African Journal of Biotechnology Vol. 7 (24), pp. 4475-4478, 17 December, 2008
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2008 Academic Journals

Full Length Research Paper

Effects of limited irrigation on root yield and quality of sugar beet (*Beta vulgaris* L.)

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Accepted 24 October, 2008

This field study was conducted in order to investigate the yield and quality of sugar beet cv zargan in relation to different irrigation regimes during 2005 at Ardabil conditions. The experimental design was a randomized complete block design with four replicates. In this experiment irrigation regimes were I_1 = Irrigation at 13.3 F.C (30% F.C), I_{2b}= Irrigation at 15.5 F.C (50% F.C), I_3 = Irrigation at 17.7 F.C (70% F.C) and I_4 = Irrigation at 19.9 F.C (90% F.C). Parameters such as root yield (t/ha), leaf yield (t/ha), sugar content (%), Molasses (%), pure sugar content (%), white sugar yield (t/ha), Na (mmol/100 g root), K (mmol/100 g root) were evaluated. Irrigation treatments had a significant effect on sugar yield and its quality. Potassium concentration was not significantly affected by irrigation treatments. Results of irrigation treatments showed that the optimum soil water content for root yield is 70% of field capacity with 78.5 t/ha. The minimum root yield (52.5 t/ha) was observed at 90% of field capacity. Irrigation at 30, 50 and 70% of field capacity (I_1, I_2 and I_3) had same effect on sugar content while sugar content decreased at 90% field capacity (I_4). When the available soil water content was at 70% of field capacity, maximum root yield and quality was observed.

Key word: *Beta vulgaris*, irrigation, root yield, sugar quality.

INTRODUCTION

Controlled deficit irrigation (CDI) (English, 1990; English et al., 1990) may well prove to be an efficient tool for further research. This technique makes it possible to relate, under water shortage conditions, the drought stress undergone by the plant at a given phenological stage to possible decreases in the production or quality of the crop harvested.

The CDI technique which relates aspects of water management, such as irrigation scheduling, to plant physiology has been studied more in ligneous than in herbaceous crops (Mitchell et al., 1984). It has been used systematically by Fabeiro et al. (2000, 2002a, b;) and Fabeiro et al. (2003) in various types of mainly agricultural crops.

The sustainability of cropping systems can be achieved through the choice of certain field crops which are better than others to exploit natural resources, like solar radiation – which is a no-cost resource – and water – which is becoming more and more expensive. One of these crops is the sugar beet (*Beta vulgaris* L.), a crop cultivated for the production of sucrose and, potentially, for the production of energy (bio-ethanol). In the cropping areas from 38ºN to 60ºN beet is usually sown in spring (March–April) and harvested in autumn. In the southern areas of Iran, Spain, Italy and Greece (at varying latitudes according to the climatic zones, between 35ºN and 45ºN), the beet is sown in autumn, using lines resistant to bolting, with several advantages including extension of growing period, early harvest (end of July), reduction of the irrigation requirements and reduced risks of a low root sugar content (Rinaldi and Vonella, 2006). In the Mediterranean region and Iran, adequate sugar beet production

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requires irrigation, but in recent years drought stress has become a major constraint to sugar beet cultivation even in Northern Europe, causing serious reductions in productivity (Jaggard et al., 1998; Pidgeon et al., 2001).

Also, sugar beet tolerates mid and late-season plant water stress and this characteristic makes it a suitable crop for production with “limited” irrigation. Under irrigation conditions, the sugar beet is regarded as a highly water-consuming crop, which prevents its expansion in areas with limited availability of water resources.

Many studies have led us to assume that water rationing can take place on a highly selective basis in certain phonological periods without causing any significant losses in terms of quality and quantity of the final output (Groves and Bailey, 1997; Urbano and Arroyo, 2000; Urbano et al., 2000).

Wittenmayer and Schilling (1998) showed that sugar beet plants respond to water stress by an increase in taproot proportion in relation to whole plant dry matter. Richter et al. (2001) found that drought stress is the major cause of yield loss on sugar beet in the UK. It causes an average annual yield reduction of 10% (Jaggard et al., 1998) and in every dry year it decreased yields by as much as 50%, corresponding to 4 t/ha. There are conflicting reports about the sensitivity of sugar beet to water stress conditions (Dunham, 1993).

Javaheri et al. (2006) reported that the best autumn planting date was 22 august with sugar yield of 9.4 t/ha, root yield of 8.5 t/ha and white sugar content of 11.44% and suggested that autumn planting of sugar beet in Orzoih-Kerman can be successful. Late harvesting increased beet root yield from 440 to 675 g and sugar content (%) from 16.09 to 18.02 (Camakci and Tingir, 2001; Jozefyova et al., 2002). Late sowing enhanced percentage emergence and shortened emergence time (Durr and Boiffin, 1995), but developing soil moisture deficit later reduced emergence and increased gaps in plant stands (Jaggard et al., 1995). Gale et al. (1990) showed that early sowing increased root soluble carbohydrates and sugar content Mohammadian (2001) studied effects of drought stress, on white sugar yield of sugar beet at early growth stages and stated that the decrease of white sugar yield depended on soil physical properties, climatic conditions, stored soil moisture, plant nutrition condition after water stress elimination, and water stress duration.

Many studies showed the influence of early season water stress on the sugar beet root yield. Some researchers reported that water stress at the beginning of season remarkably reduced root yield (Hills et al., 1990), whilst Penman (1970, 1971) did not find these results. The difference between these findings may be mainly due to the severity of drought stress.

Effects of water deficit on sugar concentration, white sugar, molasses sugar and recoverable white sugar were not significant among treatments. Hills et al. (1990) reported no significant difference between early season water stress and non-stress conditions for white sugar concentration of dry matter but significant differences were found for the fresh root weight and the white sugar concentration increased under increasing water stress condition. Brown et al. (1987) showed that early season water stress decreased sugar percentage whilst Winter (1980) and Dunham (1988) found that drought stress did not significantly change the sucrose percentage.

This study was proposed to evaluate the effects of irrigation regimes on beet yield and quality to determine suitable amount of soil water condition.

MATERIALS AND METHODS

This field study was conducted in order to investigate the yield and quality of sugar beet cv zargan in relation to difference irrigation regimes during 2005 at Ardabil conditions. Ardabil is located in the north-west of Iran (Lat 38º, 11' N; Long 48º, 17' E and Elevation 1400 m) with mean 30-year averages of 303.9 rainfall per year and 9.0ºC temperatures.

According to soil analysis carried out prior to sowing, the soil texture was a sandy-clay-loam with EC = 0.753 dsm^{-1}, pH = 7.4, organic mater (%) = 1.9, soil P_2O_5 = 12 ppm, K_2O = 379 ppm, field capacity = 21% (w/w), wilting point = 10% (w/w) and the volume weight of the soil was 1.21 $g.cm^3$. Climate temperature and rainfall from sowing to harvest are presented in Table 1.

During growth season, the average temperature in Ardabil is within the optimum range for root development and below the retarding sugar accumulating temperature of 30ºC (Kipps, 1981) while the drop in temperature in August-September period is conducive to raising the sugar content of the beet.

The experiment field received 80 $kg.ha^{-1}$ of P_2O_5, 2/3 of which was applied during deep ploughing in autumn and 1/3 in spring prior to disk harrowing. Nitrogen at a rate of 100 kg/ha was applied, in the form of urea, the first half of which during disk harrowing in spring and the remaining half before hoeing when the plants reached the 6 leaf stage.

The experimental design was a randomized complete block design with four replicates. In this experiment four levels of irrigation were used: I_1 = Irrigation at 13.3 of field capacity (30% F.C), I_2 = Irrigation at 15.5 F.C (50% F.C), I_3= Irrigation at 17.7 F.C (70% F.C) and I_4= Irrigation at 19.9 F.C (90% F.C).

To measure require water for each plot, following equation was used:

Field capacityv= 21% (w/w) wilting point= 10% w/w
Plot area = 5 × 8 = 40 m^2; root depth = 45 cm.
If Soil volume weight = 1.21 $g.cm^3$, therefore 1 m^3 (soil) = 1210 kg.
Soil volume for irrigation = 40 (m^2) × 0.45 (m) = 18 m^3
18 m^3 soil = 21780 kg

I_1 = 21780 × 0.133 (w/w) = 2897 liter water per plot
I_2 = 21780 × 0.15.5 (w/w) = 3376 liter water per plot
I_3 = 21780 × 0.177 (w/w) = 3855 liter water per plot
I_4 = 21780 × 0.199 (w/w) = 4334 liter water per plot

The sowing date was done as soon as the soil conditions permitted. Each plot measured 5×8 m (= 40 m^2). The beet crop is grown at a density of eight plants m^2 (Smit, 1993; Akinerdem et al., 1994; Lauer, 1995) by over-sowing and hand thinning to the required density.

The sugar beet was established with furrow irrigation on single row planting system. Irrigation treatments were done during June-August and then soil water content remained at field capacity for all

Table 1. Mean temperature (ºC) and rainfall (mm) of site from sowing to harvest.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug	Sep	Oct	Nov	Dec	Annual
Temp (ºC)	-0.8	-2.0	5.5	10.3	13.6	15.7	20.0	19.0	16.5	12.5	6	4.9	10.1
Rainfall (mm)	16.3	13.9	33.5	24.6	81.1	16.1	5.2	1.9	14.9	22.1	45.2	5.6	280.4

Table 2. Mean sugar beet yield and its quality as affected by limited irrigation.

Treatment adjective	Irrigation			
	30% F.C	50% F.C	70% F.C	90% F.C
Root yield (t/ha)	63.00 ^{c}	68.00 ^{b}	78.5 ^{a}	52.5 ^{d}
Leaf yield (t/ha)	29.59 ^{b}	31.77 ^{a}	32.03 ^{a}	27.24 ^{c}
Sugar content (%)	16.92 ^{c}	17.45	17.23	15.5
Pure sugar content (%)	12.26	12.63	12.15	11.81
Molasses (%)	4.67	4.83	5.08	3.67
White sugar yield (t/ha)	7.73	8.60	9.54	6.2
Potassium (K)*	7.48	7.15	6.26	6.55
Sodium (Na)*	1.52	2.38	2.39	2.27

Means followed by the same latter within row were not significantly different at the *0.01* probability level, according to the LSD test.
*: mmol/100 g root.

treatments. Seedbed was prepared using the appropriate field machinery. Weeds were controlled by hand when necessary. Harvesting was done by pulling the beet manually, and topped by cutting the crown at the base of the leaves. The topped beets were weighted for yield measurements and samples were taken for the determination of sugar content using the Pol method (Payne, 1968). Harvesting was done on 25 October and data were collected. Data were collected at harvest on root yield (t/ha), leaf yield (t/ha), sugar content (%), Molasses (%), pure sugar content (%), white sugar yield (t/ha), sodium (Na) and potassium (K).

Data given in percentages were subjected to arcsine transformation before statistical analysis. The SAS software package was used to analyze all the data (SAS Institute, 2001) and means were separated by the least significant difference (LSD) test at P < 0.01.

RESULTS AND DISCUSSION

Results showed that irrigation had a significant effect on sugar yield and its quality (P<0.01). However, potassium concentration was not affected by irrigation. Mean yield and other studied adjectives which were affected by irrigation are presented in Table 2. Mean root and leaf yield as affected by irrigation treatments ranged from 52.5 to 78.5 t/ha and 27.24 to 32.03 t/ha, respectively (Table 2). The highest root and leaf yield was obtained at 70% F.C, compared to other treatments. Results of irriga-tion treatments showed that the optimum soil water content for root yield is 70% of field capacity with 78.5 t/ha (Table 2). The minimum root yield (52.5 t/ha) was observed at 90% of field capacity.

Irrigation at 50 and 70% of field capacity (I_2 and I_3), and 30 and 90% of field capacity (I_1 and I_4) had same effect on leaf yield. Abayomi (2002) found that leaf growth showed high sensitivity to soil water deficit. Water deficit early in the growing season had larger effects on leaf growth. Mid- or late-season soil water deficit showed relatively smaller effects on leaf growth. Kenter et al. (2006) concluded that irrigation (soil water content) had no significant influence on leaf growth rate but root growth rate increased significantly with increasing soil water content.

Both early and late soil water deficit decreased sugar yield and sugar concentrations. Irrigation at 30, 50 and 70% of field capacity (I_1, I_2 and I_3) had same effect on sugar content while sugar content decreased at 90% field capacity (I_4). Javaheri et al. (2006) concluded that sugar beet yield was related to root yield and not to sucrose content and that sucrose content was not affected by irrigation treatments. Also, Jaggard et al. (1998) and Wittenmayer and Schilling (1998) mentioned that if sugar beet is subjected to water stress, the root yield decreased. Dunham (1993) found that early water stress (June and early July) decreased root yield more than late stress.

The concentrations of K and Na present as impurities in extracted root sap have been shown to be inversely related to the amount of extractable sugar (Last et al., 1983). Potassium concentration was not affected by irrigation treatments. Irrigation at 50, 70 and 90% of field capacity (I_2, I_3 and I_4) had same effect on sodium concen-aion, but irrigation at 30% of field capacity (I_1) decreased sodium concentration.

Conclusion

Results showed that the optimum soil water content for root yield in Ardabil condition is 70% of field capacity. Sugar content was not affected by I_1, I_2 and I_3 but it decreased at 90% of field capacity. Therefore, soil water content at 70% of field capacity is suggested in beet cultivation in Ardabil condition.

ACKNOWLEDGEMENTS

We gratefully acknowledge the anonymous referees for helpful comments and suggestions. We would like to thank Dr Ebadi for his support and helpful comments.

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