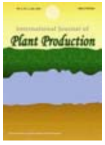

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Effect of deficit irrigation on crop growth, yield and quality of onion in subsurface drip irrigation

N. Patel[a,*], T.B.S. Rajput[b]

[a]*Senior Scientist Water Technology Centre, Indian Agricultural Research Institute, New Delhi.*
[a]*Principal Scientist, Water Technology Centre, Indian Agricultural Research Institute, New Delhi.*
*Corresponding author. E-mail: neelam@iari.res.in

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Abstract

India has the largest area under onion (*Allium cepa*) crop but its average productivity (14.21 t ha^{-1}) is considerably lower than the world's average of 19.4 t ha^{-1}. Besides low productivity, irrigation efficiencies are also very low i.e. 30-35% in India. Managing onion crop with less than adequate irrigation water availability is a challenge in several parts of the country. Options of i) deficit irrigation (DI) i.e. 20% or 40% less water application at one of the growth stages of the crop and ii) controlled deficit of 20% or 40% on all growth stages i.e. regulated deficit irrigation (RDI) were explored for maximizing IWUE of onion under deficit water application through subsurface drip irrigation. A field experiment was conducted on onion (var. Agrifound light red) for three years from October to May in 2007-08, 2008-09 and 2009-10 to study the effect of DI and RDI on onion yield and its quality under subsurface drip irrigation. In DI treatments, the crop was provided the irrigation with 60% and 80% of ETc creating water stress of 40 and 20%, respectively at developmental (2nd), bulb formation (3rd) and bulb maturity (4th) crop growth stages. In case of RDI treatments, 20% and 40% water stress was created throughout the crop season by applying the irrigation water at 80% and 60% ETc. The maximum yield (44.7 t ha^{-1}) was obtained in the full-irrigation treatment (T_1). In RDI, 20 and 40% deficit water application saved 19.2 and 41.7% water and resulted in 20 and 32% reduction in yield, respectively. In DI, 20% water deficit in the growth stages of 2nd, 3rd and 4th saved 2.1, 13.2 and 4.6% of water with 19.8, 18.3 and 11.2% reduction in yield, respectively in comparison to full irrigation water application. This suggests that RDI is better option of water saving than DI. Saving of water through RDI may be used to irrigate additional cropped area. Strategy suggested for productions of onion crop can be adopted in large scale to offset high cost of onion, which is cause of concern for all stake holders.

Keywords: Subsurface drip irrigation; Onion yield; Water use efficiency; Onion quality.

Introduction

India has the largest irrigation system in the world but its irrigation efficiency has not been more than 40 per cent. Increasing high cost of development of additional water resources make it necessary to use available water more efficiently. Achieving food security is a high priority in many countries including India and agriculture must not only provide food for rising population, but also save water for other uses. The challenge is to develop and supply water saving technology and management methods and, through capacity building enable farming communities to adopt new approaches in irrigated agriculture. To meet the food security, income and nutritional needs of the projected population in 2050, the food production will have to be almost doubled. Thus, judicious use of irrigation water is more important to enhance total production and area under irrigated agriculture (Water Resources Development in India, 2010). It can be achieved by introducing advance method of irrigation like micro-irrigation coupled with other improved water management practices. Therefore, innovations are needed to increase the efficiency of use of the available irrigation water.

In India, agriculture consumes more than 80% of the available water demanding the efficient utilization of this critical input through technology interventions, management methods and capacity building. Deficit (or regulated deficit) irrigation is one of the methods of maximizing the irrigation water use efficiency (IWUE) per unit of applied water. In this method, the crop is exposed to a certain level of water stress either at a particular stage or throughout the growing season (English and Raja, 1996). The expectation is that the yield reduction by inducing controlled water stress (supplying lesser irrigation water) will be insignificant compared with the benefits gained through diverting the saved water to irrigate additional cropped area (Kirda, 2002; Kirnak et al., 2002; Gijón et al., 2007). Owusu-Sekyere et al. (2010) revealed that reduction in 20% water need of hot pepper has no significant effect on growth, development and fruiting of the crop. Samson and Tilahun (2007) observed that deficit irrigations increased the water use efficiency of onion from a minimum of 6% by stressing the crop during the first growth stage to a maximum of 13% by partially stressing the crop at 75% ETc of the optimum application throughout the growing season. Karam et al. (2007) conducted experiment in sunflower. They reported that deficit irrigation at early (WS_1) and mid (WS_2) flowering stages reduced seed yield by 25% and 14%, respectively, in comparison with the control. Onder et al. (2005) conducted experiment in potato with surface drip and subsurface drip, water deficiency more than 33% of the irrigation requirement could not be suggested as it affected the crop yield significantly.

India has the largest area (1.06 mha) under onion (*Allium cepa*) followed by China (0.956 mha) but its average yield of 14.21 t ha^{-1} (http://faostat.fao.org/) is considerably lower than that of the world average of 19.4 t ha^{-1} (http://nhb.gov.in/). Indian onions are known for their pungency and are available round the year with two harvesting cycles, the first starting from November to January and the second starting from January to May. As a shallow rooted crop, onion demands frequent irrigation. Indian farmers mostly use surface irrigation for growing onion which is mainly responsible for the low water use efficiency and productivity. Practicing deficit irrigation could increase the irrigated area with a limited yield reduction which is likely to be more than compensated by substantial increase in economic returns. Therefore, the present study was planned to identify optimum management strategies under deficit irrigation through subsurface drip and their impact on crop growth, yield and quality of onion. The onion crop was exposed to full irrigation and predetermined levels of water stress at different stages of crop growth and throughout the growing season and the resulting growth and yield of crop were monitored.

Materials and Methods

System installation and design of field experiments

A field plot of 54×30 m was selected for the experiment. It was divided into 54 plots of 1×30 m with two consecutive plots of 1×30 m representing a single treatment. The experiment was laid out following the CRBD design with nine treatments and three replications for each treatment. The experiment was conducted for three years during October to May in 2007-08, 2008-09 and 2009-10. Under DI treatments, the crop was provided the irrigation with 60% and 80% of ETc (creating water stress of 40 and 20%, respectively) at different crop growth stages namely 2nd, 3rd and 4th. In case of RDI treatments, 20% and 40% water stress was created throughout the crop season by applying the irrigation water at 80% and 60% of ETc through subsurface drip irrigation. Application of water at 100% ETc at all crop growth stages was considered as control treatment. Description of different treatments is given in Table 1. Installation of the subsurface drip system commenced in October 2007 with head works, which included a sand media filter (flow rate 25 m^3 h^{-1}, 50 mm size, silica sand size 0.7 mm), back flush mechanisms and a fertilizer injection system (venturi). The experimental soil was loam with a depth of 0.60 m and Cation Exchange Capacity of 8.65 cmol$^+$ kg^{-1} soil. The soil properties are given in Table 2.

The volumetric water content of the 0.3 m soil depth was 28.6% at field capacity (soil matric potential -0.03 MPa and 6% at wilting point (soil matric potential -1.5 MPa).

Table 1. Description of different water deficit treatments.

Treatments	Irrigation water applied in different growth stages				Description
	1st	2nd	3rd	4th	
Control					
T_1	100%	100%	100%	100%	100% crop evapotranspiration (no water deficit at any stage)
Deficit irrigation					
T_2	100%	80%	100%	100%	20% water deficit in 2nd stage
T_3	100%	100%	80%	100%	20% water deficit in 3rd stage
T_4	100%	100%	100%	80%	20% water deficit in 4th stage
T_5	100%	60%	100%	100%	40% water deficit in 2nd stage
T_6	100%	100%	60%	100%	40% water deficit in 3rd stage
T_7	100%	100%	100%	60%	40% water deficit in 4th stage
Regulated deficit irrigation					
T_8	80%	80%	80%	80%	20% water deficit in all stages
T_9	60%	60%	60%	60%	40% water deficit in all stages

1st stage: Initial stage of crop (15 days).
2nd stage: Crop development stage (35 days).
3rd stage: Bulb formation stage (70 days).
4th stage: Bulb maturity stage (35 days).

Table 2. Soil properties of experimental area.

Soil properties	Soil depth, cm		
	0-15	15-30	30-60
Physical properties			
Particle size distribution			
Sand (%)	72	69	56
Silt (%)	12	10	20
Clay (%)	16	21	24
Hydraulic conductivity (cm h^{-1})	1.22	1.39	0.70
Bulk density (gm cm^{-3})	1.56	1.63	1.57
Field capacity (%)	16.27	17.17	18.1
Permanent wilting point (%)	6.48	8.10	10.27
Chemical properties			
pH	8.18	8.12	8.17
EC, dS/m	0.50	0.19	0.26
Organic carbon (%)	0.50	0.22	0.13
Total nitrogen (N) (kg/ha)	225.79	163.07	125.44
Phosphorous (kg/ha)	60.48	51.52	3.36
Potassium (kg/ha)	385.28	761.66	997.92
NO_3-N (mg/l)	25.00	50.00	69.64

Onion (var. Agrifound light red) was transplanted during the last week of December at a plant to plant and row to row spacing of 10×15 cm. Spacing between two laterals was 1.0 m four rows of onion were transplanted with a drip lateral in each treatment. The average discharge of the dripper located at a spacing of 0.30 m from each other was 1.65 l h^{-1}.

The tests for uniformity of water application of the subsurface drip system were carried out. Coefficient of variation, application efficiency and statistical uniformity were estimated to be 3, 98.2 and 95%, respectively, therefore system performance was considered acceptable as per the guidelines of ASAE (ASAE, 1996a; ASAE, 1996b).

Crop water requirements and irrigation

The reference evapotranspiration (ET_o) was estimated using the FAO Penman-Monteith equation employing daily data from a nearby automatic weather station (Table 3). The crop duration of onion (155-days) was divided into four stages, namely, 1^{st} (15 days), 2^{nd} (35 days), 3^{rd} (70 days) and 4^{th} (35 days). The crop water requirements were calculated by multiplying the ET_0 values with the onion crop coefficients (Kc) given by Allen et al. (1998) as 0.7 for the 1^{st}; 0.90 for the 2^{nd}, 1.05 for the 3^{rd} and 0.75 for the 4^{th} growth stages. Optimal or ‘‘no stress’’ irrigation (control) was calculated as the net amount of irrigation required to recharge the soil moisture deficit with daily application of irrigation water. The depth for other treatments was taken based on the percentage of optimal irrigation at a specific growth stage or throughout the growing season. Table 3 shows average daily net irrigation in different weeks of crop growth during the experiment. The details of the applied irrigation water in different treatments during 2007-08, 2008-09 and 2009-10 are shown in Table 4. The irrigation water use efficiency (IWUE) was estimated using the Equation (1) as the ratio of crop yield, Y (kg ha^{-1}) and total irrigation water applied (ET_a, m^3 ha^{-1}):

$$IWUE = \frac{Y}{ETa} \qquad (1)$$

Nutrient management

In order to meet the nutritional requirement of onion crop, farmyard manure 40 t ha^{-1}, N 160 kg ha^{-1}, P 115 kg ha^{-1} and K 95 kg ha^{-1} were applied. Urea, muriate of potash and phosphoric acid were used to supply N, K and P, respectively. Fertigation was started 15 days after transplanting of onion and was stopped 30 days prior to the harvest of the crop. During the remaining 112 days of crop duration, fertigation was done weekly.

Table 3. ET_0 and crop water requirement of onion crop at every 7-day interval.

Weeks	Days	2007-08		2008-09		2009-10	
		ET_0, mm day^{-1}	Water applied, mm day^{-1}	ET_0, mm day^{-1}	Water applied, mm day^{-1}	ET_0, mm day^{-1}	Water applied, mm day^{-1}
1	Dec. 21-Dec. 27	1.60	1.10	1.14	0.80	1.44	0.60
2	Dec. 28-Jan. 3	1.70	1.20	1.41	1.00	1.18	0.50
3	Jan. 4-Jan. 10	1.50	1.30	1.28	0.50	1.12	0.60
4	Jan. 11-Jan. 17	1.70	1.50	1.70	1.60	1.22	0.70
5	Jan. 18-Jan. 24	1.60	1.50	1.85	1.70	1.92	1.10
6	Jan. 25-Jan. 31	1.90	1.70	1.73	1.60	2.24	Nil
7	Feb. 1-Feb. 7	1.80	1.70	1.67	0.60	1.18	0.70
8	Feb. 8-Feb. 14	2.10	2.20	2.30	2.50	2.33	1.30
9	Feb. 15-Feb. 21	2.30	2.40	3.07	3.30	3.38	2.20
10	Feb. 22-Feb. 28	3.30	3.50	3.83	4.10	4.86	3.20
11	Mar. 1-Mar. 7	3.90	4.10	4.31	4.70	4.64	3.00
12	Mar. 8-Mar. 14	4.40	4.60	4.67	5.10	5.55	3.60
13	Mar. 15-Mar. 21	5.10	5.30	4.08	3.90	5.68	3.70
14	Mar. 22-Mar. 28	6.00	6.30	4.58	5.00	6.58	4.30
15	Mar. 29-Apr. 4	5.60	5.90	5.30	5.50	7.32	4.80
16	Apr. 5-Apr. 11	6.20	6.50	7.03	7.60	8.27	5.40
17	Apr. 12-Apr. 18	6.00	6.30	7.87	8.50	7.57	4.90
18	Apr. 19-Apr. 25	7.70	6.10	8.53	6.90	6.47	2.00
19	Apr. 26-May 2	8.80	6.60	7.61	4.90	7.03	3.60
20	May 3-May 9	8.10	6.10	8.60	6.70	8.99	4.20
21	May.10-May 16			No irrigation			
22	May. 17-May 23			No irrigation			

Table 4. Actual controlled deficit irrigation scheduling.

Treatment	Growth stages											
	2007-08				2008-09				2009-10			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
	Water applied in different growth stages, mm											
T_1	23.6	61.1	332.2	149	13.7	43.1	357.1	120.6	13.9	38.3	432.2	106.7
T_2	23.6	47.6	332.2	149	13.7	32.4	357.1	120.6	13.9	28.3	432.2	106.7
T_3	23.6	61.1	260.7	149	13.7	43.1	284.5	120.6	13.9	38.3	345.5	106.7
T_4	23.6	61.1	332.2	119	13.7	43.1	357.1	95.0	13.9	38.3	432.2	84.9
T_5	23.6	34.1	332.2	149	13.7	21.6	357.1	120.6	13.9	18.3	432.2	106.7
T_6	23.6	61.1	189.2	149	13.7	43.1	211.9	120.6	13.9	38.3	258.9	106.7
T_7	23.6	61.1	332.2	89	13.7	43.1	357.1	69.4	13.9	38.3	432.2	63.1
T_8	18.9	47.6	260.7	119	10.9	32.4	284.5	99.4	11.1	28.3	345.5	84.9
T_9	14.2	34.1	189.2	89	8.2	21.6	211.9	65.4	8.3	18.3	258.9	63.1

Plant growth and post harvest quality determination

Plant height was measured in each treatment by using a meter scale at a 15-day interval. Observation for dry matter accumulation was started after 50 days of transplanting and was continued up to 150th day at 15-day intervals. Destructive sampling was done. The biomass (the part above the ground) was cut into small pieces and dried at 70 ^{o}C to a constant weight for the estimation of dry matter. Dry biomass percentage (DBP) was calculated by using the Equation 2.

$$DBP=(\text{Total dry weight of sample}/\text{Total fresh weight of sample})\times 100 \quad (2)$$

Matured crop was harvested after 155 days of transplanting for the estimation of onion yield. For the determination of yield, 0.60×1.0 m area was marked in each treatment in the head, middle and tail reaches of the field. From the total weight, total number of harvested bulbs and the mean bulb weight were determined. Similarly, a 10 kg sample of onion bulbs was taken randomly from each treatment for measuring the polar and equatorial diameter of bulbs by using a vernier calipers. The mean size of the bulb was presented as the square root of polar and equatorial diameters multiplication (Ranganna, 1986).

For grading, the bulbs were classified into four categories based on their sizes: A, with size > 6 cm; B, with size 6 to 5 cm; C, with size 5 to 4 cm and D, with size < 4 cm. The total soluble solids (TSS) in bulbs was estimated using a hand held refractometer (0-50 8B, ERMA, Japan). Percentage protein in the bulbs was estimated using a spectrophotometer (model UV 5704 SS) by following the standard procedure (AOAC, 2000).

Results and Discussions

Growth dynamics of plant

The average plant growth parameters with different levels of applied irrigation water were similar during all the three years (data not shown). The plant height did not vary much in the treatments T_1 to T_7, where adequate amount of irrigation water was applied at the 1st stage of the crop growth (Figure 1). In treatment T_8 though 20% water deficit was imposed throughout the crop season but the plant height was not different from treatments T_1 to T_7. In the treatment T_9 i.e. 40% water deficits all through the crop season, plant height was reduced significantly (by 6 cm).

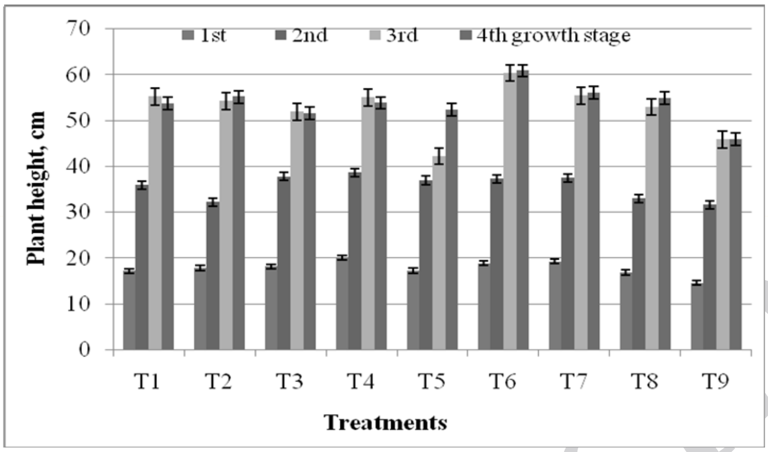

Figure 1. Onion plant height in different water stress treatments.

Results indicated that the dry biomass percentage (DBP) changed significantly with the amount of applied irrigation water. Figure 2 shows that the DBP increased throughout the growing season up to 100 days after transplanting (DAT) for all treatments. The DBP was less in the treatments T_7 and T_9 in comparison to that in other treatments. The DBP reduced significantly in T_9 in which 40% water deficit was maintained throughout the crop season. The DBP increased progressively up to 100 days in T_3 and T_6 but very little difference was observed in all the treatments at 50 and 75 DAT (Figure 2).

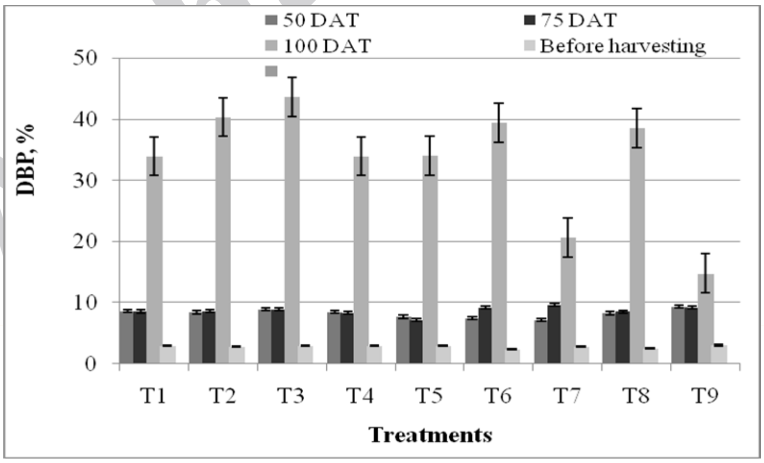

Figure 2. Onion biomass in different water stress treatments.

Yield and irrigation water use efficiency in onion

The relationship between water stress and crop yield is important for scheduling deficit irrigation. Onion crop yield obtained from different treatments is presented in Table 5. The maximum yield was observed with full irrigation i.e. in treatment T_1 (44.4 t/ha). Lowest yield was observed in treatment T_9 (28.1 t/ha) i.e. maintaining the RDI of 40% throughout the crop season. In treatment T_2, i.e. deficit irrigation of 20% saved only 2.1% of water from full irrigation but reduced the yield significantly by 19.8%. Yield obtained in treatment T_2, however, was not significantly different than the treatments T_5, T_6 and T_8 ($LSD_{0.05}$=2.24). However, water savings in treatments T_5, T_6 and T_8 was 2, 25.9 and 7.2%, respectively in comparison to treatment T_2. Water saving was significantly different in treatments T_6 and T_8 in comparison to treatment T_2 ($LSD_{0.05}$=2.10). In treatment T_3, 13.2% water was saved with 18.3% reduction in yield in comparison to full irrigation water application (treatment T_1). Yield obtained in treatment T_3 (37.1 t/ha) (20% water deficit in 3rd stage) was not significantly different than treatments T_2 (34.9 t/ha) and T_7 (39.2 t/ha). However, 13.6 and 5.35% more irrigation water was applied in treatments T_2 and T_7, respectively in comparison to treatment T_3.

Table 5. Yield, irrigation water use efficiency (IWUE), amount of water saved and yield reduction in deficit irrigated onion relative to the optimum irrigation treatment.

Treatment	Average yield, t/ha	Total irrigation water applied, m^3/ha	IWUE, kg/m^3	Relative IWUE	Water saving, %	Yield decrease, %	Rank on yield	Rank on IWUE
T_1	44.4	5630	7.89	1.00	0.0	0.0	1	3
T_2	34.9	5520	6.32	0.80	2.1	19.8	5	8
T_3	37.1	4860	7.63	0.97	13.2	18.3	4	5
T_4	40.7	5370	7.58	0.96	4.6	11.2	2	6
T_5	33.3	5410	6.16	0.78	4.0	31.8	7	9
T_6	34.4	4090	8.41	1.07	27.3	22.3	6	2
T_7	39.2	5120	7.66	0.97	9.2	10.6	3	4
T_8	32.8	4560	7.19	0.91	19.2	20.0	8	7
T_9	28.1	3280	8.57	1.09	41.7	32.0	9	1

LSD (P=0.05)=2.24.

Water deficits of 20% and 40% (T_2 and T_5) at the 2^{nd} stage saved 2.1% and 4% of water with corresponding yield decreases of 19.8 and 31.8%. Yield observed in treatment T_4 (40.7 t/ha) was significantly different ($LSD_{0.05}$) from all treatments except treatment T_7 (39.2). Irrigation water applied in treatments T_4 and T_7 was significantly different, 4.65% less in treatment T_7 in comparison to treatment T_4. Water stress at the 4^{th} stage (T_4) had limited effect on production, whereas water stress at the 2^{nd} and 3^{rd} stages had more severe effect (Table 5). The treatment T_4 received adequate watering at the 1^{st}, 2^{nd} and 3^{rd} stages allowed the crop to partially recover and yield (40.7 t ha^{-1}) higher than that of T_5. Yield obtained in treatment T_5 was not significantly different than the treatments T_6 and T_8. But in treatments T_6 and T_8, 24.4 and 15.7% water was saved, respectively in comparison to treatment T_5. Irrigation water applied in treatments T_5, T_6 and T_8 was significantly different ($LSD_{0.05}$=2.10). Treatment T_9 that received 41.7% less water of the full irrigation water throughout the growing season produced 28.1 t/ha onion. In DI, 20% water deficit in the growth stages of 2^{nd}, 3^{rd} and 4^{th} saved 2.1, 13.2 and 4.6% of water with 19.8, 18.3 and 11.2% reduction in yield, respectively in comparison to full irrigation water application. It was observed that 2^{nd} growth stage is most critical and any water deficit in this stage significantly reduce the yield. While 40% deficit irrigation in growth stages of 2^{nd}, 3^{rd} and 4^{th} saved 4.0, 27.3 and 9.2% irrigation water with 31.8, 22.3 and 10.6% reduction in yield in comparison to the full irrigation water application (treatment T_1). In RDI, 20 and 40% water deficit was created by applying irrigation water as 80 and 60% of ETc throughout the growing season could save 19.2 and 41.7% water with 20 and 32% reduction in yield. Minimum yield of onion bulbs (28.1 t ha^{-1}) was obtained in the treatment T_9, in which only 60% of the full irrigation water was applied throughout the growing season, yet the yield was more than the national average yield. The treatment T_9 was much stressed throughout the growing season with a total water use of only 3280 m^3 ha^{-1}. This suggests that RDI is better option of water saving than DI to increase the irrigated area with the saved water and this would compensate for any yield loss.

Rainfall during the year 2007-08 and 2008-09 were similar but lesser rainfall was recorded in the 3^{rd} year of experimentation i.e. 2009-10 (Table 6).

The details of statistical analysis of yield response to irrigation in all the three years of experimentation in different years are shown in Table 7. Statistical analysis showed significant increase in onion yield with increasing irrigation in all the three years of experimentation (Table 7). A 40% deficit irrigation at the 4th stage (T_7) resulted in a yield reduction of 11.6 t ha^{-1} (Figures 3 and 4). The yield reduction would have been greater if the crop was subjected to 40% water deficit during any of its earlier growth stages. The treatment T_9 showed in the highest IWUE values. In RDI, applying 80% of the full amount of water throughout the growing season improved the crop water use efficiency than full irrigation.

Table 6. Rainfall during the crop season in different years of experimentation.

Year	Crop growth stages							
	G_1 (15 days)		G_2 (35 days)		G_3 (70 days)		G_4 (35 days)	
	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm
2007-08	Nil		Jan. 10	5.01	Feb., 7	0.51	May, 6	1.02
			Jan. 11	1.02	April, 2	1.27	May, 11	1.02
			Feb. 4	0.25	April, 4	1.78	May, 12	6.60
					April, 5	13.72	May, 15	11.94
					April, 6	1.78	May, 16	3.30
					April, 7	6.35	May, 18	3.30
	Crop growth stages							
	G_1 (15 days)		G_2 (35 days)		G_3 (70 days)		G_4 (35 days)	
	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm
2008-09	Nil		Jan., 18	4.20	March, 29	3.90	May, 5	0.30
			Feb., 11	6.50	April, 9	2.00	May, 11	7.20
							May, 23	5.40
							May, 26	3.00
							May, 31	27.40
	Crop growth stages							
	G_1 (15 days)		G_2 (35 days)		G_3 (70 days)		G_4 (35 days)	
	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm
2009-10	Nil		Feb. 9	11.8	Feb. 23	1.20	May, 1	3.00
					April 30	1.20	May, 2	4.60

Table 7. Mean squares from the variance analyses of the yield of onion.

Source of variation	df	Sum of squares	Mean square	Computed F	Table value 1%
Year (2007-08)					
Replications	2	0.325	0.162		
Treatments	8	555.52	69.44	123.69**	3.89
Error	16	7.40	0.462		
Total	26	563.25			
CV=2.04%					
Year (2008-09)					
Replications	2	0.854	0.427		
Treatments	8	671.97	83.99	102.28**	3.89
Error	16	13.13	0.821		
Total	26	685.96			
CV=2.23%					
Year (2009-10)					
Replications	2	1.62	0.81		
Treatments	8	908.58	113.57	123.69**	3.89
Error	16	14.69	0.91		
Total	26	924.90			
CV=2.65%					
Years (Y)	2	54.67	27.33		
Replication within year	2	1.39	0.70		
Treatments (T)	8	1760.44	220.05	7.06**	3.89
Y×T	16	498.84	31.18	40.67**	
Pooled error	48	36.79	0.77		
CD=7.2					

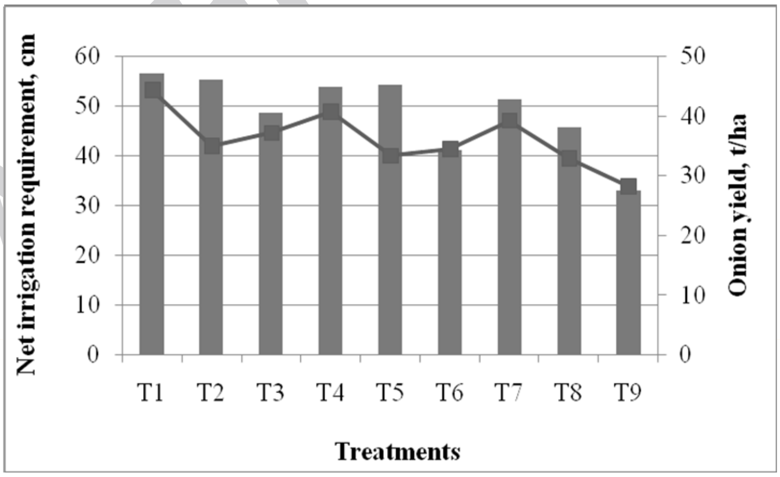

Figure 3. Net irrigation requirement and onion yield.

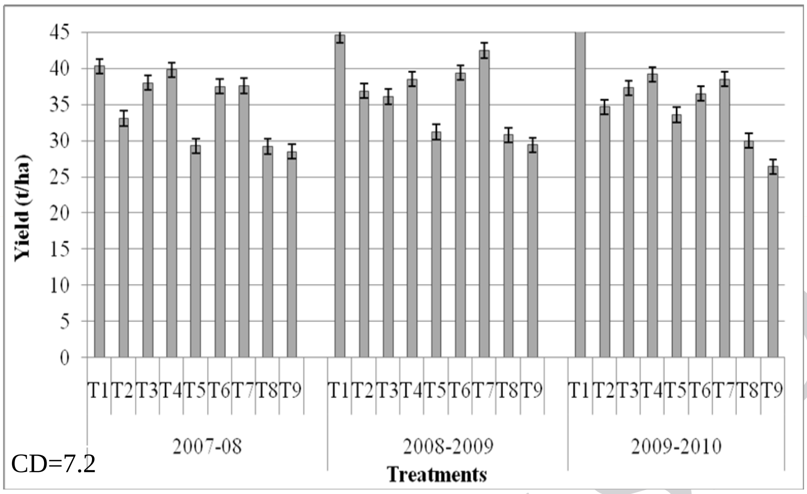

Figure 4. Onion yield recorded in different treatments.

The total crop water saved and the relative yields and IWUE obtained under different deficit water applications are presented in Table 5. The treatment T_1, which was not subjected to water stress gave the maximum yield of bulbs (44.4 t ha^{-1}) but it's IWUE was ranked third. The IWUE was also the lowest in the treatment T_2 (rank 8) and T_5 (rank 9) (Table 5). If sufficient irrigation water is not available, then the option of T_9 is the optimal solution. A deficit of 40% at the 3rd stage resulted in an IWUE of 8.41 kg m^{-3} (rank 2). It was observed that all deficit irrigation applications increased the irrigation water use efficiency from a minimum of 2.92% in T_7 to a maximum of 21.9% in T_5 against the full water application in T_1. Diverting the saved water to increase the irrigated area may more than compensate the decrease in crop yields. However, what is important is that one must decide on the deficit level and the time of its imposition to achieve the highest IWUE at minimum cost (Englsih et al., 1990).

Singh and Sharma (1991) reported that more frequent irrigation produced 17.0 to 27.4 t ha^{-1} of onion in sandy loam soils. The treatment T_2 received slightly lesser volume of water than T_1 at the 2nd stage. The IWUE of T_2 was lesser than that of T_1. The treatment T_3 conducted under adequate watering at 1st and 2nd stages, followed by water deficit at the 3rd stage, resulted in the fifth lowest bulb yield of 37.1 t ha^{-1}. Saving of 77 mm of irrigation water reduced the yield by 11.1 t ha^{-1} (Figures 3 and 4) because adequate watering early in the season led to the development of an abundant leaf cover and a shallow root depth owing to which the crop was unable to withstand water stress at later stages (Bazza, 1999). When a severe water stress follows, the crop rapidly depletes the soil water stored in the root zone and wilts before the completion of additional root development to greater soil depth (Gary et al., 2004).

Shoke et al. (1998) and Shoke et al. (2000) indicated that the bulb and dry matter production of onion is highly dependent on appropriate water supply. Similar results were reported by Bazza (1999) in different vegetable and cereals crops leading to the conclusion that minimum yield was gained during full stress, but stressing the crops at the during initial and final stages of the growing season did not affect the yield significantly. Bazza (1999) further reported that stressing the crop at the third growth stage resulted in greater yield reductions compared to that caused when the crop was stressed at the 1^{st} and 4^{th} growing stages.

Onion yield characteristics and quality

Variation in size of onion bulbs under different treatments was recorded (Figure 5). Chung (1989) reported that water stress during the critical growth period caused reduction in size and weight of onion bulbs. The onion bulbs of grades the preferred size A (bulb size > 6 cm) and B (bulb size 6 to 5 cm) in the treatments T_4 and T_8 were not significantly different from full irrigation, probably due to adequate soil moisture present in these treatments for optimum production. These results are in agreement with Orta and Ener (2001). The percentages of A and B grade bulbs were high (above 65%) in all the treatments but in treatment T_1 and T_4, the percentage of grade A was the highest. Full application of water at all growth stages produced maximum onion of grade A. Deficit irrigation of 20% at the 4^{th} stage saved only 26 mm of water from the full irrigation but 77.3% of bulbs were found in grades A and grade B. However, 20% deficit at the 2^{nd} stage reduced the percentage grade A onion significantly (10% less than full irrigation application) (Figure 5). Grades and B of bulbs were more in 2008-09 than in 2007-08 and 2009-10. However, the lowest percentage of D grade bulbs was produced in T_9. In general, the percentage of C grade bulbs (bulb size -5 to 4 cm) was more in 2007-08. In T_5, the bulbs of grade B were maximum and 66.4% bulbs were of grades A and B. Grade a bulbs decreased significantly in T_5 and T_9 in comparison to those in T_1. A similar effect of irrigation on size of onion bulb was observed by Olalla et al. (2004) under drip irrigation system.

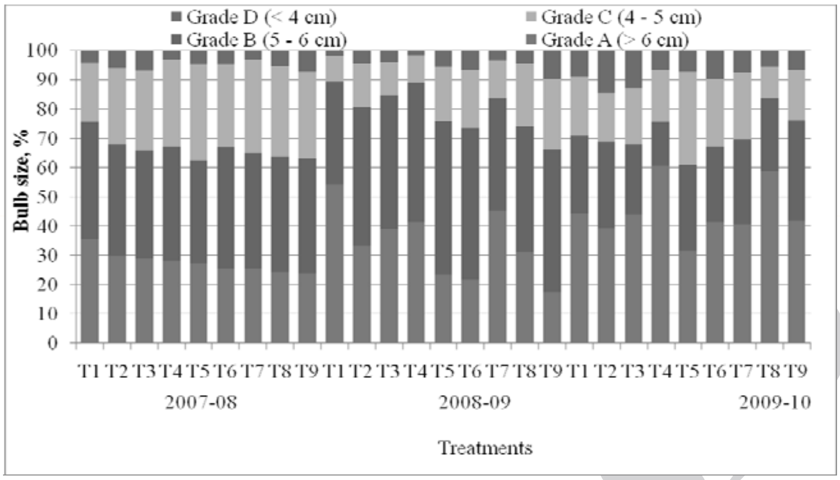

Figure 5. Onion of different grades produced under different water stress treatments.

The average values of three years of experimentation of DBP, protein content (g/100g) and total soluble solid, TSS (%) under different treatments are presented in Table 8. The DBP varied significantly between the treatments except in T_4 and T_5. The least irrigation (T_9) produced the maximum dry matter (7.6%). In T_3, with water deficit at the 4th stage resulted in higher dry matter (7%). Full application of water in T_1 and 40% deficit at the 2nd stage produced the same amount of dry matter (Table 8).

Table 8. Post harvest quality of onion plant and bulb.

Treatment	Dry biomass percentage	Protein (g/100g)		TSS (%)
		Plant top	Bulb	
T_1	5.4	0.253	0.805	11.9
T_2	6.4	0.262	0.840	12.2
T_3	7.0	0.332	1.12	13.1
T_4	5.9	0.297	0.875	12.3
T_5	5.4	0.297	0.840	12.5
T_6	6.2	0.393	1.295	12.6
T_7	6.3	0.341	0.962	13.9
T_8	6.4	0.350	1.19	11.8
T_9	7.6	0.455	1.325	12.1

Protein content in onion bulb decreased with the increasing amount of irrigation water (Table 8). The highest protein content was found in T_9 which was statistically on a par with that of T_6. The least protein content was recorded in T_1 (Table 8). The protein content of onion plant top was less than that of the onion bulb. However, the trend of protein content of onion plant top was similar to that of onion bulb. El-Gizawy et al. (1993) have also observed that total protein content increased significantly with the decreasing soil moisture.

The total soluble solids (TSS) of onion bulb varied from 11 to 13.9% with different levels of irrigation from T_1 to T_9, however the difference was not statistically significant (Table 8). The TSS in subsurface drip irrigation was observed to be high which may be attributed to better utilization of nutrients under frequent and controlled irrigation water application.

Conclusions

The present study shows that increased amount of irrigation water increased the onion bulb yield. A deficit irrigation strategy of supplying water at 20% and 40% of crop evapotranspiration during the 4th stage did not reduce the onion yield significantly. The experiment revealed that a water stress imposed early in the growing season at the 1st and 2nd stages reduced the yield significantly. Therefore, adequate irrigation to be provided at the early crop growth stages for realizing high yields. A water deficit imposed late in the season, at the 4th stage, only marginally affected the yield. The most critical period of irrigation for onion is the 2nd growth stage. The next critical stage is the 3rd growth stage. These periods coincide with the highest water requirement and the crop cannot withstand water deficit at these stages without substantial reduction in yield. Meeting the full water requirement at the 4th crop growth stage is not advisable. Full irrigation early in the growing season allows the crop to develop adequate biomass and root system. For the same amount of water savings through deficit irrigation, it is better to partition the stress of 20% throughout the growing season rather than creating a stress during the critical stages of crop growth. The average water requirement of *rabi* season onion (October to April) is 60 cm (http://www.indiaagronet.com) for an average productivity of 14.21 t ha^{-1} (http://faostat.fao.org/). With 40% deficit irrigation throughout the growing season, productivity can be enhanced from 14.21 to 28.1 t ha^{-1} with water saving of 27.2 cm which is sufficient to irrigate half a hectare of additional area of onion crop and earn higher economic returns.

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