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INTERACTIVE EFFECT OF DEFICIT IRRIGATION AND MULCHING ON SUGAR BEET PRODUCTIVITY IN PAKISTAN

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Abstract

In dry regions, irrigated agriculture is facing increasing demand for decreasing water resources. For sustainable and efficient use of the available water resources, field scale water saving strategies must be applied to enhance water productivity and crop yield. Deficit irrigation application along with suitable soil moisture conservation technique is one of the strategies and its successful application depends on crop response to different water stress levels. This research paper presents results of two years (2011–12 and 2012–13) study carried out at Sugar Crops Research Institute (SCRI) Mardan, to determine the effect of different irrigation deficit levels applied throughout the crop growing season and different types of mulching on productivity of sugar beet. The field experiments included four water stress levels designated as FI (full irrigation), DI_{20}, DI_{40}, DI_{60} (20, 40 and 60 percent deficit irrigation levels) and three moisture conservation practices; No mulch (NM), black polyethylene film mulch (BFM) and straw mulch (SM), respectively. Results revealed that different water stress levels and mulching combination produced significant effects on yield of sugar beet and its water productivity. The highest mean root yield was produced by FI– BFM combination and the highest mean sugar yield by DI_{20}–BFM treatment. Results further revealed that the relative amounts of irrigation water saved by irrigation regimes and mulching interaction was ranged from 5.83 to 66.53% and the relative reduction in seasonal water used was ranged between 2 and 47%, respectively. The mean root and sugar water productivities observed in this study were lowest for FI and NM combination and the highest for DI_{60} and BFM. Overall finding of this study is that deficit irrigation and mulching can save water and improve its water productivity significantly.

Key words: Deficit irrigation, Mulching, Sugar beet yield, Sugar contents, Water productivity

Introduction

Growing scarcity of fresh water has become a major constraint to socio-economic development and a threat to livelihood in most parts of the world (Liu *et al.,* 2017). Due to the enormous growth in population along with urbanization, industrialization, and climate change, very limited amount of fresh water will be available in near future to meet irrigation demands. Accordingly, it will be hard to make use of full irrigation potential for attaining maximum yield in irrigated agriculture. Therefore, producing more crops with minimum use of irrigation water and optimizing crop yield is the greatest challenge of today's agriculture (Heris *et al.,* 2014). One way of coping with this challenge is the adoption of practices that help improvement in field- scale irrigation water management (El-Waheed *et al.,* 2017). Integrated use of regulated deficit irrigation along with some soil moisture conservation practices e.g. mulching looks to be one of the promising strategies in achieving this goal (Igbadun *et al.,* 2012).

Deficit irrigation (DI) is an irrigation management practices in which crops are exposed to a certain degree of water stress by maintaining soil moisture content below optimum level in a particular stage of crops or throughout its growth season and thus helps in sustainable production in water scarce area (Enchalew *et al.,* 2016). Although, with the adoption of deficit irrigation management strategy, the farmer may lose certain degree of their economic yield (Galindo *et al*., 2018); however, a visible amount of irrigation water can be saved (Sharma *et al*., 2015) that can be effectively utilized for bringing larger area under irrigation and thus overall increase in productivity per unit of water. Studies have also revealed that, with the adoption of suitable management strategies, yield under moderate deficit irrigation is as good as under full irrigation strategy (Arshad & Ibrahim 2014), and thus can be considered as a viable practice to promote sustainable water development in water scarcity regions (Greavesa & Wang, 2017), improve total farm income (Mila *et al*., 2017; Galindo *et al*., 2018), improve water productivity (Temesgen *et al*., 2018), optimize yield and water use efficiency (Bell *et al*., 2018).

Mulching is a practice that involves laying/spreading of organic (crop residues or grasses) or inorganic material (polyethylene sheets) on soil surface and is considered as a sustainable, affordable and cheap agricultural technology that can be equally utilized by small as well as large farmers (Lalljee, 2013). The basic purpose of this practice is to conserve soil moisture by reducing direct evaporation from soil root zone. This way, more soil water will be available for plants growth and thus farmers can obtain higher crop yield and improved water productivity. The positive effects of mulching in terms of improved crop yield and water productivity has been reported by many researchers for different crops in different parts of the world. Jiang *et al*., (2018) observed that mulch application on ridges significantly improved maize yield, water use efficiency (WUE) and nitrogen use efficiency (NUE) in the China Loess Plateau. Malik *et al.,*

(2018) concluded that the application of different mulching techniques significantly improved all the yield components and WUE of sugar beet crop, in comparison to that produced by No-Mulch treatment. Ma *et al*., (2018) reported that the application of plastic film mulch is an effective tool for improving crop yield and economic return in water limiting areas. Bakht *et al*., (2014) concluded that the application of black film mulch was an effective mean for enhancing competitiveness of tomato with weeds and improving its fruit qualities. Farazi *et al*., (2017) concluded that mulch application had great efficiency for soil water conservation in semi-arid regions. Mukulkumar *et al*., (2018) concluded that the yield of Turmeric (Curcuma longa L.) under plastic mulch in India was increased by 28%.

Sugar beet is the leading sugar crop in the world after sugar cane and can be grown under different climatic conditions. Sugar beet is a high delta crop with total water consumption ranging from 900 -1195 mm. Response of sugar beet to deficit irrigation have been reported by some researchers under different climatic conditions. Sahin *et al*., (2014) on the basis of two years experiments carried out under semi-arid environment in Turkey concluded that deficit irrigation regimes adversely affected all the yield components; however, irrigation water productivity was improved. Gharib & EL-Henawy (2011) based on their two years study carried out in Egypt observed that sugar beet yield and water productivity were significantly decreased when irrigations were applied at 70% reduction in available soil moisture content when compared with the irrigation application at 55% reduction in available soil moisture content. Kiziloglu *et al*., (2006) observed significant decrease in all components of sugar beet yield when the crop was subjected to deficit irrigation under semi-arid environment. Perry, (2014); Malik *et al*., (2014) observed that despite being increase in water productivity, considerable loss of sugar beet yield occurred when deficit irrigation was applied.

In the light of above research studies, one can conclude that deficit irrigation can increase water productivity, however using this strategy alone leads towards a considerable yield loss. Therefore, to optimize sugar beet yield with the least possible amount of irrigation application under semi-arid environment, applying deficit irrigation along with mulching can be a useful field scale water management strategy. The effectiveness of this strategy in terms of increased yield and WUE has been reported by several investigators in different regions of the world (Dimple *et al*., 2018; Yaseen *et al*., 2014; Igbadun *et al*., (2012; Ramalan *et al*., 2010). However, so far, to the best of our knowledge, no research has been conducted to study the impact of this strategy on sugar beet yield components and irrigation water productivity. Keeping in view the current water scarcity problems in arid and semi-arid areas, the present study was carried out to investigate the combine effect of these two factors (deficit irrigation and mulching) on sugar beet yield components and water productivity under field conditions.

Materials and Methods

Experimental Site: The research was conducted at Sugar Crops Research Institute (SCRI) Mardan, using furrow irrigation system. Experiments were conducted on deeply developed fine textured soil classified as loess and reworked loess with isotropic soil structure having almost flat topography with an average slope of 0.2 percent. The general climate of the study area is hot subtropical continental type with erratic and low rainfall that is characterized by excessive seasonal fluctuations. Generally, summer season in the area is very hot with steep rise in temperature during May and reaches to maximum in the month of June. The temperature in the months of July, August and September is also quite high. However, a rapid fall in temperature is observed from October onwards. January is the coldest month of the year. The relative humidity is quite high due to intensive cultivation and irrigation activities in the area. The growing season climatic data and the effective rainfall are presented in (Fig. 1.) Total precipitation recorded during the cropping period of the study years 2011–12 and 2012–13 were observed as 292 mm and 375 mm respectively. The effective precipitation, P_e was estimated using an empirical model 'Dependable Rain' developed by FAO/AGLW based on analysis for different arid and sub-humid climates that is reproduced as:

$$P_e = 0.6 * P - 10 \quad \text{for } P \leq 70 \text{ mm} \qquad (1)$$

$$P_e = 0.8 * P - 24 \quad \text{for } P \geq 70 \text{ mm} \qquad (2)$$

where P is the measered prepcipitation.

Experimental Layout of Treatments and Agronomic Practices: Factorial combination of four irrigation regimes i.e. No-deficit or full irrigation (FI), 20% deficit irrigation (DI_{20}), 40% deficit irrigation (DI_{40}) and 60% deficit irrigation (DI_{60}), and three forms of mulching practices i.e. No mulch (NM), black polyethylene film mulch (BFM) and straw mulch (SM) were assessed in randomized complete block design with three replications. In BFM plots, beds and ridges were first covered with black polyethylene film and accordingly sugar beet seeds were manually sown at about 2 cm depth in already prepared holes. In plots with straw mulch, the chopped maize straw along with sugarcane trashes at 6 tons ha^{-1} rate was applied just after the completion of germination process. A distance of 18 cm was maintained between plants and 45 cm between rows. The amount of water needed for each full irrigation (FI) treatments was determined by the model as described by Michael (1978). Irrigation water was first diverted from canal into field water course and then for the purpose to achieve precise application, the measured amount of water were pumped into the respective experimental units using the centrifugal pump. The model of Jensen (1980) was used to calculate the pump operational time of each unit and the amount of seasonal water used was determined by the equation as mentioned by Heerman, (1985). Experimental details are presented in Table 1.

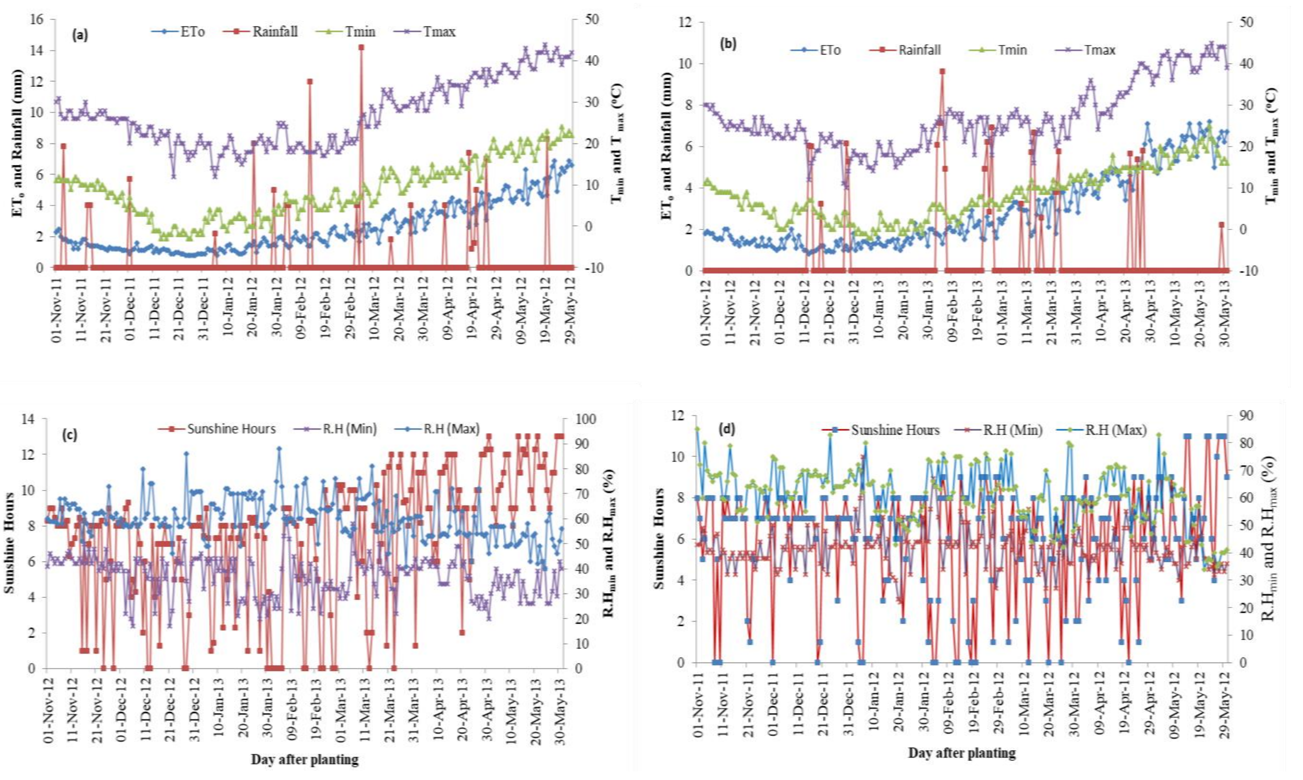

Fig. 1. Daily evapotranspiration (ET_o), rainfall, air temperature (T_{max} & T_{min}), sunshin hours, relative humidity ($R.H_{min}$ & $R.H_{max}$) during 2011-12 (a & c) and 2012-13 (b & d) of sugar beet cultivation in Mardan, Pakistan.

Table 1. Details of treatments.

Treatments	Description
FI-NM	Full irrigation-no mulch
FI-BFM	Full irrigation-black polyethylene film mulch
FI-SM	Full irrigation-straw mulch
DI_{20}-NM	20% deficit irrigation-no mulch
DI_{20}-BFM	20% deficit irrigation-black polyethylene film mulch
DI_{20}-SM	20% deficit irrigation-straw mulch
DI_{40}-NM	40% deficit irrigation-no mulch
DI_{40}-BFM	40% deficit irrigation-black polyethylene film mulch
DI_{40}-SM	40% deficit irrigation-straw mulch
DI_{60}-NM	60% deficit irrigation-no mulch
DI_{60}-BFM	60% deficit irrigation-black polyethylene film mulch
DI_{60}-SM	60% deficit irrigation-straw mulch

Table 2. Interaction effects of irrigation regimes and mulch types on amount of irrigation water applied.

Treatments	Irrigation water applied (mm)	
	2011-12	2012-13
FI – NM	736.77a[1]	675.33a
FI – BFM	617.95c	563.675c
FI – SM	674.06b	655.70b
DI_{20} – NM	589.41d	540.27d
DI_{20} – BFM	494.41f	450.93f
DI_{20} – SM	539.25e	524.56e
DI_{40} – NM	442.06g	405.20g
DI_{40} – BFM	370.81i	338.20i
DI_{40} – SM	404.44h	393.42h
DI_{60} – NM	294.71j	270.13j
DI_{60} – BFM	247.20l	225.47l
DI_{60} - SM	269.63k	262.28k

[1]Mean followed by the same letter(s) are statistically non-significant at 5% probability

At maturity, all the experimental units were harvested manually during the last week of May in both the crop growing seasons. Light irrigation was given to all plots two days prior to harvesting for the purpose to facilitate up-rooting. First the root tops were separated and then tubers were eradicated using iron hooks. Both the tubers and the tops were weighted independently, recorded in kg $plot^{-1}$ and converted into unit of tons ha^{-1}, accordingly. Percent sugar content for each individual plot was determined using the analytical laboratory of sugar crop research institute, Mardan. The percent sugar content was then converted to sugar yield (tons ha^{-1}) using the formula as mentioned by Malik *et al*., (2017). Statistical analysis was performed using analysis of variance (ANOVA) technique suing software statistics 8.1.

Results and Discussions

Impact of irrigation regimes and mulching on irrigation depth: Different combinations of irrigation regimes and mulching practices produced significant effect (at $p<0.05$) on the amounts of total irrigation water applied that varied between 269.63 and 736.77 mm in 2011-12, and from 262.28 to 675.33 in 2012-13. (Table 2). As regards the yearly variation of total amounts of irrigation water applied to all treatments, the highest amount was observed in 2011-12 and the least during 2012-13. The main reason for this may be attributed towards climatic variability between both seasons. By taking the average of two years data and comparing the results of different combinations of irrigation regimes and mulching practices with FI-NM treatments, it was observed that the amounts of saved irrigation water ranged between 16.32 and 66.53% for all BFM treatments, and from 5.83 to 62.33% for SM treatments (Fig. 2). The effectiveness of irrigation regimes and mulches interaction in terms of irrigation water saving was also reported by Hess (1997) for sugar beet, Chaudhry et al., (2004) for Eucalyptus, and Ramalan and Nwokeocha (2000) for tomato.

Impact of irrigation regimes and mulching on seasonal water use: Table 3 presents the combined effect of irrigation regimes and mulching on the amounts of seasonal water used (SWU) that varied between 412 and 896 mm in 2011–12, and from 441 to 871 mm in 2012–13. From the analysis of variance test, no significant (p<0.05) difference was found between the means of two seasons; however the amount used by different treatment were significantly different from each other with the lowest values (412.15, 440.66 mm) observed for DI_{60} and BFM combinations and the highest 895.82, 870.66 mm) for FI and NM (Table 3). The highest amounts of SWU by FI and NM combinations in the study might be attributed towards excessive water application and thus abundance availability of soil moisture along with high evaporation that might have taken place from the un-mulched soil surface and soil root zone, especially during the intial growing stages of crops. These results are in line with that reported by Obalum *et al.,* (2011) for soybean. Averaging the effects of two years data, a decrease of 2 to 47% in the amounts of SWU was observed for different combinations of irrigation regimes and mulching practices when compared with the results of FI–NM treatment (Fig. 3).

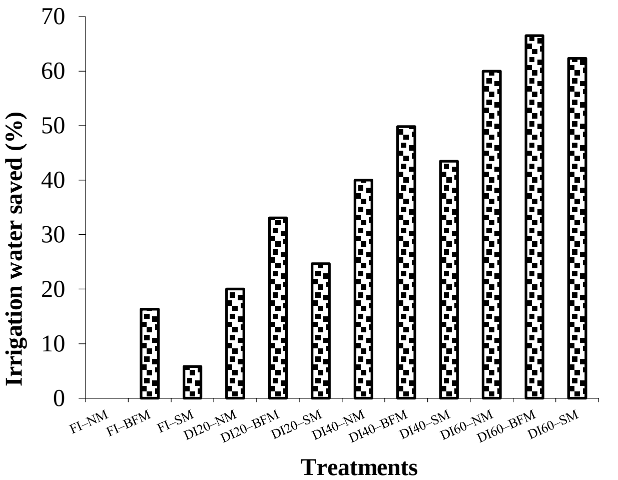

Fig. 2. Relative irrigation water saved by the interaction effects of irrigation regimes and mulching practices.

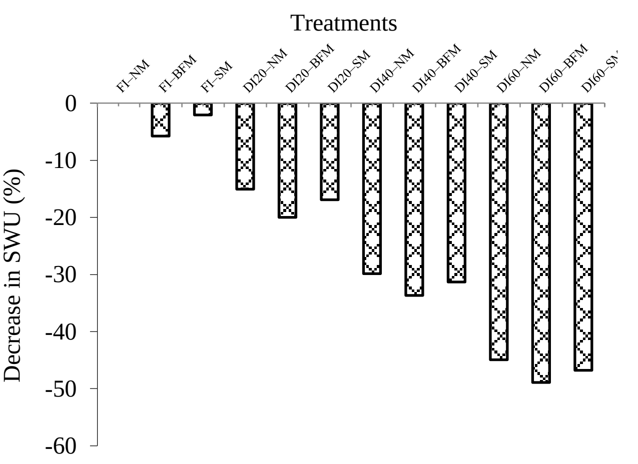

Fig. 3. Relative decrease in seasonal water use (SWU) of sugar beet under different treatments.

Table 3. Interaction effects of irrigation regimes and mulching on amount of seasonal water used.

Treatments	Seasonal water used (mm)		
	2011/2012	2012/2013	Average of years
FI – NM	895.82a[1]	870.66a	849.18a
FI – BFM	764.69c	753.79c	800.40c
FI – SM	828.56b	849.24b	831.81b
DI_{20} – NM	751.20d	742.59d	721.36d
DI_{20} – BFM	648.65f	649.17f	679.32f
DI_{20} – SM	697.25e	723.20e	705.36e
DI_{40} – NM	613.51g	621.39g	595.40g
DI_{40} – BFM	533.43i	544.42i	563.31i
DI_{40} – SM	571.71h	599.26h	583.16h
DI_{60} – NM	471.04j	492.99j	467.44j
DI_{60} – BFM	412.15l	440.66l	433.91k
DI_{60} - SM	442.87k	479.07k	451.90k

[1]Mean followed by the same letter(s) are statistically non-significant at 5% probability

Impact of irrigation regimes and mulching on yield components: Table 4 presents that the interaction of different levels of irrigation and soil mulching caused significant effect (at p<0.05) on root yield, sugar content and sugar yield of sugar beet. The highest root yield in both study years with 69.92 and 69.20 tons ha^{-1} was produced by the treatment in which the crop was raised under BFM and received FI. This was followed by FI and SM combination with 68.71 and 67.37 tons ha^{-1} and FI and NM with 66.89 and 62.43 tons ha^{-1}, respectively. The significantly lowest yield with values 37.64, 33.24 tons ha^{-1} was recorded for DI_{60}–NM. The results of this study in terms of highest yield due to the combined application of FI and mulching are also supported by Alenazi *et al.,* (2015) for muskmelon. It was also observed from the results that, for same level of irrigation, the mean root yield produced by mulched treatments was significantly higher than that produced by No-mulch treatments, and all the Black Film Mulch treatments produced more yield than the straw mulched treatments (Table 4). It was further concluded from the obtained results that root yield produced by BFM treatments with the application 20 to 60% deficit irrigation (DI) was significantly higher than that produced by NM plots with FI to 40% DI. By comparing the results of SM with NM, it was observed that the root yield under the SM with 20 and 60% DI was almost same than that produced by the NM with FI and 40% DI (Table 4). By further analyzing the data (two years average), it was noted that, for the same mulching conditions, decreasing the irrigation application depth from FI to DI_{60} the mean root yield was decreased from 4.54 to 27.59 % by BFM, 5.04 to 33.24%

by SM and 12.0 to 48.27% by NM, respectively (Fig. 4a). Irrigation regimes and mulching combination also caused pronounced effect on sugar content of sugar beet, however on contrary to the root yield; sugar content was improved when water stress was increased from FI to DI_{60} (Table 4). The uppermost sugar contents (17.59, 17.40%) in both study years were observed for DI_{60}–BFM treatments, followed by DI_{60}–SM and DI_{60}–NM with 17.42, 17.18% and 16.84, 16.50%, respectively. The minimum values (14.63, 14.40%) were observed for FI and NM combination (FI–NM) as depicted in Table 4. When the data of No-mulch plots was compared with mulched treatments, it was found that the amount of sugar content in later under the same level of irrigation regime was significantly higher than that under former. Comparing the results of BFM with SM for FI, it was found that both produced statistically similar results, however; when the results of DI regimes were compared; it was found that the former produced significantly higher than the later. On the basis of 2011–12 and 2012–13 average data, an improvement of about 2.50, 4.60 and 4.30% in sugar content for each of NM, BFM and SM was observed when the irrigation amount was decreased from FI to DI_{20}. The corresponding increase was 8.40, 9.20 and 9.19 % for DI_{40} and 12.90, 14.80 and 14.22% for DI_{60}, respectively (Fig. 4b).

Table 4 further revealed that irrigation and mulching interaction significantly affected the amounts of sugar yield. For un-mulched treatments, the highest sugar yield (9.67, 9.0 tons ha^{-1}) in both study years was observed for FI–NM, followed by DI_{20}–NM with 9.07, 8.29 tons ha^{-1}, and DI_{40}–NM with 7.91, 7.21 tons ha^{-1}, correspondingly. The smallest amount (6.35, 5.50 tons ha^{-1}) was observed for DI_{60}–NM. Under mulching situation, both the DI_{20}–BFM and DI_{20}–SM treatments produced the highest sugar yield that amounting 10.84, 10.43 tons ha^{-1} in 2011-12 and 10.26, 9.93 tons ha^{-1} in 2012-13, respectively. This was followed by FI–BFM and FI–SM; DI_{40}–BFM and DI_{40}–SM; and DI_{60}–BFM and DI_{60}–SM, respectively (Table 4).Within the same levels of irrigation, the uppermost sugar yield was produced by BFM and SM treatments. Taking the average of two years data, it was examined that sugar yield produced by BFM and SM treatments under 20, 40 and 60% deficit irrigation (DI) was higher than that produced by full irrigation (FI), 20 % DI and 40% DI, respectively. Moreover by decreasing the irrigation level in the absence of any mulch from 20% deficit level to 60% deficit, the corresponding decrease in sugar yield relative to FI was about 7.50 to 57.60%. On the other hand, the BFM in combinations to different irrigation regimes improved the sugar yield that ranged from 7.44 % for DI_{40} to 10.12% for FI (in comparison to FI–NM treatment) (Fig. 4c). By comparing the results of control i.e. FI–NM treatment with SM, it was found that the later produced about 7.60 to 8.20% higher than the former (Fig. 4c).

Table 4. Interaction effects of irrigation regimes and mulching on yield components of Sugar beet.

Treatments	Root yield (tons ha^{-1})			Sugar content (%)			Sugar yield (tons ha^{-1})		
	2011-12	2012-13	Average of years	2011-12	2012-13	Average of years	2011-12	2012-13	Average of years
FI - NM	66.89c	62.43c	64.26d	14.63j	14.40i	14.52j	9.67d	9.0c	9.33c
FI - BFM	69.92a	69.20a	69.56a	15.01i	14.82h	14.91i	10.50b	10.26a	10.38a
FI - SM	68.71ab	67.37a	68.04b	14.94i	14.74h	14.84i	10.27c	9.90b	10.09b
DI_{20} - NM	58.86e	54.74e	56.80f	15.41h	15.14g	15.27h	9.07e	8.29d	8.68e
DI_{20} - BFM	67.75b	65.05b	66.40c	16.00f	15.77e	15.89f	10.84a	10.26a	10.55a
DI_{20} - SM	65.87c	63.35bc	64.61d	15.81g	15.61f	15.71g	10.43bc	9.93b	10.16b
DI_{40} - NM	48.22h	44.65h	46.44i	16.39e	16.11d	16.25e	7.91g	7.21e	7.56g
DI_{40} - BFM	61.48d	59.21d	60.35e	16.79c	16.60c	16.69c	10.33bc	9.83b	10.18b
DI_{40} - SM	57.10f	52.17f	54.63g	16.65d	16.45c	16.55d	9.51d	8.58d	9.05d
DI_{60} - NM	37.64i	33.24i	35.44j	16.84c	16.50c	16.67c	6.35h	5.50f	5.92h
DI_{60} - BFM	52g	48.74g	50.37h	17.59a	17.40a	16.50a	9.15e	8.47d	8.81e
DI_{60} - SM	47.77h	43.08h	45.42i	17.42b	17.18b	17.30b	8.32f	7.39e	7.86f

[1]Mean followed by the same letter(s) are statistically non-significant at 1% probability

Impact of irrigation regimes and mulching on irrigation water productivity: Table 5 presents the effects of irrigation regimes and mulching practices combinations on root irrigation water productivity (RIWP) and sugar irrigation water productivity (SIWP) for the cropping seasons of 2011-12 and 2012-13, respectively. Accordingly, the data revealed that both the productivities were significantly increased ($p<0.05$) with the decrease in irrigation levels from FI under the mulching order of NM, BF, and SM to DI_{60} under the mulching order of NM, BFM, and SM, respectively. The highest mean RIWP with about 21.10 and 21.70 kg m^{-3}, and uppermost mean SIWP with about 3.70, 3.80 kg m^{-3}, in both cropping seasons, were noted for DI_{60}–BFM plot, and the next highest for DI_{60}–SM with RIWP of about 17.80 and 16.50 kg m^{-3}, and SIWP with about 3.10, 2.80 kg m^{-3}, respectively. Both the RIWP (9.00 and 9.30 kg m^{-3}) and SIWP (1.30, 1.34 kg m^{-3}) were lowest for FI–NM treatment. By taking the average of two years, a statistical similarity was found between the data of treatments FI–BFM and DI_{20}–SM, FI–SM and DI20–NM, DI20–BFM and DI40–SM, and DI40–BFM and DI60–SM, respectively. Similarly, the SIWP of treatments FI–SM and DI40–NM, FI–SM and DI20–NM, and DI20–BFM and DI40–SM were also statistically same (Table 5). The percentage raise (on the basis of two years average data) in RIWP and SIWP due to the interactive effect of various irrigation levels and mulching practices over FI–NM treatment are presented in (Fig. 5.) It is evident from this Figure that the 60%

irrigation stress under all the three mulching conditions (i.e. BFM, SM and NM) improved the RIWP by about 130, 90 and 40% and SIWUE by about 180, 120 and 60%, when compared with FI–NM combination. The increased observed in RIWP for DI40–BFM, DI40–SM and DI40–NM interactions was 87, 50 and 20%, and in SIWP was 114, 71 and 35%, respectively. Same way, all the DI_{20} and mulching combinations resulted about 50, 30 and 10% enhancement in RIWP and about 70, 40 and 20% in SIWP, respectively, and the FI under BFM and SM improved the RIWUE by about 30 and 10%; and the SIWUE by about 30 and 20%, respectively, in comparison to the FI–NM (control) treatment. These results suggested that, enhancing the irrigation water application level under the mulching order of black film mulch, straw mulch and No-mulch, respectively, instigated a consequent reduction in mean RIWP and SIWP. These results are also supported by the investigations carried out by Igbadun *et al.*, (2012) for onion and Hussain (2015) for common bean.

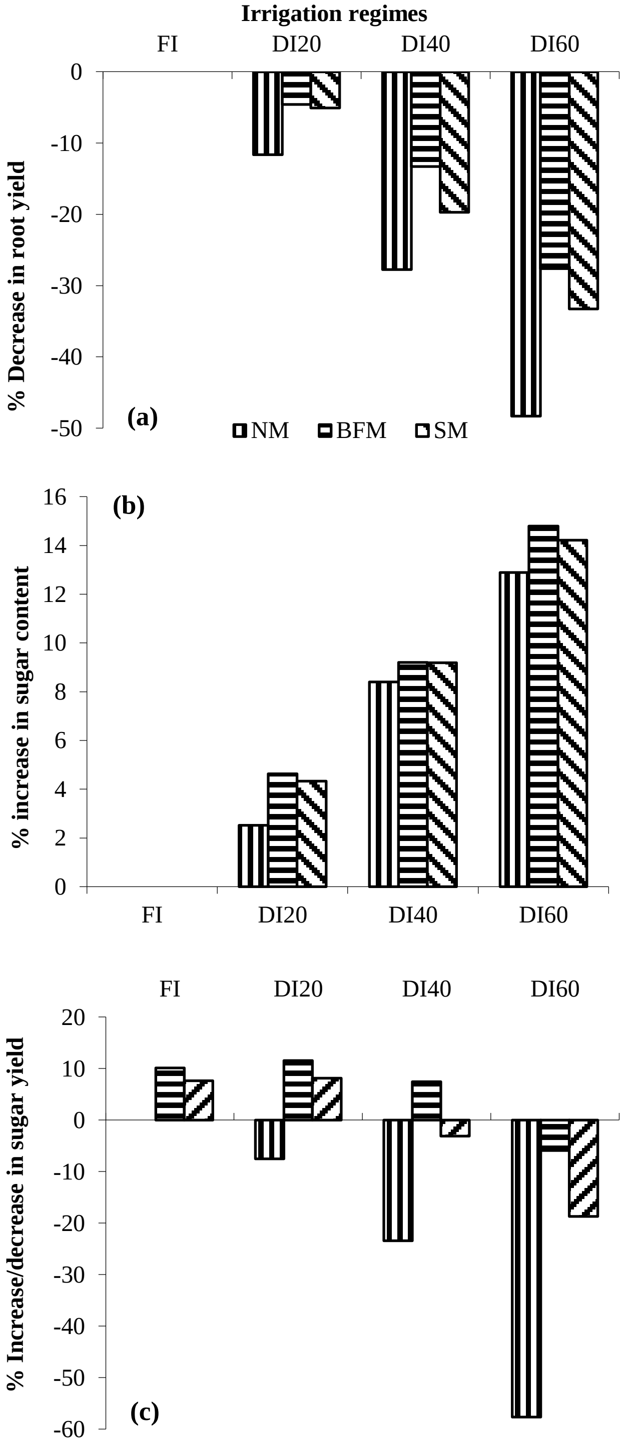

Fig. 4(a, b, c). Relative increase/decrease in (a) root yield (b) sugar content and (c) sugar yield of sugar beet caused by the interaction effect of different irrigation regimes and mulching practices.

Impact of irrigation regimes and mulching on crop water productivity: The root crop water productivity (RCWP) and sugar crop water productivity (SCWP) were significantly affected (at $p<0.05$) by irrigation regimes and mulching interaction (Table 6). Both the RCWP and SCWP under BFM conditions were significantly increased for each incremental decrease in irrigation level (i.e. from FI to DI_{60}) irrespective of the cropping season. Similar results were also obtained by Mukherjee *et al.*, (2010) for tomato and Xei *et al.*, (2005) for wheat. For SM, although the SCWP in both seasons and RCWP in 2011-12 were increased significantly with decreasing levels of irrigation, however RCWP results for DI_{20}, DI_{40} and DI_{60} in year 2012–13 were not significantly different from each other. For NM treatments, the increasing level of irrigation deficit produced no significant effect on RCWP; however, the SCWP was significantly increased. The results of the current study in terms of improved water productivity under BFM and SM in comparison to NM are also similar to that obtained by Hussain, (2015) for common been. Additionally, both the RCWP and SCWP reduced within the same level of irrigation application under mulching order of BFM, SM and BM, respectively. Earlier, Masanta and Malik, (2009) also reported similar results for wheat crop. In both the study years, highest mean RCWP with values of about 12.60, 11.0 kg m^{-3} and highest mean SCWP with values of about 2.20, 1.90 kg m^{-3} were noted for DI_{60} and BFM combination. The next highest RCWP values with 10.80, 9.0 kg m^{-3} and SCWP values with 1.90, 1.55 kg m^{-3}, respectively, were observed for DI_{60}–SM treatment. In both season, the lowest RCWP (7.40, 7.19 kg m^{-3}) and lowest SCWP were observed for FI–NM treatment (Table 6). The relative percent increase (on the basis of two year's average data) in RCWP and SCWP noted for various combinations of irrigation regimes and mulching is presented in (Fig. 6.) Accordingly, it was observed that all the three 60% DI and mulching combinations produced 62, 36 and 2% improved RIWP, and about 95, 61 and 16% improved SIWP, respectively compared to that produced by FI without mulch. The relative increase in RCWP due to the interaction of all DI_{40} and mulching combination was ranged from 3.30 to 53.80% and that due to DI_{20} and mulching was between 4.50 and 40.40%, respectively. The relative increased observe for SCWP was ranged between 16 and 77.40% for DI_{40} and between 10.40 and 53.80% for DI_{20}, respectively. Similarly, the FI and BFM interaction improved the RCWP by 25.80% and SCWP by 29.30%, and that caused by FI and SM combination was 11.40% for RCWP and 14.20% for SCWP, respectively, when compared with FI–NM treatment (Fig. 6).

Table 5. Interaction effect of irrigation regimes and mulching on irrigation water productivity.

Treatments	RIWP (kg m^{-3})			SIWP (kg m^{-3})		
	2011-12	2012-13	Average of years	2011-12	2012-13	Average of years
FI – NM	9.00i[1]	9.30i	9.15h	1.30j	1.34h	1.32i
FI – BFM	11.34g	12.30f	11.82e	1.70h	1.82ef	1.76g
FI – SM	10.22h	10.30h	10.26g	1.53i	1.52g	1.52h
DI_{20} – NM	10.03h	10.19h	10.11g	1.55i	1.55g	1.54h
DI_{20} – BFM	13.74d	14.46d	14.10c	2.20e	2.28c	2.24d
DI_{20} – SM	12.25f	12.12f	12.19e	1.94f	1.89e	1.91f
DI_{40} – NM	10.95g	11.07g	11.01f	1.80g	1.79f	1.79g
DI_{40} – BFM	16.64c	17.55b	17.09b	2.80c	2.91b	2.85c
DI_{40} – SM	14.17d	13.30e	13.73c	2.36d	2.19c	2.27d
DI_{60} – NM	12.85e	12.37f	12.61d	2.17e	2.05d	2.11e
DI_{60} – BFM	21.10a	21.70a	21.40a	3.70a	3.80a	3.75a
DI_{60} – SM	17.80b	16.50c	17.15b	3.10b	2.80b	2.95b

Table 6. Interaction effect of irrigation regimes and mulching on crop water productivity.

Treatments	RCWP (kg m^{-3})			SCWP (kg m^{-3})		
	2011-12	2012-13	Average of years	2011-12	2012-13	Average of years
FI – NM	7.40j[1]	7.19f	7.30j	1.08i	1.04g	1.06j
FI – BFM	9.16g	9.19c	9.18ef	1.37f	1.36e	1.37g
FI – SM	8.31h	7.94e	8.13g	1.24h	1.17f	1.21hi
DI_{20} – NM	7.86i	7.40f	7.63h	1.21h	1.12f	1.17i
DI_{20} – BFM	10.64d	10.04b	10.25c	1.68d	1.59c	1.63d
DI_{20} – SM	9.47f	8.78d	9.13f	1.50e	1.37e	1.43f
DI_{40} – NM	7.88i	7.20f	7.54hi	1.29g	1.16f	1.23h
DI_{40} – BFM	11.56b	10.89a	11.23b	1.94b	1.81b	1.88b
DI_{40} – SM	10.01e	8.72d	9.37e	1.67d	1.43d	1.55e
DI_{60} – NM	8.02i	6.76g	7.39ij	1.35f	1.12f	1.23h
DI_{60} – BFM	12.60a	11.00a	11.80a	2.20a	1.90a	2.05a
DI_{60} – SM	10.80c	9.00cd	9.90d	1.90c	1.55c	1.68c

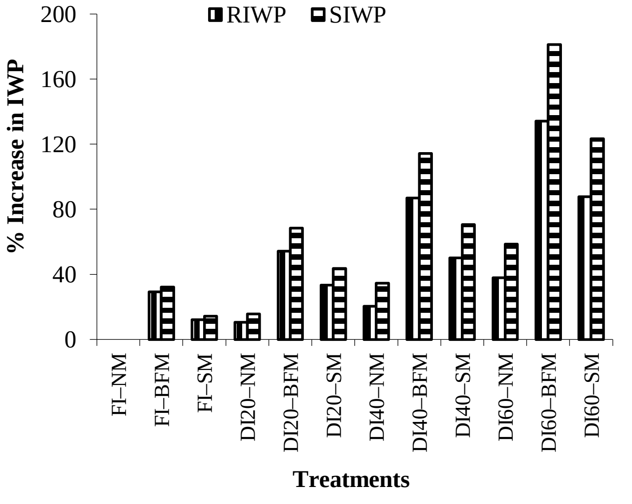

Fig. 5. Interaction effect of irrigation regimes and mulching on root and sugar irrigation water productivities (IWP).

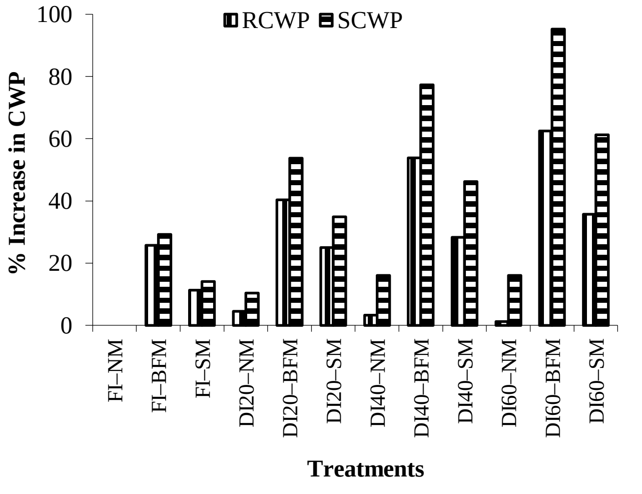

Fig. 6. Interaction effect of irrigation regimes and mulching on root and sugar crop water productivities (CWP).

Conclusion

Overall finding of this study is that deficit irrigation throughout the growing season of a crop along with suitable soil moisture conservation measures can save significant amount of irrigation water and improve water productivity. Based on two years average data, significantly highest mean root yield (69.56 tons ha^{-1}) was observed for FI–BFM treatment and significantly highest mean sugar yield of (10.55 tons ha^{-1}) was observed for DI_{20}–BFM, respectively. Both the RIWP and SIWP were increased with the increasing levels of deficit irrigation from DI_{20} to DI_{60} for all treatments. Under the same level of deficit irrigation regimes in combination with NM, BFM and SM, all the RIWP, SIWP, RCWP and SCWP were highest for BFM. On two years average basis, the highest RIWP (21.40 kg m^{-3}), SIWP (3.75 kg m^{-3}), RCWP (11.80 kg m^{-3}) and SCWP (2.05 kg m^{-3}) were recorded for DI_{60}–BFM treatment. These values were 134, 181, 62.47 and 95.28 % respectively, higher to that recorded for FI–NM treatment.

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