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Full Length Research

Residue mulch and irrigation effects on onion productivity in a subtropical environment

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Onion (*Allium cepa* L.) is one of the most important spices as well as vegetable crop of the world. It requires light and frequent irrigation owing to most of the roots are concentrated in upper surface. Moreover depleting groundwater resources in Punjab demands for optimum irrigation schedule and water saving technique. Onion productivity is constrained by high soil evaporation and temperature during second half of the growing periods. These can be altered through the mulching and irrigation. Mulching with surplus rice residue is likely to provide favorable hydrothermal regime, check weed infestations, economize irrigation water use and enhance onion bulb yield. This study examined the combined effects of residue mulching and irrigation regimes on onion bulb yield and water productivity in a semi-arid sub-tropical environment of north-west India. Treatment included two mulch rates viz., No mulch (M_0) and rice straw mulch @ 6 t ha^{-1} (M_6) in main plots and sub plots comprised of three irrigation regimes based on IW/Pan-E=2.0, 1.4 and 0.8 ratios with four replicates. Onion was transplanted in first week of January with recommended doses of N, P_2O_5 and K_2O and harvested in second fortnight of May.Results revealed that residue mulch improved onion bulb yields by 17 per cent over no mulch plots (24.2 t ha^{-1}). Response of onion to irrigation regimes was observed significantly up to $I_{2.0}$ irrigation regime. Irrigation based on $I_{2.0}$ and $I_{1.4}$ significantly enhanced average yield of onion bulb by 5.3 and 3.7 t ha^{-1} over the restricted irrigation with $I_{0.8}$ ratio (23.3 t ha^{-1}). Mulching benefits were more in drier year 2016 (24%) than in wet year 2015 (10%). For a similar bulb yield, mulching saved 175 mm of irrigation water. Soil moisture storage was higher in mulch plots throughout the growing period. Mulch lowered the maximum soil temperature by 1.8 to 8.8 °C over no mulch plots and also changed the minimum soil temperature during the growing season. The maximum soil temperature was higher by 0.1 to 4.5 °C with the irrigation regime IW/Pan-E=0.8 over IW/Pan-E=2.0. Weed infestation was lower by 92 per cent in mulched plots. Increase in frequency of irrigation weed biomass also increased. Mulch enhanced water use efficiency and these effects were greater in less-frequent irrigations. Mulch recorded more per cent of larger size (>50 mm) bulbs on mass basis. Both mulching and irrigation frequency improved total N uptake. Mulching effects on bulb yield and irrigation economy are attributed to its effect on moderation of soil temperature, reduction in soil water evaporation and weed infestation.

Keywords: Onion, residue mulching, irrigation, water productivity, bulb yield

INTRODUCTION

ONION *(Allium cepa* L) is one of the most important vegetable crops having huge export potential and grown widely in India. The *rabi* season onions are transplanted from first week of December to mid January and raised through March-May hot periods when the evaporation rates (4-10 mm day^{-1}) are relatively high requisite more irrigations. This has led to excessive pumping of the water leading to depletion of the groundwater and increased pumping cost. Since, it required more water, the increasing water scarcity for agriculture and competition from non-agricultural sectors warrants an urgent need to improve the water productivity. Therefore, need has arisen to search for optimum irrigation schedule for growing onion to save the most precious resource. Soil moisture management is a key factor in onion production because of an inefficient, insufficient and shallow rooting system, thus, it requires a constant supply of moisture throughout the growing season (Brewster 1994). According to Anisuzzaman *et al* (2009), onion requires light and frequent irrigations because most of water required by the crop is extracted from upper 30 cm soil depth and very little from lower depths; thus the upper soil layer must be kept moist to encourage root growth and provide adequate water for the plant growth. Effects of moisture on yield and quality of onion have been documented by Singh *et al* (2008) and Shock *et al* (1998). Higher bulb yields are generally associated with higher irrigation frequencies, which avoid any water stress particularly at the time of bulb formation (Al-Jamal *et al* 1999). Doorenbos and Kassam (1986) observed that onion may require irrigation at every 2-5 days interval for better yield. Irrigation based on available soil moisture depletion and IW/Pan-E ratio saved water and enhanced water productivity (Igbadun *et al* 2012; Singh *et al* 2008). Reports had shown that soil surface evaporation contributes largely to the total evapotranspiration in the cropped field (Ahmad *et al*, 2007). Evaporation dominates the moisture depletion from the plant root zone till the crop attains full vegetative cover. Water loss through evaporation, though may have assisted in influencing the micro-climate in which the crop developed, is not beneficially used by the crop in yield production. Reducing the evaporation by mulching caused more water readily available in the soil. The crop is therefore able to balance its transpiration rate with atmospheric water demand, thus maintaining plant leaves turgidity, which in turn enhances radiation use efficiency and biomass yield production. Mulching with plant residues and/or synthetic materials is a well-established technique for increasing the profitability of many crops (Gimenez *et al* 2002).

Soil temperature is a crucial edaphic factor that effecting root activity related to water and nutrient uptake that affect crop growth and productivity. Many factors control soil temperature but only mulching and soil moisture are subject to some manipulation. Although, onion is grow under diverse climatic conditions, but it grows well under mild climate without extreme heat or cold or excessive rainfall. Very low temperature at an early stage results in bolting and sudden rise in temperature favour early maturity and small sized bulbs. Shrinking groundwater resources and higher energy consumption for pumping, there is an urgent need to devise management practices for efficient use of limited water. The combined practice of mulching and irrigation scheduling appears to be very promising in achieving this goal. This can be carried out by mulching which involves the use of organic or inorganic materials to cover the cropped soil surface. Mulching has the potential of reducing evaporation, conserve soil moisture, modify soil temperature, and improve aeration. Crop residues and grasses are typical organic materials commonly used for mulching, while synthetic materials (e.g. polyethylene sheet of different thickness and colours) are typical inorganic materials used for mulching. This study examined the combined effects of rice residue mulch and irrigation regimes on soil temperature, weed biomass, bulb yield and water productivity of onion in an irrigated sub-tropical environment in north-west India.

MATERIALS AND METHODS

A field experiment was carried out for two cropping seasons (2015 and 2016) on sandy loam soil at Punjab Agricultural University Research Farm, Ludhiana, Punjab, India (30° 56' N, 75° 48' E, 247 m above mean sea level). The important soil characteristics are given in Table 1. The soil was alkaline in nature, low in organic carbon and high in available P and medium in available K. The groundwater level was more than 15 m deep. Weather information during the cropping seasons is given in Table 2. Total rainfall during 2015 was 194.2 mm, which was higher than the normal value of 133.4 mm and rainfall during 2016 (97.5 mm) was below the normal. Pan evaporation during 2015 was lower than normal value but was higher than normal value in 2016. Mean maximum air temperature varied between 15.6 and 39.6 $^{\circ}$C during different cropping seasons against long term average values of 18.1-38.8 $^{\circ}$C, while mean minimum temperature was 7-24.6 $^{\circ}$C against the normal values of 5.7-22.5 $^{\circ}$C.

During the two experimental years, main plot treatments comprised of two mulch rates: No mulch (M_0) and rice straw mulch @ 6 t ha^{-1} (M_6) and sub plot treatments included three levels of irrigation on the basis of IW/Pan-E = 2.0 ($I_{2.0}$), 1.4 ($I_{1.4}$) and 0.8 ($I_{0.8}$) ratios with four replications. Each sub plot measured 7.05 m x 3.0 m with a bund height of 0.15 m to minimize out or inflow water. Irrigation water (IW) of 70 mm depth was applied. Initially two common irrigations were applied to establish the seedling and thereafter differential irrigations were imposed. The cumulative Pan-E was recorded since sowing of the crop to work out differential irrigations. The irrigation was timed when cumulative Pan-E after previous irrigation reached at 35, 50 and 87.5 mm net evaporation from USWB Class A Pan evaporation after accounting for rainfall for three irrigation regimes, respectively. Measured amount of irrigation water was applied through Parshall Flume (Parshall 1950). Irrigation water of 630, 490 and 350 mm was applied during 2015 in treatment $I_{2.0}$, $I_{1.4}$ and $I_{0.8}$, respectively. The corresponding value for IW during 2016 was 840, 630 and 420 mm, respectively. Rice straw was spread over whole soil surface as a mulch material in designated plots in the first week of March.

The rice harvested field was irrigated in first week of December and farmyard manure (FYM) @ 50 t ha^{-1} (fresh weight basis) was added to the field. The field was disked once and cultivated twice at field capacity

Table 1: Physical and chemical characteristics of experimental site

Soil depth, m	% sand (2000-20 µm)	% clay (<2 µm)	pH (1:2)	EC, dS m^{-1}	OC (%)	Water retention, vol. %	
						FC[a]	-1.5 MPa
0-0.15	70.6	16.2	7.85	0.31	0.31	26.6	11.3
0.15-0.30	72.8	15.6	7.9	0.27	0.17	23.4	10.8
0.30-0.60	75.2	15.2	8.12	0.22	0.12	20.3	11.5
0.60-0.90	77.8	13.7	8.16	0.20	0.08	19.1	10.3
0.90-1.20	79.2	12.6	8.19	0.18	0.05	18	10.8

[a] Determined in situ 24 h after thorough wetting

Table 2: Monthly mean of daily maximum and minimum air temperature (°C) and monthly cumulative pan evaporation (E_p, mm) and rainfall (RF, mm) in different cropping seasons

Month	2015				2016				Normal value			
	Air temp		E_p	RF	Air temp		E_p	RF	Air temp		E_p	RF
	Max	Min			Max	Min			Max	Min		
January	15.6	7	31.9	24.6	17.2	7.4	32.6	19.4	18.1	5.7	48.8	28.4
February	22.2	10.5	61.4	38.6	23	9	72.2	8.8	21.1	7.7	49.2	32.9
March	25.5	13.3	102.9	84.6	28	14.6	124.1	41.1	26.6	11.8	118.3	22.8
April	32.6	19.5	198.4	29.4	36.6	19.6	250.4	3.0	34.4	17.2	212	27.3
May	39.6	23.8	284.5	17	39.6	24.6	306.6	25.2	38.8	22.5	309.8	22
Total	-	-	679.1	194.2	-	-	785.9	97.5	-	-	738.1	133.4

Table 3: Effect of mulch and irrigation regimes on plant height and number of leaves per plant during 2016

Stage	Treatment	Plant height (cm)			No of leaves per plant		
		M_0	M_6	Mean	M_0	M_6	Mean
75 DAT	$I_{2.0}$	48.13	63.53	55.83	5.12	6.26	5.68
	$I_{1.4}$	43.40	55.88	49.64	4.48	5.45	4.96
	$I_{0.8}$	41.38	51.20	46.29	9.94	4.93	4.43
Mean		44.30	56.87		4.51	5.54	
CD (p=0.05)		M= 1.99, I= 1.14 and MxI= 1.61			M= 0.20, I= 0.23 and MxI= NS		
90 DAT	$I_{2.0}$	52.90	68.78	60.84	7.08	8.24	7.65
	$I_{1.4}$	46.93	61.00	53.96	6.38	7.48	6.92
	$I_{0.8}$	44.13	56.25	50.19	5.95	7.03	6.48
Mean		47.18	62.01		6.47	7.58	
CD (p=0.05)		M= 1.70, I= 1.21 and MxI= 1.71			M= 0.34, I= 0.24 and MxI= NS		

Table 4: Effect of mulch and irrigation regimes on dry weed biomass during 2016

Treatment	Weed biomass (t ha^{-1})		
	No mulch	Mulch	Mean
$I_{2.0}$	0.80	0.44	0.62
$I_{1.4}$	0.63	0.25	0.44
$I_{0.8}$	0.31	0.21	0.26
Mean	0.58	0.30	
CD (p=0.05)	M = 0.15, I = 0.12 and M x I = 0.17		

moisture content and planked with a wooden plank so as to obtain a levelled field. Before transplanting field was prepared by two cultivations with a tractor drawn cultivator followed by planking. Punjab Naroya seed of onion was sown in nursery on last week of October and was transplanted in main field during first week of January. Close planting at 15 cm between rows and 7.5 cm between plants was done. There were 20 rows in

Table 5: Total water use (mm) as influenced by mulch and irrigation regimes in different cropping seasons

Treatment	2015			2016		
	M_0	M_6	Mean	M_0	M_6	Mean
$I_{2.0}$	874.4	855.3	864.9	901.5	876.2	888.9
$I_{1.4}$	734.7	712.8	723.8	700.5	666.8	683.4
$I_{0.8}$	607.1	581.1	594.1	492.4	460.7	476.6
Mean	738.7	716.4		698.2	667.9	
Overall mean	Year: 2015=727.6; 2016=683.0					
	Mulch: M_0=718.5; M_6=692.2					
	Irrigation: $I_{2.0}$=876.9; $I_{1.4}$=703.6; $I_{0.8}$=535.4					

Table 6: Onion bulb yield (t ha^{-1}) as influenced by mulch and irrigation regimes in different cropping seasons

Treatment	2015			2016		
	M_0	M_6	Mean	M_0	M_6	Mean
$I_{2.0}$	27.6	30.7	29.2	25.7	30.2	27.9
$I_{1.4}$	26.3	28.2	27.2	24.1	29.5	26.8
$I_{0.8}$	22.3	25.7	24.0	19.2	26.0	22.6
Mean	25.4	28.2		23.0	28.6	
Overall mean	Year: 2015=26.8; 2016=25.8					
	Mulch: M_0=24.2; M_6=28.4					
	Irrigation: $I_{2.0}$=28.6; $I_{1.4}$=27.0; $I_{0.8}$=23.3					
CD (p=0.05)	Year =NS					
	Mulch =0.76					
	Year x mulch =1.1					
	Irrigation =0.81					
	Year x irrigation = NS					
	Mulch x irrigation = NS					
	Year x mulch x irrigation = NS					

one plot and each row contained 94 onion plants. The recommended dose of phosphorus (50 kg P_2O_5 ha^{-1} as single super phosphate), potash (50 kg K_2O ha^{-1} as murate of potash) and half dose of nitrogen (50 kg N ha^{-1} as urea) were applied before transplanting and remaining half was applied four weeks after planting as top dress. Weeds were controlled by spraying Stomp 30 EC (pendimethalin) @ 750 ml ha^{-1} within a week of transplanting nursery followed by one hoeing at two weeks after planting. In spite of weed control there was weed infestation observed during cropping season. To record the data on weed biomass manual uprooting of weeds was done a week before harvesting of onion in all the plots during 2016. Three sprays of Indofil M-45 @ 1500 g in 500 litres of water ha^{-1} were done for the control of Purple blotch starting from 21st March at 10 days interval. Crop was harvested manually during 2nd fortnight of May when tops had dried and fallen down.

Soil moisture determined gravimetrically at 0.15 m increments to 0.30 m depth and at 0.30 m increments thereafter to 1.20 m. Soil temperature was measured in all plots with the help of mercury in glass thermometer placed at 0.05 m depth at 07:30 and 14:00 h during 2016 cropping season. Plant height as well as number of leaves per plant was recorded at 75 and 90 days after planting during 2016. Manual uprooting of weeds was done a week before harvesting of onion in all the plots. The weed biomass was recorded and expressed on dry weight basis. Bulbs from each plot on mass basis were graded by passing through four different sizes of sieves i.e. >50, 45-50, 35-45, <35 mm. Bulb yield at harvest was determined from a net area of 21.2 m^2 per plot. Treatments effects on bulb yield and other parameters were tested for significance using ANOVA for split plot design, while mulch effects on soil temperature was analysed by *t* test for paired observations. Bulbs and onion tops were analysed for N concentration by the Kjeldahl method (Keeney and Nelson 1982) to estimate uptake of total N. Crop water productivity was computed as the ratio of bulb yield to water use calculated as sum of change in soil water content from planting to harvest plus irrigation and rainfall during the cropping cycle (Table 5).

RESULTS AND DISCUSSION

Soil moisture

In general, soil moisture content increased with increasing soil depth (Fig 1). The mulched plots retained higher soil moisture over no mulch at 70, 82, 108 and 122 days after transplanting (DAT) and at harvest during the growing season of 2016. Due to interception of incoming solar energy by mulch, less water evaporated from the mulched plots as compared to no mulch. The

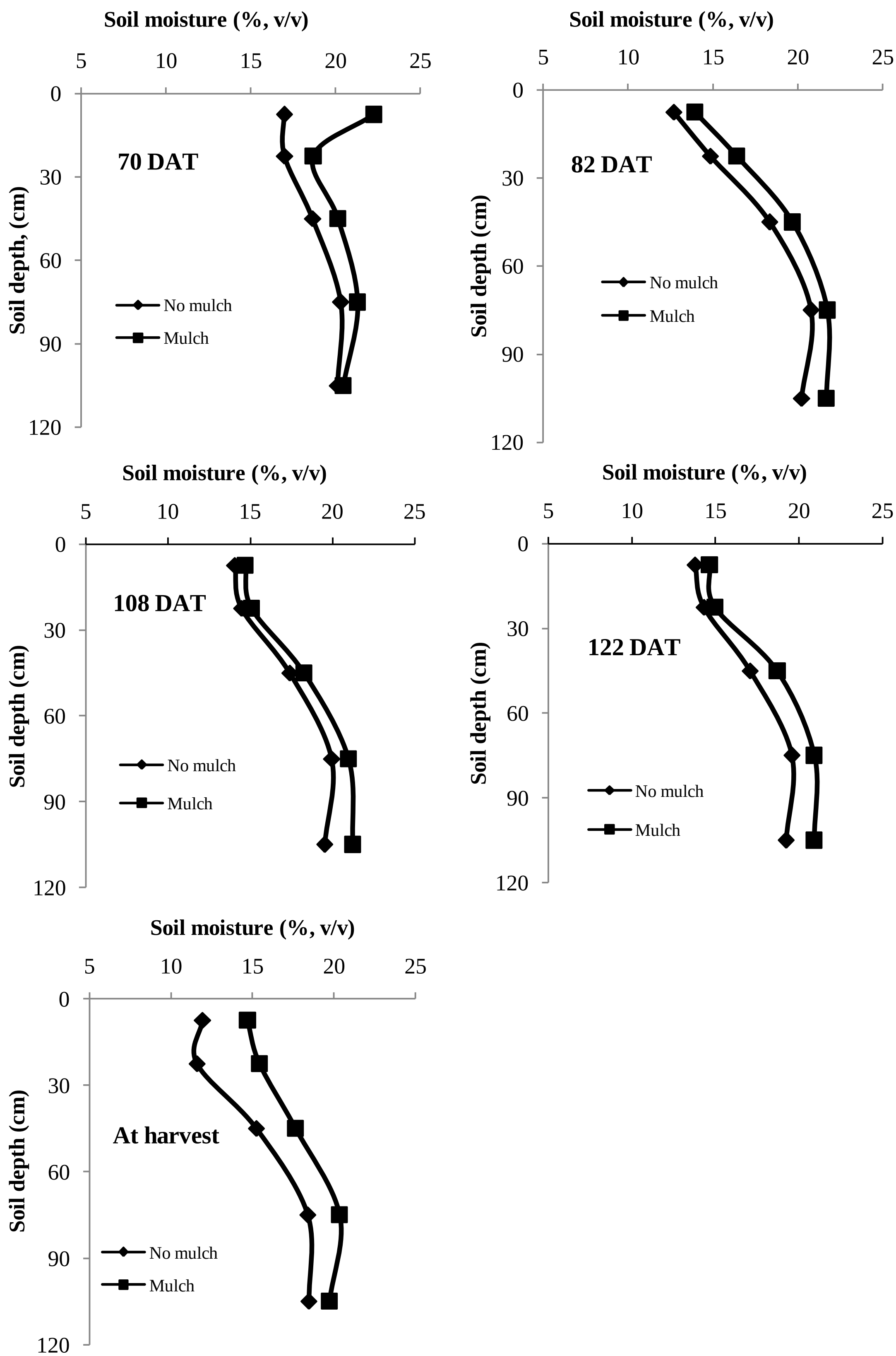

Figure 1: Soil moisture distributions as affected by mulch during 2016 cropping season

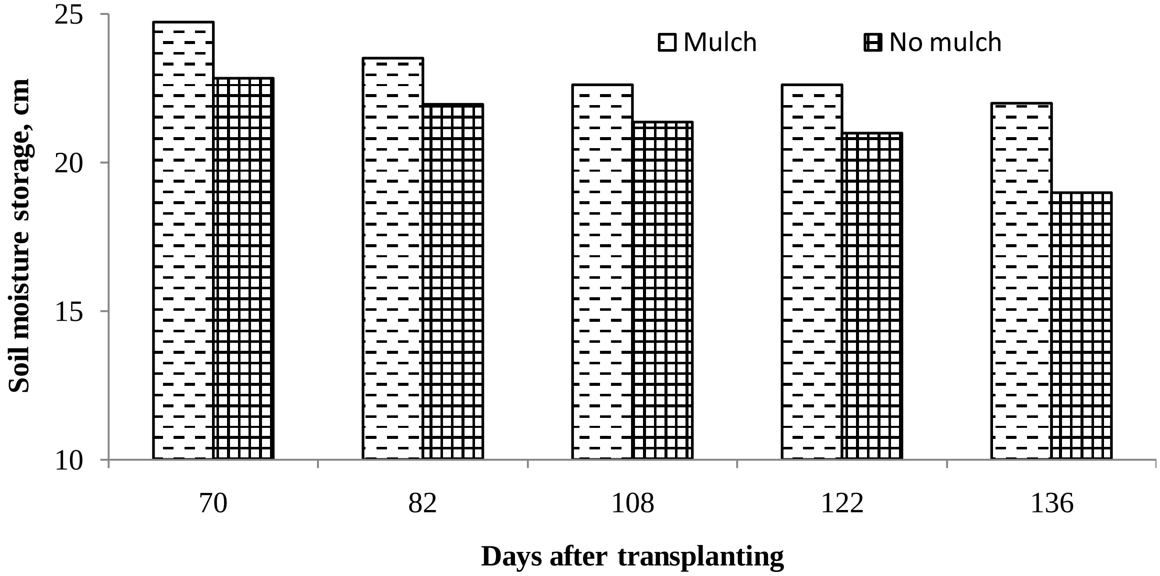

Figure 2: Soil moisture storage (cm) as affected by mulch during 2016 crop growing season

mulched plots retained higher moisture content in the soil profile which ranged from 0.3 to 5.3, 0.9 to 1.6, 0.6 to 1.7, 0.7 to 1.7 and 1.3 to 3.8 per cent on volume basis at 70, 82, 108, 122 DAT and at harvest, respectively. There was relatively more difference in moisture content at 70 DAT and at harvest between mulched and no mulch plots due to low utilization of profile moisture by crop. Soil moisture storage in mulch and no mulch plots is depicted in Figure 2 at different days after transplanting. Storage was higher in mulched plots throughout the cropping season. It was higher by 1.9, 1.6, 1.3, 1.6 and 3.0 cm at 70, 82, 108, 122 DAT and at harvest, respectively. The difference was more at harvest due to low utilization of profile moisture by crop because crop was at maturity and majority leaves dried-up. So water loss through evaporation was higher in no mulch plots. Due to presence of more moisture in mulched plots throughout the crop growing period over no mulch plots moderated soil temperature and enhanced nutrient uptake which improved plant growth and further bulb yield. Igbadun *et al* (2012) reported better soil moisture under mulch plots in onion crop. Das *et al* (2015) also found that mulched plots in cotton crop retained higher moisture content in the soil profile throughout the crop growing season.

Soil temperature

Straw mulching and irrigation regimes favourably modified soil temperature at 0.05 m depth throughout the growing season of 2016. Application of rice straw mulch @ 6 t ha^{-1} influenced both the mean daily minimum and maximum soil temperature during growing season (Fig 3). Data recorded after mulch application revealed that the maximum soil temperature observed in no mulch plots was much higher compared to mulched plots. Average maximum soil temperature during growing season was lower by 1.8 to 8.8 °C by mulch as compared to no mulch plots. Maximum soil temperature ranged from 22.2 to 35 °C in mulched plots and 25 to 41.9 °C in no mulch plots. On the other hand mulch increased minimum soil temperature by 0.3 to 1.2 °C over the no mulch up to March and thereafter it decreased soil temperature by 0.2 to 2.8 °C over no mulch plots during the growing season. Minimum soil temperature recorded ranged from 17.7 to 28.3 °C in mulched plots and 17.3 to 29 °C in no mulch plots. The soil temperature amplitude at 0.05 m depth was narrowed down by 0.5 to 6.0 °C.

Minimum and maximum mean of daily soil temperature during growing season varied from 20.5 to 30.5 °C in mulched plots and corresponding value for no mulch was 22.8 to 35.5 °C, respectively. This shows that seasonal fluctuation of soil temperature after mulch application was 12.7 °C in no mulch against the 10 °C under mulched plot. Generally maximum and minimum soil temperature increased with air temperature increase throughout the crop growing season. The favourable modification in soil temperature under mulched plot is likely to improve the crop growth and yield of *rabi* onion. Gupta *et al* (2013) examined the effect of mulching on soil temperature in sandy loam and loamy sand soils and revealed that soil temperature could be enhanced by 1-2 °C through straw mulching in onion crop. Similar observations were also recorded by Das *et al* (2015) for cotton crop on sandy loam soils. Organic mulches cover intercept solar radiations, partly reflect back the solar radiations and provide a continuous shed to the soil. During night these covers act as barriers to the release

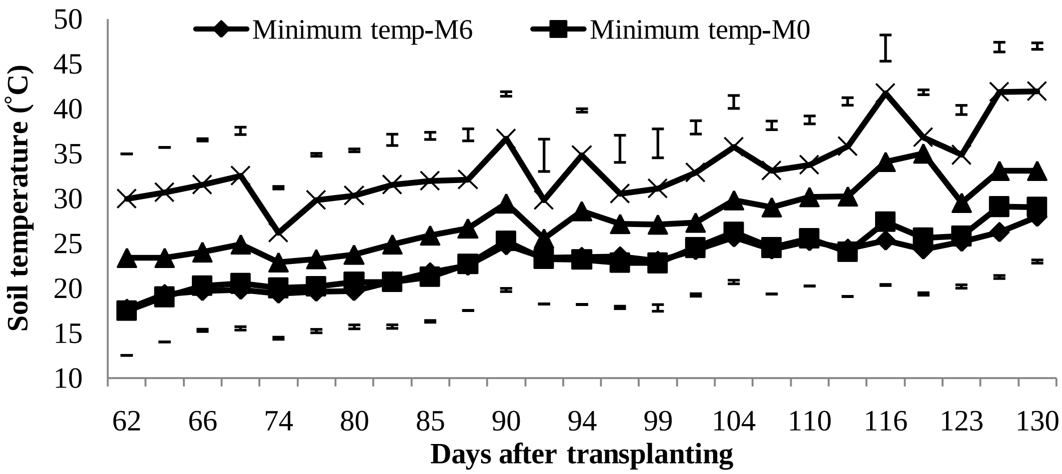

Figure 3: Periodic soil temperature at 5 cm depth as affected by mulch application during 2016 growing season, vertical bars indicate LSD (p= 0.05) value

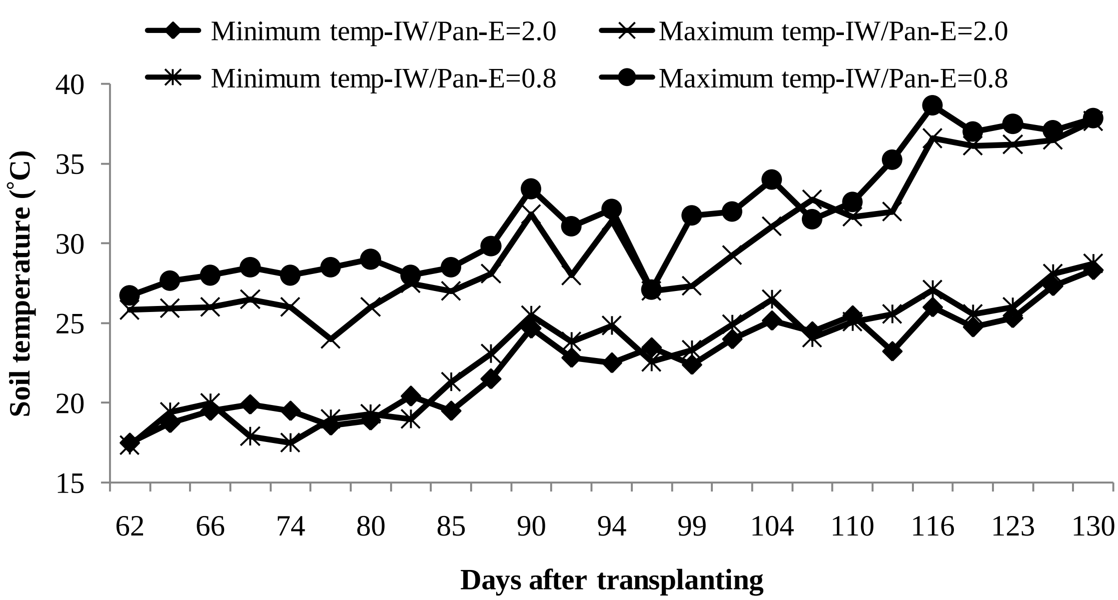

Figure 4: Periodic soil temperatures at 5 cm depth as affected by irrigation levels during 2016 growing season

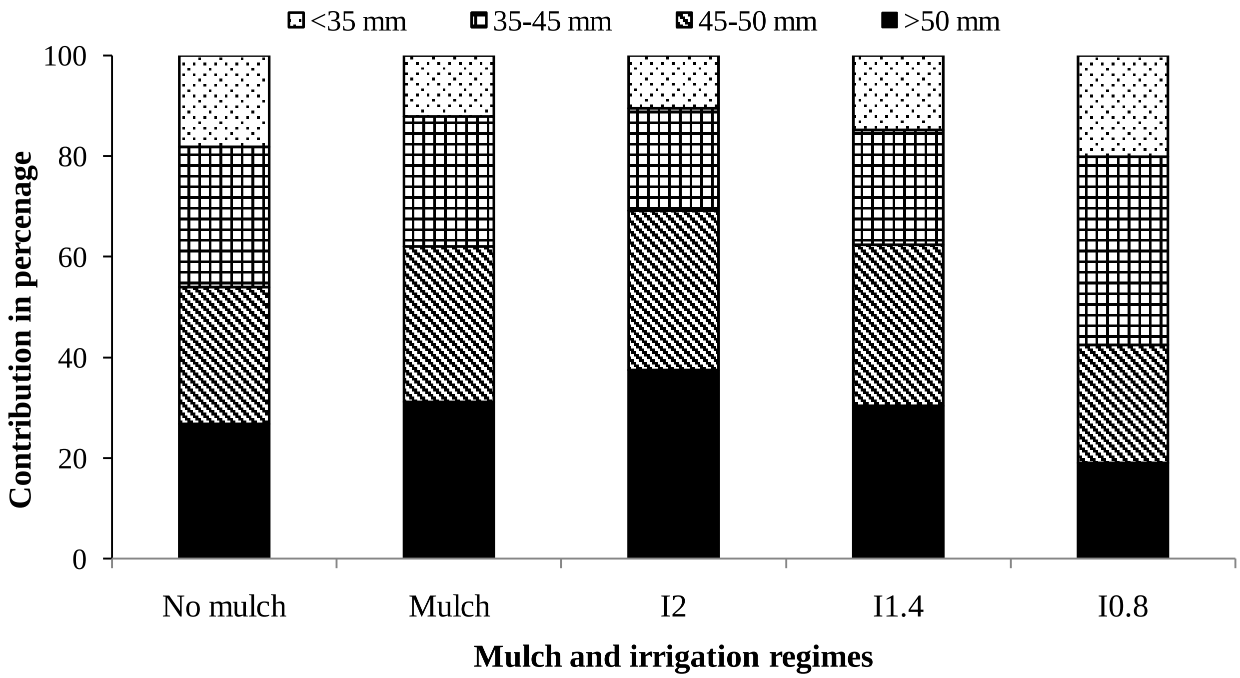

Figure 5 Effect of mulch and irrigation on contribution of different bulb sizes (Mass basis) towards yield of onion during 2016

of soil heat, there by maintaining soil at a high temperature. Arora *et al* (2011) also found that mulching in soyabean crop lowered maximum soil temperature at 0.05 m soil depth from 2.5-7.2 °C as compared to no mulch plots.

On the other hand soil temperature varied with irrigation regimes (Fig 4). The maximum soil temperature was higher in $I_{0.8}$ over $I_{2.0}$ ratio throughout the crop growing season which varied from 0.1 to 4.5 °C while minimum soil temperature was higher in $I_{2.0}$ over $I_{0.8}$ ratio up to March which decreased afterwards and it varied from 0.4 to 1.8 °C throughout the crop growing season. This was because $I_{2.0}$ received frequent irrigations than $I_{0.8}$ ratio which lowered the soil temperature. Kumar and Dey (2011) also observed that application of irrigation moderated the soil temperature.

Plant height and number of leaves

Plant height and number of leaves per plant was recorded at 75 and 90 DAT and data of year 2016 is presented in Table 4. Application of straw mulch increased the plant height significantly by 12.6 and 14.8 cm over no mulch at 75 and 90 DAT, respectively. It indicated that more soil moisture conserved under mulch over un-mulched plots thereby providing more water availability to the crop throughout the growing period. Anissuzzaman *et al* (2009) and Masalkar *et al* (2014) also revealed the similar results of onion plant height under mulch and un-mulched treatment. Plant height significantly increased with increasing irrigation frequency and the maximum height was observed in $I_{2.0}$ followed by $I_{1.4}$ and $I_{0.8}$ at 75 and 90 DAT, respectively. Similar results were also obtained by Bhagyawant *et al* (2014) that increasing irrigation frequency increased the plant height. The interactive effect of mulching and irrigation regimes was also observed at both the stages. The plant height under mulched plot with irrigation treatment of $I_{0.8}$ was higher by 3.07 and 3.35 cm over un-mulched plots with irrigation of $I_{2.0}$ at 75 and 90 DAT, respectively. So frequently irrigated plots under no mulch obtained significantly lower plant height as mulched plots under restricted irrigation.

Number of leaves per plant significantly increased with increasing irrigation frequency and the maximum number of leaves were observed in $I_{2.0}$ followed by $I_{1.4}$ and $I_{0.8}$ at 75 and 90 DAT, respectively. Residue mulching also increased the number of leaves per plant by 22.8 and 17 per cent at 75 and 90 DAT, respectively. Matwally (2011) also obtained similar results that larger amount of water was associated with more leaves per plant.

Weed biomass

The data revealed that mulch and different irrigation regimes had significant effect on the weed biomass during 2016 (Table 5). It shows that increasing frequency of irrigations increased the weed biomass from treatment of $I_{0.8}$ to $I_{2.0}$. Weed biomass was 0.62, 0.44 and 0.26 t ha^{-1} with irrigation regimes of $I_{2.0}$, $I_{1.4}$ and $I_{0.8}$, respectively. This may be attributed to low availability of soil moisture for weeds as irrigation frequency decreased from irrigation treatment $I_{2.0}$ to $I_{0.8}$. However, it was 0.58 and 0.3 t ha^{-1} with no mulch and mulch plots, respectively. Interaction between mulch × irrigation regimes depicted that with increasing irrigation frequency from $I_{0.8}$ to $I_{2.0}$ there was increased in weed biomass from 19 to 109 per cent in the presence of mulch while in no mulch plots it varied from 103 to 158 per cent, respectively. It also demonstrated that weed biomass of mulched plots with irrigation regime $I_{2.0}$ (0.44 t ha^{-1}) was at par with no mulch plots with $I_{0.8}$ (0.31 t ha^{-1}). Hence increase in irrigation frequency from $I_{0.8}$ to $I_{2.0}$ ratio decreased the weed infestation in mulched plot. This was because mulch provides a physical barrier, reduces the germination, nourishment of many weeds and physically suppress seedling emergence. Daisley *et al* (1988) and Ossam *et al* (2001) also observed significantly difference in weed control between mulched and un- mulched plots of eggplant, cowpea and sweet potato.

Per cent contribution of bulb sizes towards yield of onion

Mulch and irrigation regimes influence the bulb sizes on mass basis recorded at the time of harvest during 2016 (Fig 5). Application of mulch produces more mass percentage of larger bulb size as compared to no mulch plots. Mulch contribution of larger (>50 mm) and smaller (<35 mm) size bulbs towards yield was significant. Per cent contribution of larger size bulb towards yield was 31.2 as compared with 26.8 under no mulched plots. The 45-50 mm diameter bulbs also contributed more in mulched plots (30.9 per cent) than no mulch plots (27.2 per cent). However the contribution of medium size (35-45 mm diameter) and small size (<35 mm diameter) bulbs was more in no mulch plots. Igbadun *et al* (2012) also reported proportion of large sized bulb yield was higher under mulching as compared to no mulching.

The contribution of >50 mm mass of bulb (37.5 per cent) was highest while <35 mm diameter of bulb (10.5 per cent) was lowest with crop irrigated on the basis of $I_{2.0}$. However contribution of 45-50 mm diameter of bulb (32 per cent) was highest while <35 mm diameter of bulb (14.8 per cent) was lowest with crop irrigated on the basis of $I_{1.4}$ and with $I_{0.8}$ treatment contribution of both >50 and <35 mm diameter sizes was similar i.e. 19 and 20.1 per cent, respectively. Highest contribution in $I_{0.8}$ was of bulb size of 35-45 mm diameter by 37.4 per cent. The best yields recorded from $I_{1.0}$ and $I_{1.2}$ ratios, attributed with higher percentage of bulbs having diameter of more than 45 mm observed by Kumar *et al* 2007.

Bulb yield

Bulb yield response to mulch and irrigation regimes for two cropping seasons is presented in Table 6. Average bulb yield was higher during 2015 cropping season than that of 2016 by 1.0 t ha^{-1}, could partly be attributed to differences in evaporation, rainfall amounts and air temperature because 2016 season was dry year relatively and air temperature was comparatively higher in months of March and April (Table 2). Mulching caused a gain in onion bulb yield was 4.2 t ha^{-1} (17 %) over no mulch plots. An analysis of pooled data on bulb yield indicated that with increase in irrigation frequency bulb yield increase was up to $I_{2.0}$ irrigation regimes. Bulb yield improvement was 22.7 and 15.9 per cent higher in $I_{2.0}$ and $I_{1.4}$ ratios over $I_{0.8}$ irrigation regimes. Interaction of year and mulch indicated that application of residue mulch benefits were more in relatively dry year 2016 (24%) than in wet season of 2015 (10%). For obtaining a similar onion bulb yield, mulching caused a saving of 175 mm of irrigation water.

In 2015 bulb yield was more by 11 per cent over no mulch (25.4 t ha^{-1}). With increase in irrigation frequency bulb yield increased significantly. There was 21.7 and 13.3 per cent more bulb yield in $I_{2.0}$ and $I_{1.4}$ ratio over $I_{0.8}$ (24 t ha^{-1}). In 2016 also mulch enhanced onion bulb yield by 24 per cent over no mulch plots (23.0 t ha^{-1}). Gupta *et al* (2013) and Masalkar *et al* (2014) also reported similar results of onion owing to mulch. Bulb yield was also significantly affected by irrigation regimes. Irrigation based on $I_{2.0}$ and $I_{1.4}$ ratio significantly enhanced average bulb yield of onion by 5.34 (23.6 %) and 4.23 t ha^{-1} (18.7%) over the restricted irrigation with $I_{0.8}$ ratio (22.6 t ha^{-1}) during 2016. Kumar *et al* (2007) also observed that with irrigation ratio of IW/Pan-E=1.2 bulb yields increased by 21.6 and 75 per cent over 0.8 (26.7 t ha^{-1}) and 0.6 (18.5 t ha^{-1}) irrigation ratios.

Water use efficiency

Treatments effects on seasonal total water use in the cropping seasons (Table 5) shows that water use was greater in 2016 than 2015 attributed to more irrigation water input. As expected increasing irrigation frequency from $I_{0.8}$ to $I_{2.0}$ total water use increased. With mulching total water use decreased.

Contrary to yield water use efficiency was higher in 2016 than 2015 by 3.1 kg ha^{-1} mm^{-1} (Table 7). Water use efficiency (WUE) improved with mulch application. It

Table 7: Water use efficiency (kg ha^{-1} mm^{-1}) as influenced by mulch and irrigation regimes in different cropping seasons

Treatment	2015			2016		
	M_0	M_6	Mean	M_0	M_6	Mean
$I_{2.0}$	31.6	35.9	33.8	28.9	35.1	32.0
$I_{1.4}$	35.8	39.5	37.7	35.1	45.1	40.1
$I_{0.8}$	36.7	44.2	40.4	40.5	57.5	49.0
Mean	34.7	39.9		34.8	45.9	
Overall mean	Year: 2015=37.3; 2016=40.4					
	Mulch: M_0=34.8; M_6=42.9					
	Irrigation: $I_{2.0}$=32.9; $I_{1.4}$=38.9; $I_{0.8}$=44.7					
CD (p=0.05)	Year =NS					
	Mulch =1.54					
	Year x mulch =2.17					
	Irrigation =1.98					
	Year x irrigation = 2.1					
	Mulch x irrigation = 2.1					
	Year x mulch x irrigation = 2.96					

Table 8: Effect of mulch and irrigation regimes on total N uptake by onion crop (Onion + onion tops) during 2016

Treatment	N uptake (kg ha^{-1})		
	M_0	M_6	Mean
$I_{2.0}$	52.36	59.95	56.15
$I_{1.4}$	48.73	57.21	52.97
$I_{0.8}$	42.63	52.37	47.50
Mean	47.91	56.51	
CD (p=0.05)	M = 4.36, I = 2.13 and M x I = NS		

enhanced significantly by 23.3 per cent in mulched plots over no mulch (34.8 kg ha^{-1} mm^{-1}). Higher WUE with mulching was also reported by Chandra *et al* (2002). On the other hand WUE increased significantly with decrease in irrigation frequency. It was enhanced by 35.9 and 18.2 per cent in $I_{0.8}$ and $I_{1.4}$ ratio, respectively over $I_{2.0}$ irrigation regime (32.9 kg ha^{-1} mm^{-1}). Year x mulch interaction also responded significantly indicating only 15 per cent improvement in WUE during 2015 cropping season while, in 2016 season it was 31.9 per cent . Interaction between year × irrigation revealed that enhancement in WUE was 19.8 and 11.5 per cent under $I_{0.8}$ and $I_{1.4}$ regimes over $I_{2.0}$ (33.8 kg ha^{-1} mm^{-1}) in 2015 while corresponding increase in 2016 was 53.1 and 22.2 per cent over $I_{2.0}$ (32 kg ha^{-1} mm^{-1}). Mulch and irrigation interaction showed that in no mulch plots there was 27.4 and 17.2 per cent increase in WUE with $I_{0.8}$ and $I_{1.4}$ regimes over $I_{2.0}$ (30.3 kg ha^{-1} mm^{-1}) while corresponding improvement with mulch was 43.4 and 19.2 per cent over $I_{2.0}$ (35.5 kg ha^{-1} mm^{-1}). Year x mulch x irrigation interaction showed improvement by 16.1 and 13.3 per cent in $I_{0.8}$ and $I_{1.4}$ ratios over $I_{2.0}$ ratio (31.6 kg ha^{-1} mm^{-1}) under no mulch plots in 2015 and corresponding vales in 2016 was 40.1 and 21.5 per cent over $I_{2.0}$ (28.9 kg ha^{-1} mm^{-1}) irrigation regime and in mulch plots during 2015 was 23.1 and 10 per cent over $I_{2.0}$ (35.9 kg ha^{-1} mm-1) while it was higher in mulch plots during 2016 which was 63.8 and 28.5 per cent over $I_{2.0}$ (35.1 kg ha^{-1} mm^{-1}) ratio. Igbadun *et al* (2012) observed similar results of mulching and irrigation effects on WUE in onion crop.

Total N uptake

Total N uptake at harvest during 2016 (Bulb + onion tops) was found to be significant with the application of residue mulch and it was increased by 17.9 per cent over the N uptake of 47.9 kg ha^{-1} in no mulch plots (Table 8). This may be attributed to higher biomass in mulch plots as compared to no mulch. Sekhon *et al* (2008) also observed an increase in total N uptake by 18.7 per cent with mulching in chilli crop. Average N uptake increased significantly by 18.2 and 11.5 per cent with irrigation regimes of $I_{2.0}$ and $I_{1.4}$ over the $I_{0.8}$ regime (47.5 kg ha^{-1}). Singh *et al* (2008) also observed increase of N uptake in onion crop by 22.7 and 42.3 per cent with irrigation regimes of $I_{2.0}$ and $I_{1.5}$ over the $I_{1.0}$ regime loamy sand soil. Similarly Kumar and Dey (2011) observed positive and significant effect of mulch as well as irrigation methods on the N uptake.

CONCLUSION

This study has revealed that mulching with crop residues enhances crop yields and economizes water by providing better hydrothermal conditions in semi-arid subtropical irrigated regions. With the application of mulch bulb yield was improved by 17 per cent. Mulching benefits were more in dry season. For a given yield mulch saved 175 mm of water. Growth parameters were higher in mulch and improved with increase in irrigation frequency. Larger size bulbs (>50 mm and 45-50 mm in diameter) contributed more towards bulb yield with mulching. Mulching enhanced water use efficiency. Mulching gains on bulb yield, WUE and irrigation saving are attributed to its effect on moderation of soil temperature, reduction in soil water evaporation and weed infestation. Thus use of rice residue as mulch enhance bulb yields and save water.

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