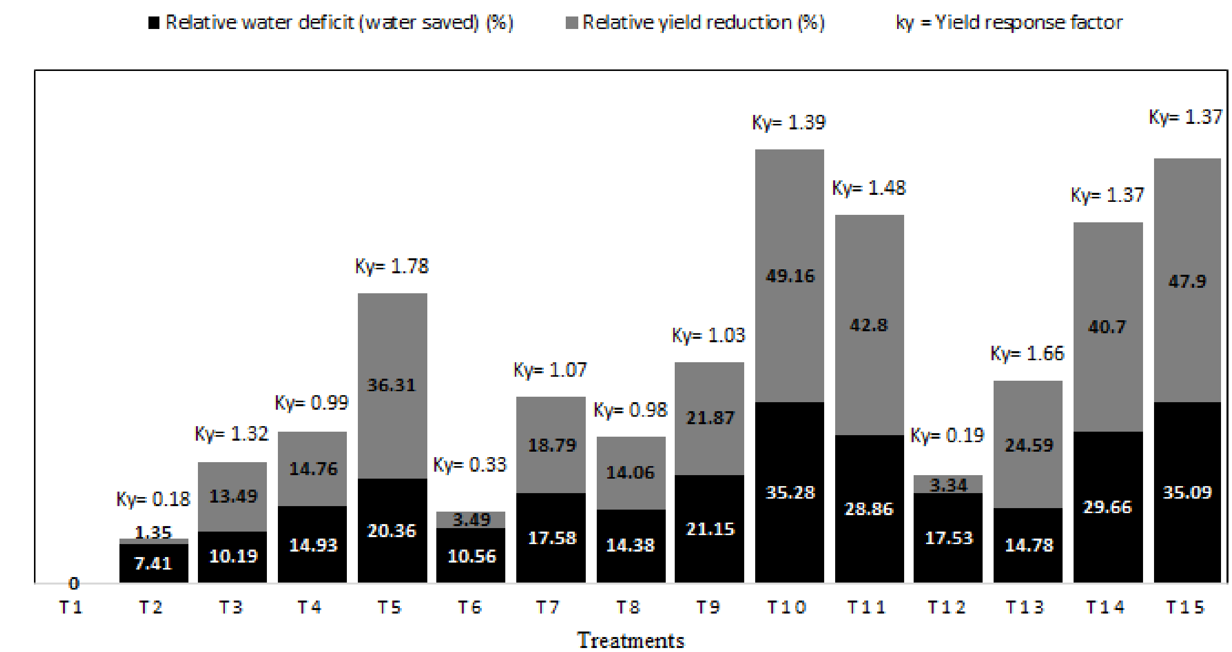

Figure 2. Crop yield response factor as deficit irrigation caused yield reduction

CONCLUSION

The results of the study revealed that, the deficit irrigation can improve the water productivity without significantly reducing the bulb yield,consideringthe sensitive stage of the crop.However, stressing onion either by one-half or one-quarter of ETc at the bulb formation stage resulted in lower yield next to stressing the crop throughout the growing season. This indicates that the most critical period for irrigation is the bulb formation stage. Therefore, in schedulingirrigation with scarce water for onion bulb production, it is better to avoided stressing the crop during the bulb formation stage.Further, if water stress is unavoidable at the bulb formation stage, it is better to stress the crop by one-quarter than one-half of the crop requirement.In case, when water stress is imposed early in the growing season, high yield of onion bulb could easily be sustained provided adequate watering conditions take place during the rest of the growing season, specially the bulb formation stage.

Onion water productivity is lower when optimumirrigation water is applied throughout the growth season but higher when the crop is stressed by one-quarter Etc at individual or combination of stages excluding bulb formation stage. Higher water productivity can be obtained by stressing onion crop by one-quarter deficit at developmental and/ or bulb formation stage than stressing by one-half.

Overall, a strategy of stressing onion by one-quarter of ETc at individual or coupling stages keeping bulb formation stage unstressed, and using the water to irrigate additional area, results in higher bulb production than providing optimum irrigation throughout the season for a smaller area.

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