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YIELD RESPONSE AND WATER USE EFFICIENCY OF SUGAR BEET IN SEMI-ARID ENVIRONMENT UNDER DIFFERENT DEFICIT IRRIGATION REGIMES

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ABSTRACT

A field study was conducted to find the effect of deficit irrigation regimes on yield and water use efficiency of sugar beet under furrow irrigation system during the cropping season of 2011-2012 and 2012-2013 at Sugar Crops Research Institute Mardan, Khyber Pakhtun Khawa, Pakistan. Randomized Complete Block Design was used to conduct the experiment and three replications were applied. Four levels of irrigations, designated as full irrigation, 20% deficit irrigation, 40% deficit irrigation and 60% deficit irrigation were tested. Results showed that for all deficit irrigation treatments the root yield was low but the sugar content and water use efficiency were improved. Average root yield for full irrigation was found as 59.75 tonnes ha^{-1} where for 60 % deficit irrigation root yield was 32.02 tonees ha^{-1}. Average sugar content for full irrigation was 14.14%, and for 60 % deficit irrigation sugar content was 16%. Where, the root water use efficiency was in the range of 8.13 for full irrigation to 10.87 kg m^{-3} for 60% deficit irrigation. The sugar water use efficiency was in the range of 1.15 for full irrigation to 1.74 kg m^{-3} for 60% deficit irrigation. Yield response factor was in the range of 0.91 to 1.08. The relationship obtained between root yield and evapotranspiration was linear. It can be concluded from the study that, for better sugar beet yield, full irrigation treatment should be used for semi arid conditions with no water shortage. However, in water limited situation, sugar beet may be irrigated at 80% of full irrigation. This might decrease the sugar beet root and sugar yields by 13.7% and 9.10%, however it may save 20% irrigation water that can be used to bring more area under irrigation.

INTRODUCTION

Irrigated agriculture is the largest consumer of fresh water, contributing towards the world food security[1]. However, due to population blast and rising living standards, irrigated agriculture is facing competitive challenges[2]. Due to this increasing competition for fresh water among various sectors, irrigated agriculture being the largest user of fresh water is the first affected sector[3]. Therefore in near future, global demand for fresh water will only be full filled by its efficient use[4]. For effective, efficient and sustainable utilization of the available scarce water resources, new irrigation strategies like deficit irrigation (DI) must be established. DI is the practice of irrigation scheduling in which crop is exposed to a certain level of water stress by irrigating deliberately below their water demands. This practice is not only productive but also efficient and sustainable for dry regions[5]. It also improve the irrigation water use efficiency[6] and minimize the nutrient loss through leaching [7, 8]. It is a mean of reducing crop consumptive use while minimizing adverse effects on yield[9]. DI is an optimization strategy in which water less than full irrigation requirement of crop is provided. It is assumed that any loss of yield as a result of deficit irrigation will be compensated by bringing more area under irrigation with the water saved by deficit irrigation and hence results in increased production[10, 11].

Sugar is an essential ingredient in our daily diet. A balanced diet should contain about 50% carbohydrates for which sugar is a key source[12]. In the developed and industrial countries, sugar beet is the main source of sugar production, while in the developing countries the main source of sugar is sugar cane. However, sugar cane takes long time to be matured occupying land for about 12 to 14 months and consumes 153 to 204 cm of water. On the other hand sugar beet is 6 to 7 months crop consuming 39 to 77 cm of water[13]. Sugar beet also has the capability to withstand mid and late-season plant water stress. These qualities of sugar beet make it an appropriate choice for crop production under deficit irrigation[14]. In Pakistan, sugar beet is an important industrial crop after sugar cane, sown in October to November and harvested in late May. The North-West part of the country offers one of the best land for sugar beet in the whole sub-continent[15]. So far sugar beet has not been investigated under different levels of deficit

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irrigation in Pakistan. However, literature suggests that the sugar beet is very responsive to water. For example Aursaj and Miller[16] concluded that under the water scarcity conditions, sugar beet is able to keep growing satisfactorily. Similarly Winter[17] argued that under deficit irrigation, despite the reduction in sugar beet yield, more benefit can be earned by water saving in comparison with other crops. Kenn and Gencoglan[18] reported that there is linear relationship between sugar beet root yield and applied water. Topak et. al.[19] reported high water use efficiency under deficit irrigation. Keeping in view the water scarcity problems in Pakistan and the benefits of deficit irrigation that have been explored in different parts of the world for different crops, a research study was carried out to investigate yield response and water use efficiency of sugar beet in semi-arid environment under different deficit irrigation regimes. The purpose was to optimize sugar beet yield with the least possible amount of irrigation water.

MATERIALS AND METHODS

A field study was conducted to investigate the response of sugar beet (Beta vulgaris L.) to different irrigation application depths, regarding yield and water use efficiency, during growing seasons of 2011-12 and 2012-13 at Sugar Crops Research Institute Mardan, Pakistan. The study area located at about 34° north latitude and 72° east longitude, and at an altitude of 305 m above mean sea level. This region is known for semi-arid subtropical continental type of climate with scanty and uncertain rainfall having mean annual precipitation of 435 mm. According to the long-term data, the annual average relative humidity is 64.06% and the annual average maximum and minimum temperatures are 28.6 °C and 16.5 °C, respectively. August and March are the wettest months while the June and October are the driest. The hottest month is June and the coldest one is January. The mean annual evaporation (E_p) is 1504 mm.

Table 1 presents some of general physical properties of the experimental field. Soil textural class was found by hydrometer method using USDA soil texture classification[20]. Clay was the dominant texture class for the entire experimental plots. Soil moisture content in the upper 0-90 cm layer, with 30 cm increment was measured gravimetrically (105°C, 24 hr) before and after each irrigation. Soil water content at field capacity (FC) and at permanent wilting point (PWP) were determined using pressure plate apparatus method. The soil bulk density was determined by the method of USSL[21]. Sugar beet variety Kaweterma was sown on November 15, 2011 and November 20, 2012, with seed rate of 4.4 kg-hectare^{-1}. Seeding was done manually. Three seeds per hill were placed 18 cm apart from each other. Row to row distance was kept 45 cm. Based on soil tests, fertilizers Di-ammonium phosphate (DAP) and Urea were added to the soil at a rate of 220 and 110 kg hectare^{-1} respectively before sowing seeds. While second doze of Urea, at the rate of 110 kg hectare^{-1}, was applied in February. All other recommended agronomic practices were followed uniformly for all the treatments. At 2 to 4 leaf stage, one plant per hill was maintained. Randomized Complete Block Design (RCBD) was used to conduct the experiment and replicated three times. Four level of irrigations designated as full irrigation (FI_{100}) i.e. irrigation with no water deficit, 20% deficit irrigation (DI_{20}), 40% deficit irrigation (DI_{40}) and 60% deficit irrigation (DI_{60}) were tested during the experimental years 2011-12 and 2012-13. The full irrigation (FI_{100}) was the control treatment to which enough water was applied to bring the soil profile to field capacity. The deficit irrigation treatments i.e. (DI_{20}), (DI_{40}) and (DI_{60}) received irrigation water at the rate of 80, 60 and 40% of that applied by full irrigation treatment (FI_{100}). Amount of water applied to full irrigation treatment was calculated using equation 1[22].

Table 1: Physical characteristics of the soil of study area.

Soil depth (cm)	Clay (%)	Sand (%)	Silt (%)	Texture	Bulk density (g cm^{-3})	Field capacity (%)	Wilting point (%)
0-30	66	26	8	Clay	1.24	34	22
30-60	62.2	28.6	9.2	Clay	1.24	34.5	23
60-90	59.6	31.2	9.2	Clay	1.22	34.3	23.2

$$d = \sum_{n=1}^{i} \left(M_{fc} - M_{bi}\right) A_i \, D_i \qquad (1)$$

Where,

D = Depth of water needed to provide the soil water deficit and to bring the soil to field capacity level within the root zone (mm)

Mfci = Soil water content (%) in the ith layer of the soil at field capacity

Mbi = Soil water content (%) in the ith layer of the soil before irrigation

Ai = Bulk density of soil (g cm^{-3}) in the i^{th} layer

Di = Depth of the i^{th} layer in the root zone, mm.

Time for the application of measured quantity of water was calculated using equation 2[23].

$$T = Ad/Q \qquad (2)$$

Where,

T = Time required to irrigate the respective plot, sec

A = Respective plot area, m^2

d = Irrigation application depth, mm

Q = Flow rate, m^3/sec

Crop evapotranspiration was calculated using equation 3[24].

$$ET = I + R - D \pm \Delta W \qquad (3)$$

Where,

ET = Evapotranspiration (mm)

I = Depth of irrigation water applied (mm)

R = Amount of rainfall (mm)

D = Depth of deep percolation (mm)

ΔW = Change of soil water storage in the measured soil depth.

For the purpose to investigate the effect of water stress on crop yield, Stewart et al.[25] model (eq. 4) was used.

$$1 - \left(Y_a / Y_m\right) = k_y\left(1 - \left(ET_a / ET_m\right)\right) \qquad (4)$$

Where,

Y_a = Actual harvested yield (tonnes ha^{-1})

Y_m = Maximum harvested yield (tonnes ha^{-1})

ET_a = Actual evapotranspiration (mm)

ET_m = Maximum evapotranspiration (mm)

k_y = Yield response factor

$1-(Y_a / Y_m)$ = Relative yield decrease

$1-(ET_a/ET_m)$ = Relative evapotranspiration deficit.

Relationship between water used and yield was determined using regression analysis. For conducting yield components analysis, a representative 3 rows of 2*10 m^2 sample area from each plot was hand harvested in the last week of May. Sugar beet root yield was recorded in kg-$plot^{-1}$. Sucrose percentage was determined in the laboratory of sugar crop research institute. Irrigation water use efficiency (IWUE) for root and sugar yield was calculated using equation 5[26]:

$$IWUE = \frac{Y}{W} \qquad (5)$$

Where,

IWUE = Irrigation water use efficiency (kg m^{-3})

Y = Root or sugar yield (kg ha^{-1}),

W = Irrigation water (mm) applied

Analysis of variance (ANOVA) was conducted to evaluate the effects of the treatments on sugar beet root yield (tonnes ha^{-1}) and sugar yield (tonnes ha^{-1}), while Statistics 8.1 software was used for testing the statistical significance of the results at 5%.

RESULTS AND DISCUSSION

Root yield and sugar percentage

The root yield and sugar content obtained under different irrigation regimes are shown in Table 2. The table shows that, in the year 2011-12, root yield was 62.50, 54.42, 45.14 and 34.58 tonnes ha^{-1} for the four irrigation treatments (FI_{100}, DI_{20}, DI_{40} and DI_{60}) respectively. In year 2012-13, the harvested root yield was observed as 57.00, 48.67, 39.68 and 29.46 tonnes ha^{-1} for the irrigation treatments FI_{100}, DI_{20}, DI_{40} and DI_{60} respectively. Taking average of both years yield data, it was observed that the root yields obtained in DI significantly decreased as compared to FI_{100}. The reduction observed was 13.7%, 29% and 46.34% for DI_{20}, DI_{40} and DI_{60} respectively. The low yield obtained with the application of deficit irrigation regimes could be due to crop water stress as all

Table 2: Different irrigation strategies Vs. Yield and irrigation

Years	Treatments	Irrigation water applied (mm)	Effective rain fall (mm)	ΔW (mm)	Seasonal water used (mm)	Root yield (tonnes ha-[1])	Sugar content (%)
2011-12	FI_{100}	770	105	54.8	929.8	62.50[a]	14.24[a]
	DI_{20}	616		58.2	779.2	54.42[b]	14.87[b]
	DI_{40}	462		69.11	636.11	45.14[c]	15.51[c]
	DI_{60}	308		73.6	486.6	34.58[d]	16.18[d]
2012-13	FI_{100}	700	155	42.5	897.5	57.00[a]	14.04[a]
	DI_{20}	560		49.2	764.2	48.67[b]	14.61[bc]
	DI_{40}	420		61.8	636.8	39.68[c]	15.21[cd]
	DI_{60}	280		70.40	505.4	29.46[d]	15.80[d]

[1] Means followed by the same letter are not significantly different according to LSD (0.05)

other management factors were similar for all treatments.

Maximum sugar beet root yield results of this study were much lower than the 77.3, 78.5 tonnes ha^{-1}, 120.73 and 108.90 tonnes ha^{-1}, reported by Topak et. al.[19], Mahmoodi et. al.[30] and Ghamarina et al.[31].

Table 2 also presents percent sugar content data in relation to different irrigation regimes. It is evident from data presented in Table 2 that the sugar content increased as the water deficit was increased. Sugar content was the lowest (14.24 and 14.04%) for full irrigation treatment and highest (16.18 and 15.80%) for 60% deficit irrigation treatment for the study years 2011-12 and 2012-13 respectively. A significance level of less than 5% ($P<0.05$) was obtained for the effects of different level of deficit on sugar content. Taking the average of two years experimental data, applying 20%, 40% and 60% deficit irrigation caused 4.20, 8.60 and 13.10% higher sugar content respectively than that obtained in full irrigation treatment. The results revealed that the sugar content in sugar beet increased in response to deficit irrigation treatments. Similar results were also obtained by other researchers in other parts of the world. Noorjo and Baghaekia[32] reported 13.3% increase by applying 16.50% deficit irrigation. Kenan and Cafer [33] reported 5.62, 11.7, 13.22, 16.11 and 17.5% high sugar content for 6, 15, 30, 45 and 60% deficit irrigation respectively. Mahmoodi et al.[30] observed 16.92, 17.45, 17.23 and 15.5% sugar content by irrigating the field at 30, 50, 70 and 90% respectively. Ghamarnia et al.[34], based on their experiment conducted in 2006 in western Iran reported 4.45, 17.32 and 37.63% higher sugar content by applying 25, 50 and 75% deficit irrigation. Therefore it is necessary to optimize irrigation application along with suitable agricultural measure for obtaining high sugar concentration in the sugar beet production[18].

Irrigation water applied and seasonal water used

Table 2 summarizes the effect of different irrigation regimes on water depth applied and seasonal water used for the experimental years 2011-12 and 2012-13. In both study years, the highest (770, 700 mm) amount of irrigation water were applied in full irrigation (FI_{100}) treatments and the lowest (308, 280 mm) levels were applied in 60% deficit irrigation (DI_{60}) treatments. Kenan and Cafer[33] applied 1232 and 1331 mm water in full irrigation treatment and 298 and 449 mm in deficit irrigation in years 1999 and 2000 respectively. Weeden[35] reported that, in areas like USA, Egypt and Pakistan, about 500 to 1000 mm irrigation water was applied for sugar beet. Ehlig and Lemert[36] concluded that total seasonal water used for sugar beet varied from 900 mm in the driest plot to 1195 mm in the wettest plot. Topak et al.[19] in their research study during 2005 and 2006 seasons in middle Anatolian, Turkey, applied 244.2 mm in 75% deficit irrigation treatment and 977 mm in full irrigation. The depth of irrigation water used in the current study is different than the depth reported in the literature cited.

The difference may be due to the difference in climatic conditions and mode of irrigation application.

The amount of seasonal water used varies from 486.6 to 929.9 mm in 2011-12 season and from 505.5 to 897.5 mm in 2012-13 season. The highest seasonal water used (929.9 mm in 2011-12 and 897.5 mm in 2012-13) occurred in the full irrigation treatment (FI_{100}) and the lowest (486.6 mm in 2011-12 and 505.5 mm in 2012-13) was seen in the 60% deficit irrigation treatment (DI_{60}). High evapotranspiration occurred in the FI_{100} treatment due to the adequate supply of irrigation water. In previous studies, evapotranspiration requirements of 700 to 1200 mm have been observed in sugar beet crop depending on the location and mode of irrigation. Seasonal water requirement for sugar beet in Peshawar valley has been reported as 874.3 mm by Tariq and Arshad[37]. Dunham[38] reported 900 mm water requirement for sugar beet on seasonal basis. Yildirim[39] reported 824 and 953 mm for furrow irrigation, while for drip irrigation method it was 865 mm. Faberio et al.[40] observed 690 to 897 mm variation in seasonal water requirement for sugar beet in Spain. Barbanti et al.[41] from their research study reported that seasonal water used for sugar beet ranging from 1262 (for full irrigation regime) to 567 mm (for deficit irrigation regime). Ogretir and Gungor[42] reported that, depending on irrigation regimes, seasonal evapotranspiration for sugar beet varied from 716 and 311 mm in Bursa conditions. Katerji and Mastrorilli [43] observed 731 and 836 mm seasonal water used for sugar beet in Mediterranean conditions.

Water use efficiency (WUE)

Table 3 shows the root and sugar irrigation water use efficiencies for the experimental years 2011-12 and 2012-13. The average root irrigation water use efficiency (RIWUE) in our study ranged from 8.13 to 10.87 kg m^{-3} and the average sugar irrigation water use efficiency (SIWUE) ranged from 1.15 to 1.74 kg/m^{-3}. Both the root and sugar irrigation water use efficiencies were highest for deficit irrigation treatment and the lowest for full irrigation treatment. Similar results were also obtained by Topak et al.[19], who reported that the maximum WUE occurs at less than the maximum evapotranspiration. Root water use efficiencies obtained in this study are less than that reported by Sakellarious-Makrantonaki et al[44] (13.58-14.75 kg m^{-3}), Fabeiro et al.[40] (13.3-17.5 kg m^{-3}) and Rinaldi and Vonella[45] (16.72 to 21.11 kg m^{-3}). However, the values are higher than that reported by Kiziloglu et al.[46] (6.96-9.18 kg m^{-3}) and Suheri[47] (6.62-8.40 kg m^{-3}). Similarly, the sugar water use efficiency obtained in our studies are also higher than that reported by Panahei et al.[48] (0.49 kg m^{-3}), Shahabifar and Rahimian(0.82 kg m^{-3})[49] and Hassanli et al.[50] (1.26 kg m^{-3}). The difference might be due to the influence of irrigation application methods and variation in climatic conditions.

Relationship between sugar beet root yield and seasonal evapotranspiration

The sugar beet root yield in this study for both the experimental years were linearly related to seasonal evapotranspiration as shown in Fig. 1. It supports the results of Ghamarnia et al.[31], Topak et al.[19], Ucan and Gencoglan[18], Kiziloglu et al.[44] and Suheri et al.[45].

Crop response factor (k_y)

Crop response factor $k_{y,}$ was determined from the two years experimental data of 2011-12 and 2012-13. In order to determine relative evapotranspiration deficit

Table 3: Combined average for Root IWUE and Sugar IWUE for sugar beet in 2011-13

Treatments	RIWUE (kg/m3)			SIWUE (kg/m3)		
	2011-12	2011-12	2 years average	2011-12	2012-13	2 years average
$FI1_{00}$	8.12	8.14	8.13	1.16	1.14	1.15
DI_{20}	8.83	8.69	8.76	1.31	1.27	1.29
DI_{40}	9.77	9.45	9.61	1.52	1.44	1.48
DI_{60}	11.23	10.52	10.87	1.82	1.66	1.74

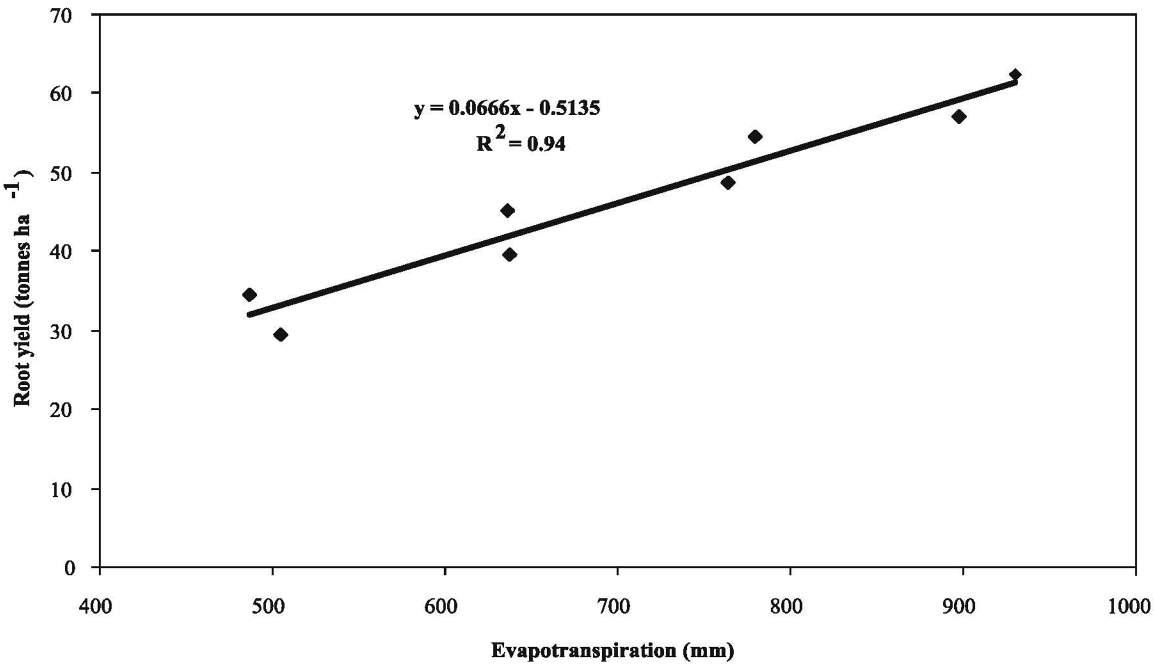

Figure 1: Relationship between seasonal evapotranspiration and root yield according to combined data of 2011-11 and 2012-13 seasons

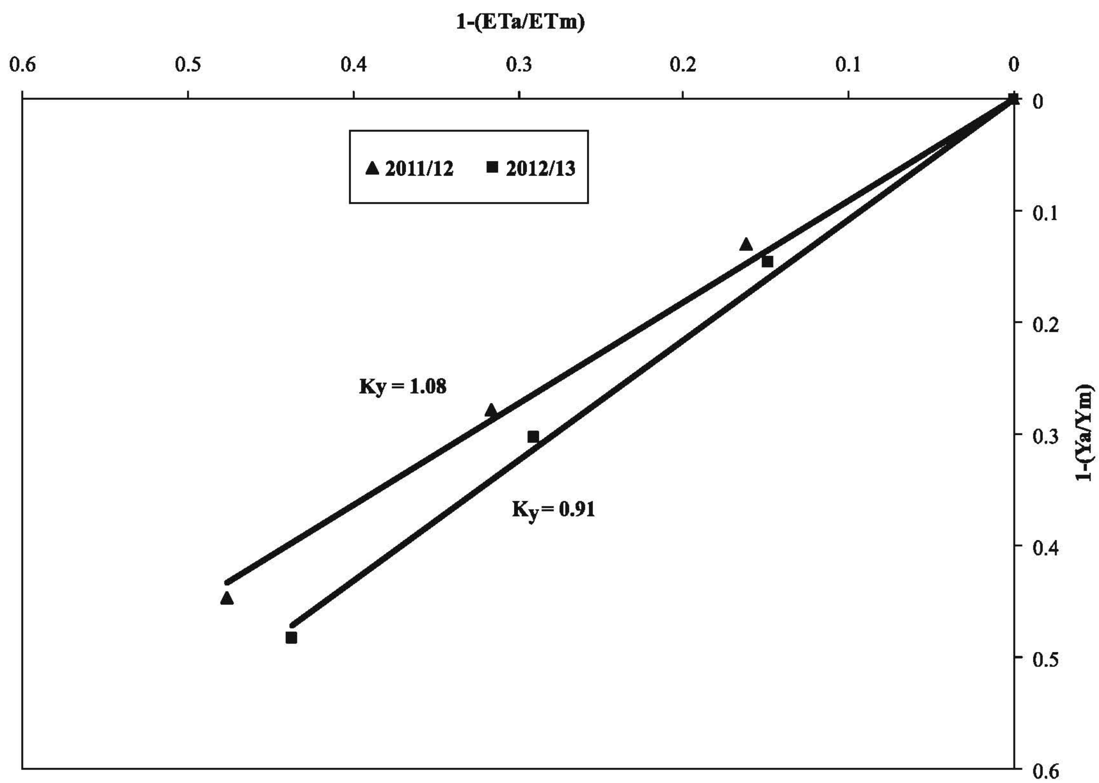

Figure 2: Relationship between evapotranspiration deficit and relative root yield reduction for sugar beet during 2011-12 and 2012-13 seasons

$(I-E_a/E_m)$ and relative yield decrease $(1-Y_a/Y_m)$, data regarding to actual evapotranspiration (E_a), maximum evapotranspiration (E_m), actual yield (Y_a) and maximum yield (Y_m) were used. The relationship between relative yield decrease $(1-Y_a/Y_m)$ and relative evapotranspiration deficit $(I-E_a/E_m)$ were plotted as shown in figure 2. Crop response factor (k_y) for sugar beet for the experimental years 2011-12 and 2012-13 were determined as 0.91 and 1.08. The values of k_y obtained in this study are different than that reported by Topak[7] et al. (0.97 and 0.89), Doorenboss and Kassam (1.0), Utset el al. (1.0), Shrestha et al. (1.01), Kodal (0.7) and Werker (0.62). The differences in the crop response factor might be due to the variation in climatic conditions, mode of irrigation application methods and cultural practices etc.

CONCLUSION AND RECOMMENDATIONS

Sugar beet yield response to different levels of deficit irrigation and water use efficiency was studied in field at sugar crop research institute, Mardan, Pakistan during the 2011-12 and 2012-13 seasons. Deficit irrigation significantly affected both the root yield and sugar content. The highest root yield (62.50 and 57 tonnes ha^{-1}) was obtained from FI_{100} treatment and the lowest (34.58 and 29.46 tons/ha) was for FI_{40}. However, sugar content was higher for all the deficit irrigation treatments when compared to full irrigation. Taking the average of two years experimental data, applying 20%, 40% and 60% deficit irrigation caused 4.20, 8.60 and 13.10 percent higher sugar content respectively than the full irrigation treatment. Evapotranspiration ranged from 486 to 929.8 mm in year 2011-12 and 505.4 to 897.5 mm in 2012-13. The highest average irrigation water use efficiency (10.87 kg/m^3) was obtained in treatment DI_{60} and the lowest (8.13 kg/m^3) in FI_{100}. The crop response factor (k_y) was in the range of 0.91 to 1.08. This value could be used as a base for developing irrigation water strategy in water limited semi-arid areas.

It is recommended that in semi-arid areas, where water is not limited, full irrigation should be used for growing sugar beet. In areas, where water is moderately limited, 20% deficit irrigation could be useful. Because under 20% deficit, 20% water saving were obtained with 13.7% root yield loss. In the severe water limited semi-arid areas, 60% deficit irrigation will be the best alternative. In this case, 46% reduction in root yield occurred with 60% water saving. This 60% saved water can be used for irrigating 60% more land and thus total production from the irrigated area may be increased.

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