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Effect of Early Season Drought Stress on Growth Characteristics of Sugar Beet Genotypes

R. MOHAMMADIAN[1]*, M. MOGHADDAM[2], H. RAHIMIAN[3], S.Y. SADEGHIAN[1]

[1]Sugar Beet Seed Institute, Karaj, P.O. Box: 31585-4114, IRAN

[2]Faculty of Agriculture, Tabriz University, Tabriz, IRAN

[3]Faculty of Agriculture, Tehran University, Tehran, IRAN

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Abstract: This study was conducted to determine the effects of early season drought stress on some plant characteristics of 9 sugar beet genotypes in the Khorasan Agricultural and Natural Resource Research Station, NE Iran. The experimental design was a split plot with a randomized complete block arrangement. Leaf area index, leaf dry weight, shoot dry weight and root dry weight decreased under drought stress compared to non-stress conditions. The decrease was more pronounced as the rate of stress increased. Leaf area index was more affected by water stress than was leaf weight (losses of leaf area indices were 14.1% and 66.6% in mild and severe stresses, respectively, and losses of total leaf dry weights were 16.2% and 54.2% in mild and severe stresses, respectively). Mild stress affected root dry weight more than shoot dry weight (percent losses of root dry weight and shoot dry weight were 31.7 and 19.5, respectively), while the effect was reversed under severe stress (percent losses of root dry weight and shoot dry weight were 50.5 and 60.2, respectively). Most of the genotypes with a high root dry weight and low shoot to root ratio before termination of stress also had a lower root dry weight under stress than non-stress and produced higher white sugar yields. The differences between the genotypes in leaf area index, leaf dry weight and shoot dry weight before termination of stress were not high enough to have a considerable effect on white sugar yield. Counting the leaf number before termination of stress and 1 month after termination of stress revealed that stress delays the growth of sugar beet. Although a higher number of leaves per plant is a good character under stress, this trait characteristic could not increase the shoot to root ratio. MSTC2 and 7233.P3 genotypes appeared to be better than the other genotypes for the studied traits under mild and severe drought stresses early in the growth season.

Key Words: drought, genotype, morphology, stress, sugar beet

Introduction

Sugar beets have been credited with a rather wide range of response to drought stress (Winter, 1980). Water deficits induce a series of morphological and physiological changes in the sugar beet plant such as reduction in leaf area and photosynthesis. Senescence of old leaves may be accelerated by stress, thus reducing leaf longevity (Stocker, 1960; Brown et al., 1987).

The reduction in leaf area due to water stress may represent an increase in xeromorphy (Stocker, 1960), because the sugar beet plant can adjust to reduced water availability by losing leaves, yet retaining the ability to later respond to improved conditions by growing additional leaves (Winter, 1980).

When water uptake is reduced, leaf expansion is decreased and there is less use of carbohydrates. If a greater proportion of assimilates is allocated to the root system it could lead to preferential root growth, especially in soil with higher moisture (Hasegawa, 1998).

Under drought conditions, beet leaves wilt in response to water deficiency, tend to lie flat on the soil and thus increase the effective area exposed to the direct sun radiation (Clover, 1997). As a consequence of the reduction in transpiration rates of such leaves, leaf temperature increases and may result in leaf scorching and death. Mohammadin et al. (2001) reported significant differences among sugar beet genotypes in leaf temperature under water stress, and leaf temperature

* Correspondence to: r_mohammadian@hotmail.com

Abbreviations: GDD (Growth degree-days); LAI (Leaf area index); LDW (Leaf dry weight); LEACHM (Leaching Estimation and Chemistry Model); N (North), NE (Northeast); RDW (Root dry weight); RY (Root yield); SDW (Shoot dry weight); TDR (Time Domain Reflectometry); WSY (White sugar yield) under non-stress was always lower than under stress. Lorenzetti et al. (1991) showed that high temperature, about 30 ºC, caused an increased need for transpiration and a significant reduction in the advancement of plant phenology.

Brown et al. (1987) studied the effect of early season drought stress in sugar beet and reported that it affected the fibrous roots severely, lowered the canopy expansion rate and decreased radiation interception and the rate of water use fell below Penman potential transpiration. The relative effects on growth were reflected in the final sugar yield. In spite of these results, Penman (1970, 1971) did not observe any effect of early drought stress on sugar yield although he showed a reduction in leaf growth. The disagreement between the 2 sets of experiments could be explained by assuming that the early soil moisture deficit in Penman's experiments was lower than those in the prior experiment.

It was proved that the decrease of yield depends on the amount of stored soil water at the time of termination of irrigation (Davidoff and Hanks, 1989). The effect of soil type on root development and drought resistance has also been reported (Nishimune et al., 1982). In addition, based on Mohammadian et al. (2001, 2003a, 2003b) sugar beet genotypes responded differently to water deficiency at the early growth stage, indicating that stress tolerance can be a heritable trait.

In dry and semi-dry regions, such as the Khorassan province of Iran, sugar beet farmers refuse to irrigate the field at the early growth stage, due to the need to irrigate the winter cereal crops at the same time. It is, therefore, necessary to identify sugar beet genotypes that are more tolerant to drought in the early growth season.

The objectives of our research were:

1- to study the effect of early season drought stress on some growth and phenology characteristics of sugar beet.

2- to identify a suitable index to screen suitable genotypes in early season drought stress conditions.

3- to select sugar beet genotypes tolerant to early season drought.

Materials and Methods

Field experiments were conducted in the Khorassan Agricultural Research Station, Mashhad, NE of Iran, over a 2-year period (1998 and 1999). The station is located at 36° 12` N latitude 59° 40` E longitude, at an altitude of 985 m above sea level. Based on the DeMarton classification Mashhad is regarded as a semiarid region. The soil texture was silty in the first 15-cm layer, and silty loam in the layer below.

The experiment design was a split plot with a randomized complete block arrangement in 4 replications. Two irrigation regimes (non-stress and water stress conditions) were allocated to the main plots and 9 sugar beet genotypes to the subplots. Only 6 genotypes were common to both years (Table 1).

In the stress condition, irrigation was withheld when plants reached about the 8- to 10-leaf stage. The duration of water stress in 1998 and 1999 was 41 (9 June-20 July) and 53 (1 June-24 July) days, respectively. The first irrigation was performed on May 24 and May 10 in 1998 and 1999, respectively. Plot size was 8 x 5 = 40 m^2 and rows were spaced 0.61 m apart. Plants were thinned to 5 plants per meter of a row at the 4-leaf stage. During the stress period, no effective precipitation was recorded.

Soil moisture was measured using time domain reflectometry (TDR) in 3 soil layers (0-20, 20-40 and 40-60 cm) in 1999. The soil matric potential was calculated using a water retention curve. The models of soil matric potential variations during stress and non-stress conditions were obtained using the computer model LEACHM (Hutson and Wagenet, 1992). No significant differences between data estimated by the LEACH model and data observed from TDR were obtained. Therefore, the soil matric potential variation of 1998 was predicted based on the information from 1998.

Destructive plant samples were taken during 6 growth stages of these, 4 samples were taken during the stress period and 2 after termination of the stress from all plots. Fresh and dry weights of leaves, petioles, roots (5 plants in 1998 and 3 plants in 1999 in each plot) were also measured. Leaf area was obtained using equation 1, proposed by Gohari and Rouhy (1993), for the 1998 experiment.

$$\begin{aligned} Y &= -201.2558 + 12.401L + 13.35W \qquad L > 16 \text{ cm} \\ Y &= 6.4736 + 0.84138L.W \qquad L < 16 \text{ cm} \end{aligned} \qquad [1]$$

Table 1. The name and characteristics of sugar beet genotypes used during 1998 and 1999 experiments.

Code	Year	Genotype	Ploidy	Germ	Specific characteristic
1	1998, 1999	7219.P69	Diploid	Multigerm	Open pollinator, Progeny line
2	1998, 1999	7233.P3	Diploid	Multigerm	Open pollinator, Progeny line
3	1998, 1999	PC9597.P58	Diploid	Monogerm	Open pollinator, Progeny line
4	1998, 1999	MSC2	Diploid	Multigerm	Mail sterile
5	1998, 1999	7219.P229	Diploid	Multigerm	Open pollinator, Progeny line
6	1998, 1999	A37.1	Diploid	Multigerm	Otype
7	1998	5797.P100	Diploid	Multigerm	Open pollinator, Progeny line
7	1999	24360.191	Diploid	Multigerm	Open pollinator, Progeny line
8	1998	7233.P8	Diploid	Multigerm	Open pollinator, Progeny line
8	1999	7233.P12	Diploid	Multigerm	Open pollinator, Progeny line
9	1998	5797.P29	Diploid	Multigerm	Open pollinator, Progeny line
9	1999	BPkaraj*MS261	Diploid	Monogerm	Hybrid

where L and W are the largest length and width of lamina in centimeters and Y is leaf area in square centimeters. In 1999, leaf area was measured by leaf area meter (Delta-T. England).

The least squares method was used to determine the regression equations for the leaf area index (LAI), leaf dry weight (LDW), shoot (leaf + petiole) dry weight (SDW), root dry weight (RDW) and total dry weight (TDW), under stress and non-stress conditions. The data from all genotypes after conversion to the Neper logarithm were fitted by linear, quadratic and cubic equations under both stress and non-stress conditions based on growth degree-days (GDD). Drought stress periods were in the range 318.5 to 1107 and 319.5 to 1309.75 GDD in 1998 and 1999, respectively. Among them, cubic regression had a larger coefficient of determination.

In order to study sugar beet phenology under stress and non-stress conditions, chlorotic, green and total leaf numbers were counted before and 1 month after termination of stress.

The light quantities above and below the canopy were measured from 11:00 to 13:00 hours, just before and 43 days after stress termination and before the final harvest using a lux meter (Lutron Lx-101) in 1999.

The percentage of light absorption in each plot was calculated using equation 2:

$$\text{Light absorption percent} = \frac{(I_0 - I)}{I_0} * 100 \qquad [2]$$

in which I and I_o are the rate of light in the upper and lower canopy, respectively. Equation 3 was used to determine the percentage of light transmission through the canopy:

Percent of light transmitted through the canopy = 100 - Light absorption percent [3]

The light extinction coefficient (K) was calculated by the following formula:

$$K = \frac{-\mathrm{Ln}\left(\frac{I_0}{I}\right)}{LAI} \qquad [4]$$

Leaf temperatures were measured by an infrared thermometer (Quick temp 850-1 model. Testo Company) from 12:00 to14:00 hours on the tenth fully developed leaf prior to the termination of stress in 1999.

At harvest, root weight from 5 square meters of each plot was determined and then their pulps were prepared to determine the sugar percent and potassium, sodium and nitrogen content. White sugar percent was also estimated using the equation in Reinefeld et al. (1974). White sugar yield for every plot was calculated from the product of root yield and white sugar percent. The MSTAT-C and STATGRAPHICS programs were used to analyze the data.

Results and Discussion

Soil matric potentials of stressed plots were lower than those of non-stressed plots in all 3 soil layers (0-20, 20-40 and 40-60 cm) in both years (Table 2). This indicates that the crops in these plots were under stress. In 1999, however, soil matric potentials in stressed plots were lower than those in 1998. The difference between these 2 years may be related to the longer period of stress in 1999, which, in turn, imposed more severe stress on the sugar beet genotypes. A much higher atmospheric demand for transpiration during 1999 made the stress conditions even more pronounced compared to 1998 (Figure 1).

The effect of mild (1998) and severe (1999) drought stress on all genotypes' LAI is presented in Figure 2. Both drought stress conditions caused a decrease in the LAI of genotypes compared to non-stress conditions. Similar results have been reported for sugar beet (Abdollahian-Noghabi, 1999) and other crops such as soybean (Jones et al., 2003) and cereals (Araus et al., 2002). A reduction in leaf area due to water stress may represent an increase in xeromorphy (Stocker, 1960). Sugar beet can adjust to reduced water availability by losing leaves and yet retain its ability to later respond to improved conditions by growing additional leaves (Winter, 1980). LAI in 1999 decreased more under stress than under non-stress in 1998. LAI decreased 14.1% and 66.6% in 1998 and 1999, respectively, as a result of water stress. LDW values in 1998 and 1999 were respectively 16.2% and 54.2% lower than the control before the termination of stress. Therefore, it is evident that LAI was affected more than LDW under severe stress. On the other hand, specific leaf weight increased more under severe than under mild stress. Hang and Miller (1986) studied the response of sugar beet to deficit irrigation in loam and sandy soils. Since drought stress happens faster in lighter texture soil, specific leaf weight was higher in sandy than in loam soils.

The effects of drought stress on SDW and RDW during the 2 years of the experiment are presented in

Table 2. Matric potential (Kpa) of soil at different depths before termination of drought stress in the 2 years.

Soil depth cm	1998 Stress	1998 Non-stress	1999 Stress	1999 Non-stress
0-25	-650	-484	-812	-600
25-40	-288	-266	-446	-345
40-70	-496	-350	-624	-434

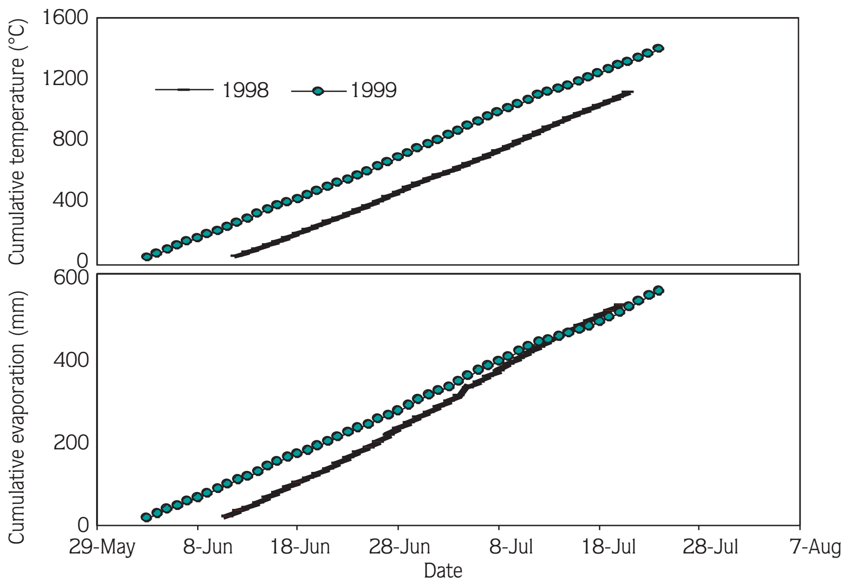

Figure 1. The rates of cumulative mean of air temperature (ºC) during the stress periods in 1998 (9 Jun-19 Jul) and 1999 (1 Jun-23 Jul) and cumulative evaporation from class A evaporation (mm) during the same period (data from the Mashhad Meteorological Station).

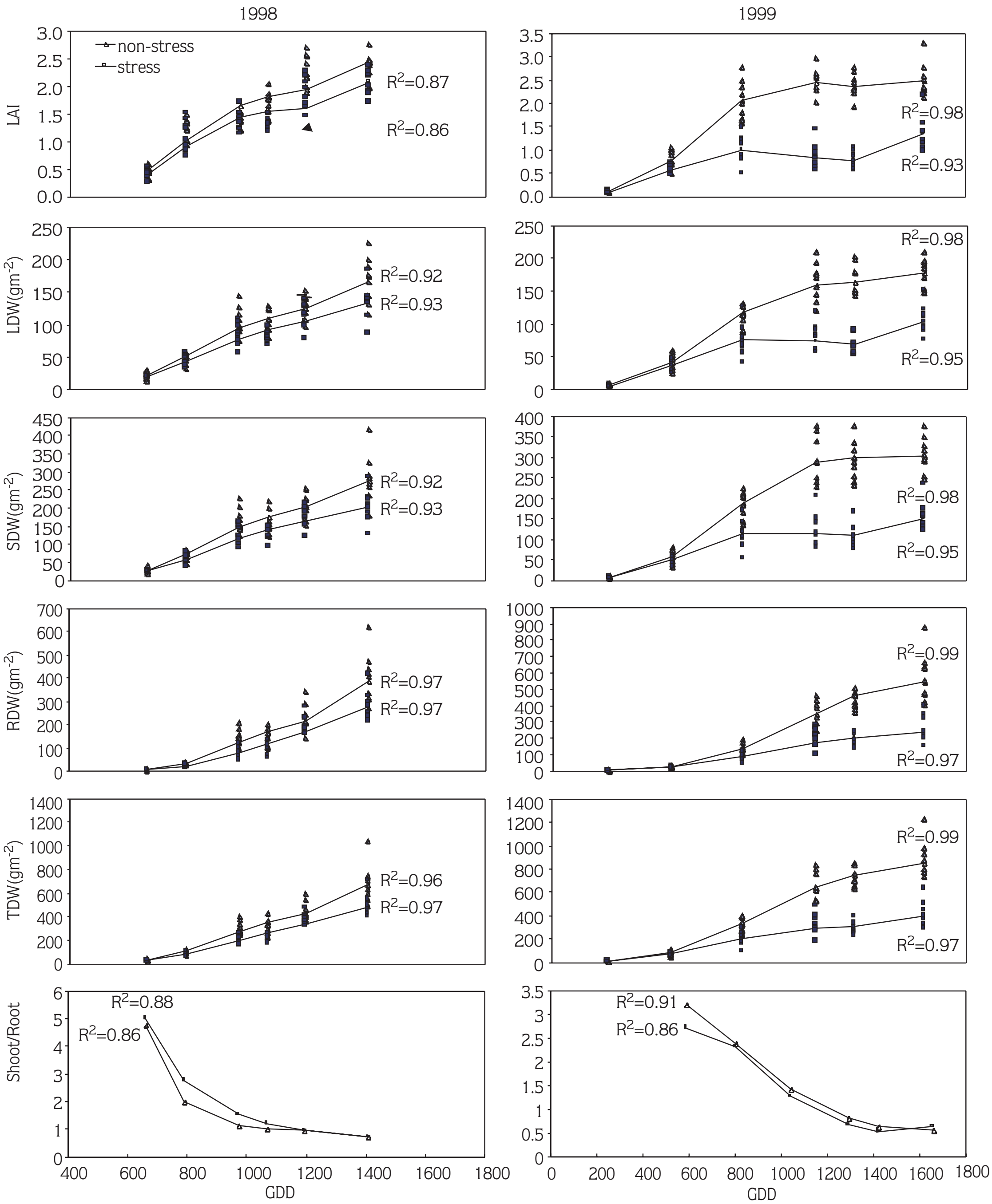

Figure 2. Variations in leaf area index (LAI), leaf dry weight (LDW), shoot dry weight (SDW), root dry weight (RDW), total dry weight (TDW) and shoot: root ratio (shoot/root) in terms of growth degree-days (GDD) for the average of 9 sugar beet genotypes before and a few days after early drought stress in both stress and non-stress conditions. Drought stress periods were 318.5 to 1107 and 319.5 to 1309 in 1998 and 1999, respectively.

Figure 2. Before termination of stress, percent losses of SDW were 19.5 and 60.2 and those of RDW were 31.7 and 50.5 in 1998 and 1999, respectively. When compared to the percent dry weigh losses in shoots and roots during the 2 years, it could be concluded that mild stress affected the dry weight of roots more than the dry weight of shoots, while SDW loss was greater than RDW loss under severe stress. Johnson and Davis (1973)

stated that root growth is more sensitive to water deficit than leaf growth. Clover et al. (1999), in field and greenhouse experiments, showed that the effects of drought stress on leaf and root weights were 20% and 29%, respectively. These effects could cause a 29% loss in total dry weight. In our experiment, early growth season drought stress caused decreases of 12.2% and 54.6% in TDW in 1998 and 1999, respectively (Figure 2).

At the beginning of the growth season shoot to root ratios (shoot/root) were high under both conditions (Figure 2). However, these ratios decreased as the season progressed. Green et al. (1986) reported the same results. There were no significant differences among shoot/root ratios under stress and non-stress conditions in either year. Hang and Miller (1986) reported that water stress affected leaf:petiole and shoot:root ratios later and less than leaf area, specific leaf weight and plant growth. In spite of this, Abdollahian-Noghabi (1999) has shown that due to limited shoot growth in severe drought stress, the ratio of shoot to root dry weight was severely reduced.

Correlation coefficients of final root yield (RY) and final white sugar yield (WSY) with other traits under stress conditions are presented in Table 3. Among these traits, RDW, TDW, shoot/root ratio and the ratio of root dry weight in stress conditions to root dry weight in non-stress conditions (RDWstress/RDWnon-stress) were correlated more with WSY and RY. The correlation coefficients of these traits with RY were 0.59, 0.70, -0.51 and 0.37 in 1998 and 0.55, 0.44, -0.68 and 0.46 in 1999, respectively. The correlation coefficients with WSY were 0.32, 0.40, -0.27 and 0.58 in 1998 and 0.42, 0.29, -0.66 and 0.44 in 1999, respectively. Therefore, those genotypes that had higher RDW, TDW and RDWstress/RDWnon-stress before termination of the drought stress, usually had higher RY and WSY, while the genotypes with lower shoot/root ratios usually showed higher RY and WSY. The major limitation to actual yield is the failure of the ability of the canopy to absorb radiation early in the growing season (Scott and Jaggard, 1978). Other researchers also affirmed that at early growth stages yield is reduced due to drought stress effects on foliage (Draycott et al., 1974; Draycott and Messem, 1977). A positive correlation of root yield with maximum leaf area index and leaf area duration and also with the ratio of these 2 characteristics at 75 to 105 days after emergence has been reported by Kazakov et al. (1988). However, in our experiment, the differences among genotypes in LDW, LAI and SDW, which represent the light receptive organs, were not large enough to explain the effect of stress on the final yields of genotypes.

Correlation coefficients of RY with WSY were significant and positive in stress conditions in the 2 years

Table 3. Correlation coefficients of white sugar yield and root yield with white sugar yield, ratio of white sugar yield under stress to white sugar yield under non-stress conditions and other growth characteristics before the early drought stress termination in 9 sugar beet genotypes.

	White Sugar Yield		Root Yield	
	1998	1999	1998	1999
Leaf Dry Weight	0.15(0.70)[a]	-0.21(0.58)	0.31(0.42)	0.07(0.86)
Leaf Area Index	0.24(0.53)	0.12(0.76)	0.39(0.30)	0.16(0.69)
Shoot Dry Weight	0.02(0.96)	0.17(0.66)	0.17(0.66)	0.28(0.47)
Root Dry Weight	0.42(0.26)	0.32(0.40)	0.55(0.13)	0.59(0.09)
Total Dry Weight	0.29(0.45)	0.40(0.29)	0.44(0.23)	0.70(0.04)
Root Dry Weight $_{stress}$ / Root Dry Weight $_{non\text{-}stress}$	0.44(0.24)	0.58(0.11)	0.46(0.22)	0.37(0.33)
Shoot/Root	-0.66(0.06)	-0.27(0.48)	-0.68(0.04)	-0.51(0.16)
(Shoot/Root) $_{stress}$ / (Shoot/Root) $_{non\text{-}stress}$	-0.18(0.64)	-0.27(0.49)	-0.023(0.55)	-0.10(0.79)
White Sugar Yield	1(0.00)	1(0.00)	0.96(0.001)	0.84(0.00)
(White Sugar Yield) $_{stress}$ / (White Sugar Yield) $_{non\text{-}stress}$	0.05(0.90)	0.2(0.61)	0.25(0.51)	-0.01(0.99)

[a] Significance level

(Table 3). While WSY is more important than RY, we studied the relationship between WSY and shoot/root ratio, RDW and RDWstress/RDWnon-stress. For this purpose, the average upper and lower limits for each trait in each year were used. In 1998, genotypes 7219.P69, 7233.P3, MSTC2, 7219.P229, A37.1 and 5797.P100 and, in 1999, genotypes 7233.P3, PC9597.P58, MSTC2 and BPkarajx261 were above the 2 average upper and lower limits based on both traits (Figure 3). MSTC2 and 7233.P3 had higher RDW and WSY in both years (severe and mild stresses).

As seen in Figure 4, under stress early in the growing season, most of the genotypes that had higher WSY usually tended to have lower shoot/root ratios. This indicates that those genotypes were more efficient than the others in carrying H_2O and minerals through their roots. Since the reduction in leaf area may cause an increase in xeromorphy (Stocker, 1960), it is possible that genotypes having low shoot/root ratios before termination of stress decrease the deleterious effects of water shortage and increase the possibility of producing new leaves when soil moisture improve. In 1998,

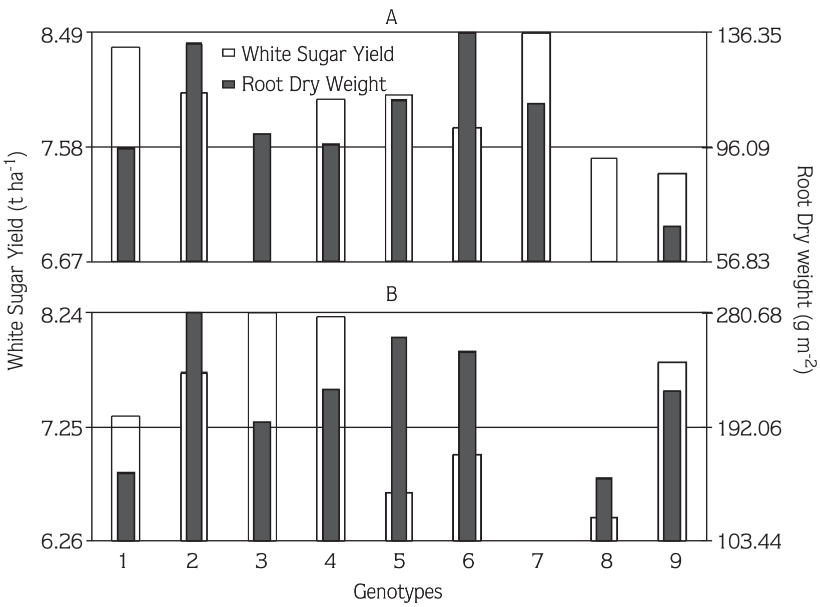

Figure 3. White sugar yield and root dry weight, before termination of stress, in 9 sugar beet genotypes under early drought stress in 1998 (A) and 1999 (B). Codes of the genotypes are presented in Table 1. Y axes are adjusted for the range of observed measurements for each trait.

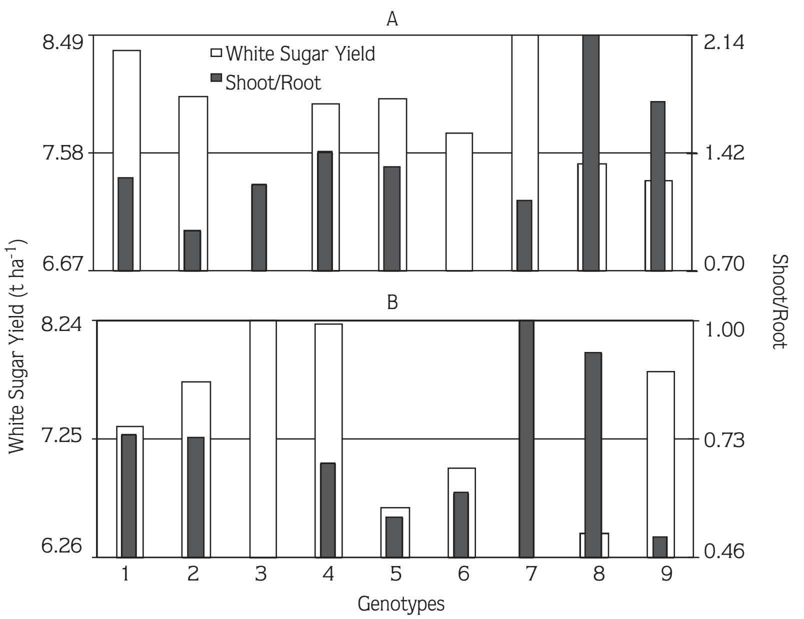

Figure 4. White sugar yield and ratio of shoot to root dry weight, before stress termination, in 9 sugar beet genotypes under early drought stress in 1998 (A) and 1999 (B). The codes of the genotypes are presented in Table 1. Y axes are adjusted for the range of observed measurements for each trait.

genotypes 7219.P69, 7233.P3, MSTC2, 7219.P229, A37.1 and 5797.P100 had low to medium shoot/root ratios and higher WSY values than the 2 average upper and lower limits. This was also true for genotypes 7219.P69, 7233.P3, PC9597.P58, MSTC2 and BPkarajx261 in 1999. Among the genotypes that were used in both years, 7219.P69, 7233.P3 and MSTC2 had high WSY and low shoot/root ratios in 1998 (mild stress) and 1999 (severe stress) experiments.

Genotypes with small decreases in RDW under stress had high WSY (Figure 5). In 1998, genotypes 7219.P69, 7233.P3, MSTC2, A37.1 and 5797.P100 and, in 1999, genotypes 7233.P3, PC9597.P58, MSTC2 and BPkarajx261 had the same or higher ratios of RDWstress to RDWnon-stress and higher WSY of the average upper and lower limits. In addition, 7233.P3 and MSTC2 showed high WSY and low ratios of RDW stress/RDW non-stress in mild (1998) and severe (1999) stress conditions.

Sugar beet phenology was significantly affected by early drought stress (Table 4). Other researchers also stated that the senescence of old leaves might be accelerated by stress conditions (Stocker, 1960; Hang and Miller, 1986; Brown et al., 1987). Lorenzetti et al. (1991) reported that the rise in temperature, about 30 ºC in summer, caused an increased need for transpiration and a significant reduction in plant phenological progress. In addition, decreases in the initiation of new leaves due to drought stress have been confirmed by other reports (Kazakov et al., 1988).

Before termination of the stress period in 1999, the average numbers of green leaves in each plant in non-stressed and stressed conditions were 20.35 and 14.52, respectively. Thus there was a 28.7% decrease in the numbers of leaves in stressed compared to non-stressed genotypes. The number of chlorotic and necrotic leaves were on average 4.33 and 6.9 per plant under non-stress and stress conditions, respectively. This shows that the number of chlorotic and necrotic leaves in stress conditions increased 58% compared with those in non-stress conditions. The effect of stress on accelerating the senescence of older leaves was considerable. During drought stress, sugar beet leaves are subjected to both heat and water stress (Clark et al., 1993). A reduction in transpiration rates causes the leaf temperature to rise, which subsequently scorches the leaves. The total leaf numbers were 24.7 and 21.39 in non-stress and stress conditions, respectively, at the termination of stress. Thus total leaf number was 13.4% higher in non–stress than in stress conditions.

The effects of drought stress on green and total leaf numbers were significant 31 days after the termination of stress (Table 3), resulting in 65.15% and 72.11% decrease in green and total leaf numbers. Although sugar

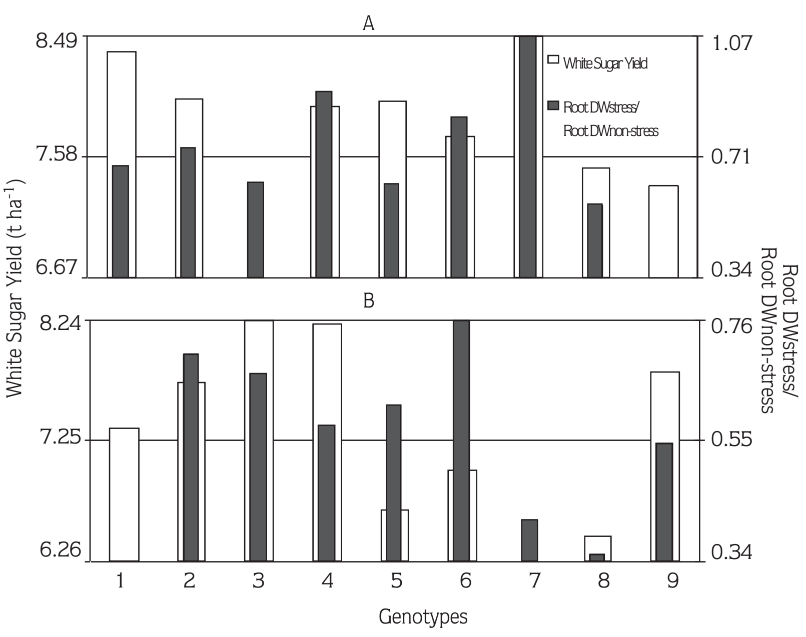

Figure 5. White sugar yield and ratio of root dry weight (DW) in stress to root dry weight in non-stress conditions, before stress termination, in 9 sugar beet genotypes under early drought stress in 1998 (A) and 1999 (B). Codes of the genotypes are presented in Table 1. Y axes are adjusted for the range of observed measurements for each trait.

Table 4. Mean square of green, chlorotic, necrotic and total leaf numbers in 9 sugar beet genotypes under early drought stress.

Source of variation[a]	DF	Mean squares					
		Before drought stress termination			One months after drought stress termination		
		Green leaf	Chlorotic and necrotic leaf	Total leaf	Green leaf	Chlorotic and necrotic leaf	Total leaf
Replication	-	-	-	-	-	-	-
Irrigation regime (I)	1	612.5**	114.458**	197.784**	426.969**	0.002n.s.	428.5**
Error a	6	-	6.84	-	-	-	-
Genotype (G)	8	7.08n.s.	0.55n.s.	6.55n.s.	5.94n.s.	3.11n.s.	10.79n.s.
G*I	8	5.46n.s.	0.70n.s.	8.20n.s.	6.81n.s.	6.95n.s.	136.58n.s.
Error b	48	6.34	1.57	7.66	7.23	4.86	11.82
C.V.%		14.71	22.33	12.01	9.37	21	8.78

[a] When the main plot error and/or replication were not significant at $P < 0.05$, they were pooled with the error term.

DF = degrees of freedom

** and n.s. = Significant at the 0.01 and not significant at 0.05 levels, respectively.

beet plants recovered somewhat from stress, they still had fewer leaves under stress conditions. One month after the termination of stress, the numbers of chlorotic and necrotic leaves increased under non-stress conditions and reached the same level as in stress conditions (average of 10.5 leaves per plant). In other words, the rate of leaf senescence in sugar beet plants in non-stress conditions was higher than that in stress conditions. Therefore the technological maturation of plants under non-stress conditions happens sooner than that of plants under early season drought stress.

Correlation coefficients of leaf numbers with RY and also WSY in stress conditions are presented in Table 5. Correlation coefficients of green and total leaf numbers with WSY were positive and significant before the termination of stress and 1 month after. However, there were no good correlations between chlorotic and necrotic leaf numbers and WSY under either condition. Comparing correlations of WSY with these traits and LAI, LDW and SDW, it seems that the total number of leaves and number of green leaves can better predict WSY than LAI, LDW and SDW. In other words, under stress conditions, genotypes that are more advanced in their phenology have higher WSY. Since the correlation coefficient of shoot/root ratio with WSY was negative, a higher number of leaves should not cause a higher shoot/root ratio.

Light transmissions through the canopy before the termination of stress were 16.8% and 66.9% in stress and non-stress conditions, respectively. This ratio (3.98) decreased to 2.0 and 0.74, 43 and 107 days after the termination of stress, respectively. This shows that water stress reduces the development of sugar beet canopy severely. However, after the termination of drought stress, the differences decrease gradually. Brown et al. (1987) and Kazakov et al. (1988) also reported the recovery of sugar beet growth after removing the drought stress. Clover et al. (1999) observed that drought stress decreased light interception by 12%, which in combination with a 16% decrease in the dry matter/light conversion coefficient, led to a decrease in growth. Furthermore, Freckleton et al. (1999) have shown that maximizing the length of the growing season may minimize the risk of yield losses due to drought. Due to the severe drought stress effect on the canopy in 1999 and the short duration of growth available for sugar beet plants after interrupting the drought stress until harvest, stressed plants developed less canopy cover than non-stressed plants. The effect of genotype and the interaction of drought stress x genotypes on light transmission were not significant before the termination of stress. However, 43 days after the termination of drought stress, the differences between genotypes and the interaction of drought stress x genotypes were significant at $P < 0.01$ and $P < 0.10$, respectively. There

Table 5. Correlation coefficients of root yield and white sugar yield with the green, chlorotic, necrotic and total leaf numbers in 9 sugar beet genotypes under early drought stress season.

	Before drought stress termination			One month after drought stress termination		
	Green leaf	Chlorotic and necrotic leaf	Total leaf	Green leaf	Chlorotic and necrotic leaf	Total leaf
Root Yield	0.55(0.12)[a]	0.24(0.53)	0.60(0.09)	0.69(0.04)	0.50(0.17)	0.62(0.06)
White Sugar Yield	0.59(0.10)	0.10(0.70)	0.59(0.10)	0.65(0.06)	0.45(0.23)	0.60(0.09)

[a] Significance level

were no significant differences, however, among the genotypes in light transmission before the final harvesting, 107 days after the termination of drought stress. The results show that the responses of genotypes may be different after the termination of stress.

Correlation coefficients of transmitted light percent through the canopy with LDW, LAI, RDW, SDW and TDW, before the termination of stress, are shown in Table 6 under both stress and non-stress conditions. Relations of LDW, LAI and SDW with transmitted light were negative in non-stress conditions, but were positive under stress conditions. Thus, by increasing these characteristics less light penetrated through the canopy under non-stress conditions, however, under stress conditions, the results were the opposite. A strong negative correlation was observed between light extinction coefficient and transmitted light percent ($R^2 = 0.998$). Therefore, under stress conditions, genotypes that were more drought tolerant produced more leaves. In this situation, genotypes with more turgid leaves could position their leaves at a more vertical angle and more light could penetrate through the canopy. The leaf architecture of genotypes could, therefore, be predicted by measuring the percentage of transmitted light through the canopy.

The correlation coefficient of transmitted light through the canopy with RDW under non-stress conditions was negative and negligible. However, under stress conditions the correlation was positive and significant at $P < 0.08$. It may be stated that under stress, the genotypes with high root biomass have more vertical leaves, which allow more light through the canopy. The correlation coefficient of TDW and light penetration through the canopy was also significant at $P < 0.02$.

The correlations of light transmitted percent with leaf-air temperature difference, ΔT, which shows the plant moisture situation (Mohammadian et al., 2001), were negative and significant at $P < 0.08$ ($r = -0.60$) and $P < 0.09$ ($r = -0.61$) under stress and non-stress conditions, respectively. It suggests that genotypes with less light transmission through their canopies have more leaf–air temperature differences under both stress and non-stress conditions. On the other hand, genotypes with more vertical leaves absorb less light, and have lower leaf–air temperature differences. When beet leaves wilt in response to water deficiency, they tend to lie flat on the soil and thus increase the effective area exposed to the sun (Clover, 1997). The leaves of 7233.P3 and A37.1 genotypes were cooler than those of the other genotypes,

Table 6. Correlation coefficients between percent transmitted light through the sugar beet canopies and some plant characteristics, before the early drought stress termination in 9 sugar beet genotypes.

	Non-stressed					Stressed				
	Total Dry Weight	Leaf Dry Weight	Leaf Area Index	Root Dry Weight	Shoot Dry Weight	Total Dry Weight	Leaf Dry Weight	Leaf Area Index	Root Dry Weight	Shoot Dry Weight
Transmitted light percent through canopy before drought stress termination	0.75 (0.02)[a]	0.62 (0.07)	0.78 (0.01)	0.61 (0.08)	0.82 (0.01)	-0.42 (0.25)	-0.66 (0.05)	-0.48 (0.19)	-0.16 (0.69)	-0.65 (0.06)

[a] Significance level

suggesting that more light had penetrated through their canopies (Figure 6).

The correlation coefficients of transmitted light with RY and WSY are shown in Table 7. Under stress and non-stress conditions, these correlations were positive. Therefore, vertical leaves are effective in increasing the final yield under both water stress and non-stress conditions. However, the correlation coefficients were different at different growth stages. Thus, the effect of transmitted light on the final yield of sugar beet genotypes depends on the growth stage. The correlation of transmitted light with RDW in non-stress conditions was much less than those with WSY and RY. Further research is needed to elucidate these relationships.

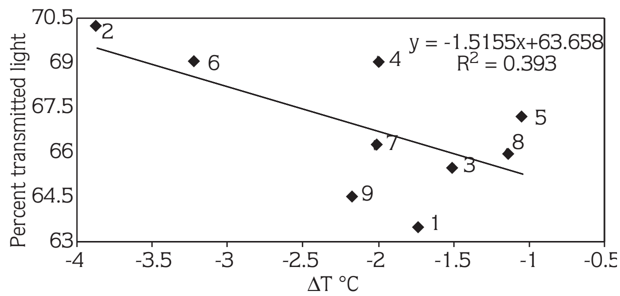

Figure 6. Relationship between transmitted light percent and the difference between leaf and air temperature (ΔT) in 9 sugar beet genotypes before terminating early drought stress. Codes of the genotypes are presented in Table 1.

Table 7. Correlation coefficients between percent transmitted light through the canopy before and after the termination of early drought stress and white sugar yield and root yield of 9 sugar beet genotypes in both stress and non-stress conditions.

	Stressed		Non-stressed	
Transmitted light percent through canopy	White Sugar Yield	Root Yield	White Sugar Yield	Root Yield
Before drought stress termination	0.06(0.88)[a]	0.07(0.85)	0.67(0.05)	0.54(0.13)
45 days after drought stress termination	0.42(0.26)	0.42(0.26)	0.14(0.72)	0.09(0.82)
Before final harvesting	0.49(0.19)	0.53(0.14)	0.12(0.77)	0.57(0.89)

[a] Significance level

Conclusion

Although there were differences among the sugar beet genotypes for some plant characteristics under stress conditions, the genotypes' yield performance cannot be predicted from a single trait. Each trait represents a specific reaction of the sugar beet plant to early season drought stress. Therefore, it is recommended that several criteria be considered to screen the genotypes for resistance to drought stress simultaneously.

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References

Abdollahian-Noghabi, M. 1999. Ecophysiology of sugar beet cultivars and weed species subjected to water deficiency stress. PhD thesis. University of Reading.

Araus, J.L., G.A. Slafer, M.P. Reynolds and C. Royo. 2002. Plant breeding and drought in C_3 cereals: what should we breed for? Annals of Botany. 89: 925-940.

Brown, K.F., A.B. Messem, R.J. Dunham and P.V. Biscoe. 1987. Effect of drought on growth and water use of sugar beet. J. Agr. Sci. (Camb.). 109: 421-435.

Clarke, N., H. Hetschkun, C. Jones, E. Boswell and H. Marfaing. 1993. Identification of stress tolerance traits in sugar beet. In: Interacting Stress on Plants in a Changing Climate (Eds.: M.B. Jackson and C.R. Black). Berlin: Springer-Verlag, pp: 511-524.

Clover, G.R.G. 1997. Effects of beet yellow virus and drought on the growth of sugar beet. PhD thesis, University of Nottingham.

Clover, G.R.G., H.G. Smith, S.N. Azam-Ali, and K.W. Jaggard. 1999. The effects of drought on sugar beet growth in isolation and in combination with beet yellow virus infection. J. Agr. Sci. 133: 251-261.

Davidoff, B. and R.J. Hanks. 1989. Sugar beet production as influenced by limited irrigation. Irrigation Sci. 10: 1-17.

Draycott, A.P., M.J. Durrant, and A.B. Messem. 1974. Effect of plant density, irrigation and potassium and sodium fertilisers on sugar beet. II. Influence of soil moisture and weather. J. Agr. Sci. (Camb.). 82: 261-268.

Draycott, A.P. and A.B. Messem. 1977. Response of sugar beet to irrigation 1965-1975. J. Agr. Sci. (Camb.). 89: 481-493.

Freckleton, R.P., A.R. Watkinson, D.J. Webb and T.H. Thomas. 1999. Yield of sugar beet in relation to weather and nutrients. Agric. Fores. Meteor. 93: 39-51.

Gohari, G. and A.V. Rouhy. 1993. Estimated of leaf area in sugar beet. J. Sugar Beet. 9: 1-12. (Persian)

Green, C.F., L.V. Vaidyanathan, and J.D. Ivins. 1986. Growth of sugar beet crop including the influence of synthetic plant growth regulaors. J. Agr. Sci. (Camb.). 107: 285-297.

Hang, A.N. and D.E. Miller. 1986. Response of sugar beet to deficit, high frequency sprinkler irrigation. II: Sugar beet development and partitioning to root growth. Agron. J. 78: 15-18.

Hasegawa, P.M. 1998. Stress physiology. In: Plant Physiology (Eds.: L. Taiz and E. Zeiger). Sinauer Associates. Inc.: Massachusetts. pp. 725-757.

Hutson, J.L. and R.J. Wagenet. 1992. LEACHM. Leaching estimation and chemistry model: A process-based model of water and solute movement, transformations, plant uptake and chemical reactions in the unsaturated zone. Version 3. Dept. of Soil. Crop and Atmospheric Sciences. Cornell University, Ithaca, NY.

Johnson, W.C. and R.G. Davis. 1973. Sugar beet response to irrigation as measured with growth sensors. Agron. J. 65: 789-794.

Jones, B.P., D.L. Holshouser, M.M. Alley, J.K.F. Roygard and C.M. Anderson-Cook. 2003. Double-crop soybean leaf area and yield responses to Mid-Atlantic soils and cropping systems. Agron. J. 95: 436-445.

Kazakov, E.A., S.M. Kazakova and B.I. Gulyaev. 1988. Effect of soil moisture on formation and necrosis of sugar beet leaf apparatus. Fiziologiya i Biockimiya Kul turnykh, Rastenii. 20: 431-438.

Lorenzetti, M.C., A.M. Pandolfi and P. Bolli. 1991. Ecological aspects of the cultivation of sugar beet [*Beta vulgaris* L. var. Saccharifera L.] in Umbria. Annali della Facolta di Agraria, Universita degli Studi di Perugia. 45: 307-320.

Mohammadian, R., F.R. Khoyi, H. Rahimian, M. Moghaddam, K. Ghassemi-Golezani, and S.Y. Sadeghian. 2001. The effect of early season drought on stomatal conductance, leaf-air temperature difference and proline accumulation in sugar beet genotypes. J. Agri. Sci. Techno. 3: 181-193.

Mohammadian, R., H. Rahimian, M. Moghaddam and S.Y. Sadeghian. 2003a. The effect of early season drought on chlorophyll *a* fluorescence in sugar beet (*Beta vulgaris* L.). Pakistan J. of Biological Sci. 6: 1763-1769.

Mohammadian, R., S.Y. Sadeghian, M. Moghaddam and H. Rahimian, 2003b. Evaluation of drought tolerance indices in determining sugar beet genotypes under early season drought conditions. J. Sugar Beet. 18: 29-51. (Persian)

Nishimune, A, G. Saito, T. Konno, I. Fujita and K. Miyazawa. 1982. Growth analysis of sugar beet grown in fields with different soil fertilities in Tokachi, Hokkaido. Res. Bulletin of the Hokkaido, National Agricultural Experiment Station.133: 31-60.

Penman, H.L. 1970. Woburn irrigation, 1960-8. IV. Design and interpretation.VI. Results for rotation crops. J. Agric. Sci. (Camb.) 75: 69-73; 89-102.

Penman, H.L. 1971. Irrigation at Woburn. VII. Rothamsted Report for 1970. part 2: pp. 147-170.

Reinefeld, E., A. Emmerich, G. Baumgarten, C. Winner and U. Beiss. 1974. Zur voraussage des melassezuckers aus rübebanalysen. Zuker. 28:2-15.

Scott, R.K. and K.W. Jaggard. 1978. Theoretical criteria for maximum yield. In: Proceedings of the 41st Winter Congress, Institut International de Recherches, Betteravieres, pp. 179-198.

Stocker, O. 1960. Physiological and morphological changes in plants due to water deficiency. In: Plant water relationships in arid and semiarid conditions. Arid Zone Res. Rev. Res., UNESCO, Paris, Vol. 15, pp. 63-104.

Winter, S.R. 1980. Suitability of sugar beets for limited irrigation in a semi-arid climate. Agron. J. 72: 118-123.