Genetic Variation for Drought Stress in Sugarbeet

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ABSTRACT

Fluctuation in sugarbeet (*Beta vulgaris* L.) yield in semi-arid regions often can be attributed to duration and intensity of drought stress. In this study, 49 diverse breeding lines were evaluated for root yield, sugar content, sugar yield, and white sugar yield, with adequate water and under two levels of drought stress at Karadj and Mashhad in 1996, 1997, and 1998. All lines were not evaluated each year; however, some lines were grown in all environments. Water stress was initiated at about the six-leaf stage. In Karadj, the stress was continuous throughout the growing season. In Mashhad, the stress period was limited to 50 days. The five indexes used to identify high-yielding genotypes in both the stressed and non-stressed environments were: stress susceptibility index (SSI), stress tolerance (TOL), stress tolerance index (STI), yield stability index (YSI), and mean productivity (MP). Root yield and sugar yield exhibited large differential genotypic responses to drought stress. Some high yielding genotypes were productive in stress and non-stress environments. Stress applied either for a limited period (Mashhad) or throughout the growing season (Karadj) gave similar results, with effects of the long-term stress being more pronounced. Under severe drought stress, root yield, sugar yield, and white sugar yield decreased to 59%, 59%, and 60%, respectively, of the values obtained with adequate water; whereas, sugar content increased 6%. Root yield, sugar yield, white sugar yield, and sugar content decreased under drought condition at Mashhad to 72%, 67%, 64%, and 95% of the well-watered sugarbeet, respectively. The stress tolerance index (STI) effectively distinguished genotypes with high

yield in both stressed and non-stressed environments. Selection based primarily on root yield in diverse environments is suggested as a breeding strategy for developing productive sugarbeet genotypes with broad adaptation.
Additional Keywords: *Beta vulgaris L.*, drought, genotype, stress index.

Water deficit is a major limiting factor affecting crop productivity in semiarid regions. Since quantity and distribution of rainfall in most arid regions is unpredictable, crop varieties need to be productive under a wide range of moisture conditions. Drought tolerance should be considered an essential breeding objective in areas where the sugarbeet crop is likely to encounter a water deficit during the growing season (Sadeghian et al., 1999).

Several statistical, morphological, and physiological approaches have been used to relate cultivar response to stress (Mustafa et al., 1996; Link et al., 1999). In common bean (*Phaseolus vulgaris* L.), seed and pod number exhibited a large differential genotypic responses to water stress and a negative correlation between relative water content (RWC) in the plant and yield was observed (Ramirez-Vallejo and Kelly, 1998). Differences in chlorophyll fluorescence, canopy temperature, and the ratio of variable fluorescence and maximal fluorescence (Fv/Fmax) were related to marketable tuber yield of potato (*Solanum tuberosum* L.) genotypes (Ranalli, 1997). Drought tolerant genotypes had the highest Fv/Fmax ratios in stress and well-watered conditions and the ratio appeared to be effective for screening potato germplasm. Drought tolerant and susceptible sugarbeet genotypes were identified using the Fv/Fmax ratio and relative water content (RWC) (Clarke et al., 1993).

Complex genotype by environment interactions and methods of identifying stable genotypes over diverse environments have been discussed (Chapman et al., 1997; Finlay and Wilkins, 1963; Eberhart and Russell, 1966; Shukla, 1972). A principal factor analysis of water stressed sunflower (*Helianthus annuus* L.) indicated that heavy biomass at maturity, plant height, and head growth rate were important for high yields (Elizondo-Barron, 1991). Sugarbeet genotypes can be categorized into four groups according to their performance in drought and favorable conditions: 1. genotypes with high productivity in both conditions, 2. genotypes with higher yield in non-stress environments, 3. genotypes with a relatively high yield in stress environments, and 4. genotypes with a poor yield in both conditions (Sadeghian et al., 1999). Genotypes with high productivity in both stress and non-stress conditions are useful for breeding purposes.

Selection criteria for identification of stress tolerant genotypes have been proposed. These usually are based on relative yields in stress and non-stress environments. Stress tolerance indicators useful for selecting adapted genotypes include: stress susceptibility index (SSI), drought index (DI), stress tolerance (TIL), and stress tolerance index (STI) as defined by Fischer and Maurer, 1978; Fischer et al., 1981; Rosielle and Hamblin, 1981; and Fernandez, 1993; respectively.

The objectives of this study were to measure drought tolerance variation among breeding lines and to compare selection criteria for identifying drought tolerant sugarbeet genotypes with high yield potential under both stress and non-stress conditions.

MATERIALS AND METHODS

A total of 49 sugarbeet lines, progeny lines, and populations were grown under well-watered and drought stress conditions at Karadj and Mashhad from 1996 to 1998. Only 26 genotypes were examined at Mashhad in 1998. Irrigation treatments differed at locations. In Mashhad, where sugarbeet growers often cannot irrigate until 30 to 50 days after seeding because of water availability, the experiment was exposed to stress for 50 days after planting, to simulate commercial production. In Karadj, irrigation was withheld until the soil water content at a depth of 0 to 60 cm reached 15% of field capacity. A randomized complete block design with two replicates was used for all experiments. Genotypes were different in the three years of the experiment; however, some tolerant and sensitive genotypes were common to all years and locations. Root yield, sugar content, sugar yield (gross sugar per hectare), and white sugar yield (marketable sugar per hectare) were determined.

Stress susceptibility index (SSI) as defined by Fischer and Maurer (1978), stress tolerance index (STI) as defined by Fernandez (1993), stress tolerance (TOL) as explained by Rosielle and Hamblin (1981), yield stability index (YSI) used by Thomas (1996); and mean productivity (MP), the average of the yields under stress and non-stress, were used to characterize each genotype. The correlation coefficients between different stress tolerance indicators (SI, STI, TOL, YSI, and MP) and the differential yield responses under the contrasting environments were computed using PC-SAS. Interrelationship among the attributes was also examined and their ability to identify widely adapted genotypes assessed.

Stress tolerance indicators were defined as follows:

D = 1 - (YD/YP),
SSI = (1 - YDi/YPi)/D,
STI = (YP)(YD)/(YPi)2,
TOL = YP - YD
MP = (YP + YD)/2, and
YSI = (YD/YP)(YPi/YDi)

Where YD = mean of a genotype under drought conditions, YP = mean of the same genotype in a well-watered environment, D = drought intensity, and YDi and YPi = mean yield of all genotypes in drought-stressed and well-watered environments, respectively.

RESULTS AND DISCUSSION

The lines evaluated exhibited a wide range of genetic variation for root yield, sugar content, sugar yield, and white sugar yield in three years of stress and non-stress experiments at Karadj and Mashhad (Table 1). Drought stress primarily affected root yield and a long period of drought resulted in a considerable reduction of root yield and related characters, such as sugar yield. Indeed, drought stress also influenced sugarbeet quality by increasing non-sugar components, such as amino-nitrogen, sodium, potassium, proline, and betaine (Sadeghian et al., 1999; Rover and Buttner, 1999).

Correlation analysis between stress tolerance indexes and mean value of genotypes under the stress (MEAN 2) and non-stress (MEAN 1) conditions combined over the three years at each location revealed a significant correlation between stress susceptibility index (SSI), and stress tolerance (TOL) and yield stability index (YST) for all characters. Since correlations between stress tolerance indexes for all characters were similar, only the correlations for white sugar yield were presented (Table 2). A strong correlation between stress susceptibility index with stress tolerance (positive) and yield stability index (negative) at both locations was observed. Correlations between stress susceptibility index (SSI), stress tolerance (TOL), and yield stability index (YSI) with white sugar yield means in stress (MEAN1) and non-stress experiments (MEAN2) were also significant. The signs of the correlation coefficient for MEAN1 and MEAN2 were opposite.

A positive correlation between stress tolerance index (STI), and MEAN1, MEAN2, and MP at Karadj and Mashhad indicated that STI is a better predictor of mean productivity than stress susceptibility (SSI), stress tolerance (TOL), and yield stability index (YSI). Selecting high yielding

Table 1. Means, ranges, and standard errors of root yield, sugar content , sugar yield, and white sugar yield obtained from stress and non-stress trials at Karadj and Mashhad, 1996-1998.

Characters	Karadj			Mashhad		
	Mean	Range	Sd[a]	Mean	Range	Sd[a]
Root yield, Mg/ha						
Non stress	47.7	30.1 - 74.8	8.5	60.0	30.3 - 101.6	16.2
Stress	28.2	15.3 - 41.5	5.0	43.0	13.9 - 77.5	9.5
P.S.[b]	59.1			71.8		
Sugar, %						
Non Stress	16.7	20.0 - 19.5	1.6	15.1	9.8 - 21.0	2.6
Stress	17.6	15.2 - 21.0	1.4	14.3	9.6 - 20.0	2.4
P.S.[b]	105.0			94.6		
Sugar yield, Mg/ha						
Non stress	8.2	10.0 - 13.3	1.6	9.1	2.9 - 15.0	3.0
Stress	4.8	1.1 - 7.2	1.0	6.2	1.9 - 10.0	1.6
P.S.[b]	59.1			67.4		
White sugar yield, Mg/ha						
Non stress	6.5	4.38 - 9.4	1.0	7.6	2.1 - 12.0	2.4
Stress	3.9	0.9 - 6.5	0.9	4.9	1.5 - 9.0	1.4
P.S.[b]	60.0			64.9		

a = standard error of mean, b = percentage of means in stress as compared to non-stress conditions.

Table 2: Correlations between drought tolerance indexes (SSI, TOL, STI, MP, and YSI), and means of non-stress trials (MEAN1) and drought-stress trials (MEAN2), for white sugar yield at Karadj and Mashhad, 1996-1998.

	Location	SSI	TOL	STI	YSI	MP	MEAN1	MEAN2
SSI	Karadj	1	0.90**	-0.19	-0.96**	0.00	0.64**	-0.68**
	Mashhad	1	0.53**	-0.05	-0.86**	0.07	0.31**	-0.34**
TOL	Karadj	-	1	0.05	-0.90**	0.07	0.76**	-0.72**
	Mashhad		1	0.43*	-0.62**	0.51**	0.82**	-0.23**
STI	Karadj	-	-	1	0.25*	0.69**	0.48**	0.44**
	Mashhad	-	-	1	0.19	0.63**	0.63**	0.37**
YSI	Karadj	-	-	-	1	0.01	-0.62**	0.70**
	Mashhad	-	-	-	1	-0.01	-0.30**	0.49**
Mp	Karadj	-	-	-	-	1	0.70**	0.65**
	Mashhad	-	-	-	-	1	0.91**	0.72**
MEAN1	Karadj	-	-	-	-	-	1	-0.87
	Mashhad	-	-	-	-	-	1	0.37**

* and ** indicate significance at the 0.05 and 0.01 probability levels, respectively.

genotypes based on SSI, TOL, or YSI indexes would not necessarily produce varieties that were productive in diverse environments. STI was the only index, which had a positive correlation with mean white sugar yield under both limited and continuous stress as well as adequate water conditions. This confirms the advantage of STI as a selection criterion for identifying high yielding, stress tolerant genotypes. Working with mungbean (*Vigna radiata L.*), Fernandez (1993) concluded that STI could effectively identify genotypes with high yield potential in both stressed and non-stressed environments.

In order to illustrate the value of drought tolerance indexes for identifying high yielding genotypes under continuous or a short-term drought stress, the relationship of MP and MEAN2 (mean value in stress condition) with STI and SSI were plotted (Figures 1.A1-A4 and B1-B4). The data from Karadj and Mashhad are included in the same graph. Since the correlations (negative or positive) among SSI, TOL, and YSI were strong, only relationships involving SSI and SST are presented in Figure 1.

With continuous (Karadj) and limited (Mashhad) drought stress, a linear relationship between STI and MP and MEAN2, for root yield and sugar yield (Figures 1.B1-B4) indicated that STI can identify genotypes with high yield potential under both stress and well-watered conditions. Diverse germplasm could be screened effectively for yield stability and drought tolerance using STI as a selection criterion. When stress susceptibility index (SSI) was plotted against MP and MEAN2 (Figures 1.A1-A4), a linear relationship was not observed in all cases. This implies that SSI, TOL, and YSI will not identify drought tolerant, high yielding genotypes for all environments.

The ranges of root and white sugar yield demonstrated that genotypes respond differently to stress (Figure 2, A1-A2, B1-B2, and C1-C2). Some genotypes performed well under both stress and non-stress conditions (No. 47 in A1 and A2; 24 in B1 and B2; and 26 in C1 and C2). However, some genotypes produced very low yields in all experiments (No. 46 in A1 and A2; 42 in B1 and B2; and 22 in C1 and C2), and some yielded well under favorable conditions but were very sensitive to drought (No. 42 in A1 and A2; 3 in B1 and B2; and 27 in C1 and C2). Some exhibited intermediate yield in both environments and were sensitive to drought (No. 31 in A1 and A2; 8 in B1 and B2: and 14 in C1 and C2).

Drought tolerance breeding programs should focus on the selection of genotypes with high root yield in diverse environments and high extractable sugar.

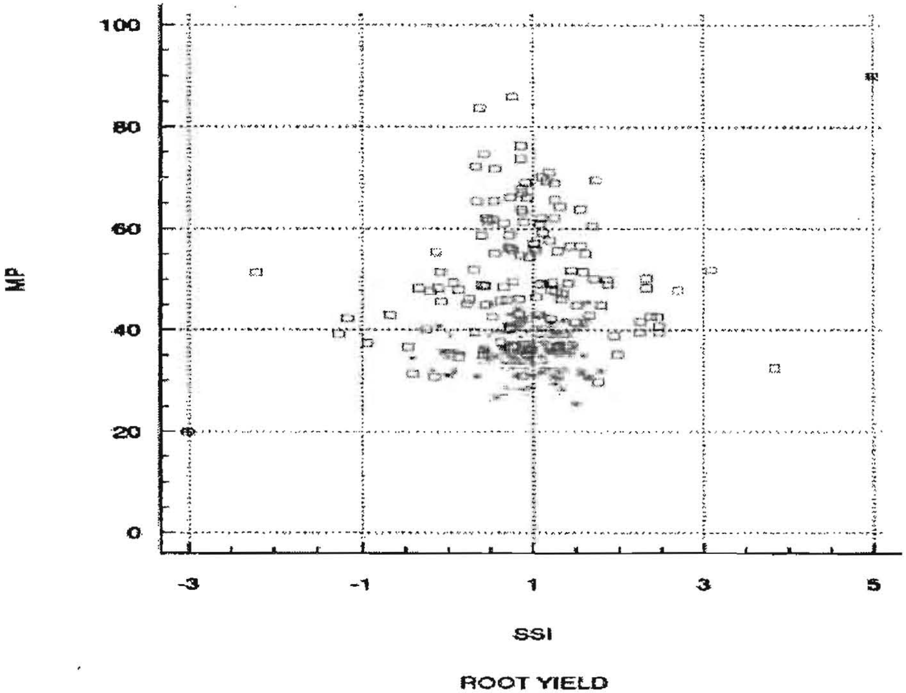


Figure 1A1: The relationship between two drought tolerance indexes, SSI and STI, and means under stress (MEAN2) and non-stress conditions (MP) are presented for root yield and sugar yield. A1-A4 include relationship between SSI, and MP and MEAN2. * and □ are data from Karadj and Mashhad trials, respectively.

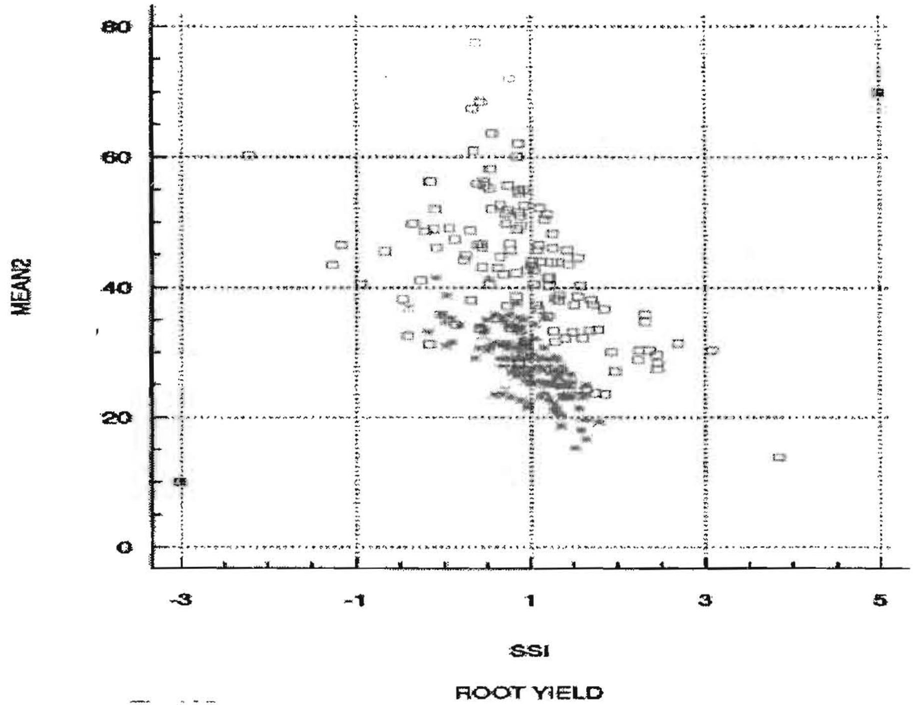


Figure 1A2: The relationship between two drought tolerance indexes, SSI and STI, and means under stress (MEAN2) and non-stress conditions (MP) are presented for root yield and sugar yield. A1-A4 include relationship between SSI, and MP and MEAN2. * and □ are data from Karadj and Mashhad trials, respectively.

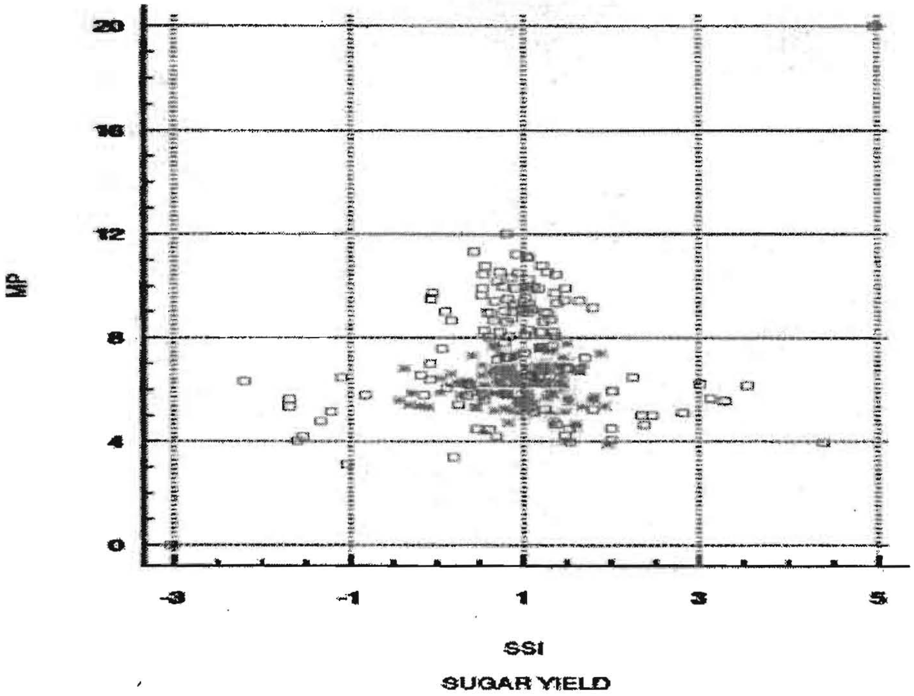


Figure 1A3: The relationship between two drought tolerance indexes, SSI and STI, and means under stress (MEAN2) and non-stress conditions (MP) are presented for root yield and sugar yield. A1-A4 include relationship between SSI, and MP and MEAN2. * and □ are data from Karadj and Mashhad trials, respectively.

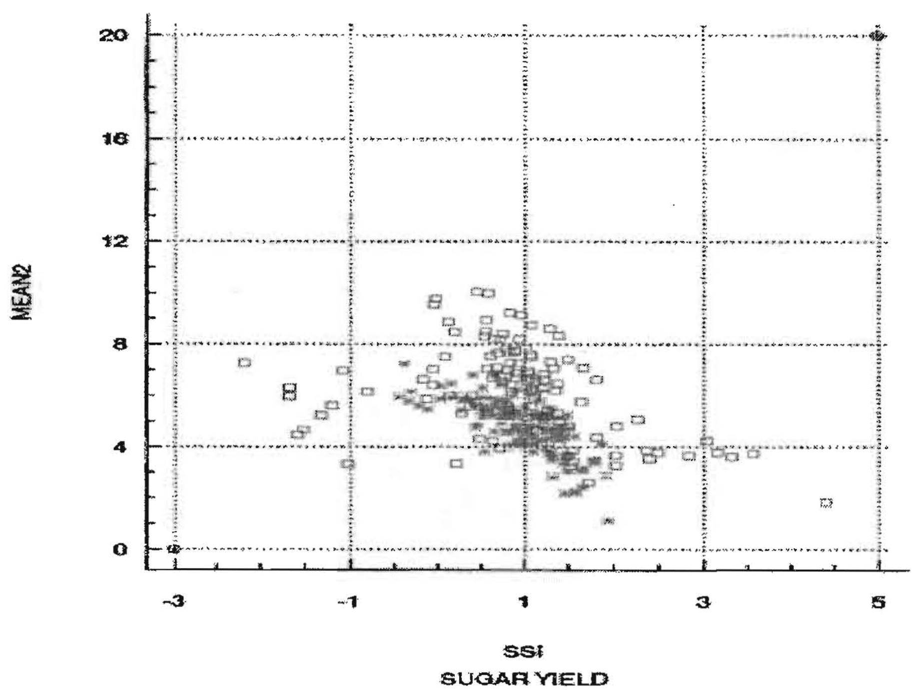


Figure 1A4: The relationship between two drought tolerance indexes, SSI and STI, and means under stress (MEAN2) and non-stress conditions (MP) are presented for root yield and sugar yield. A1-A4 include relationship between SSI, and MP and MEAN2. * and □ are data from Karadj and Mashhad trials, respectively.

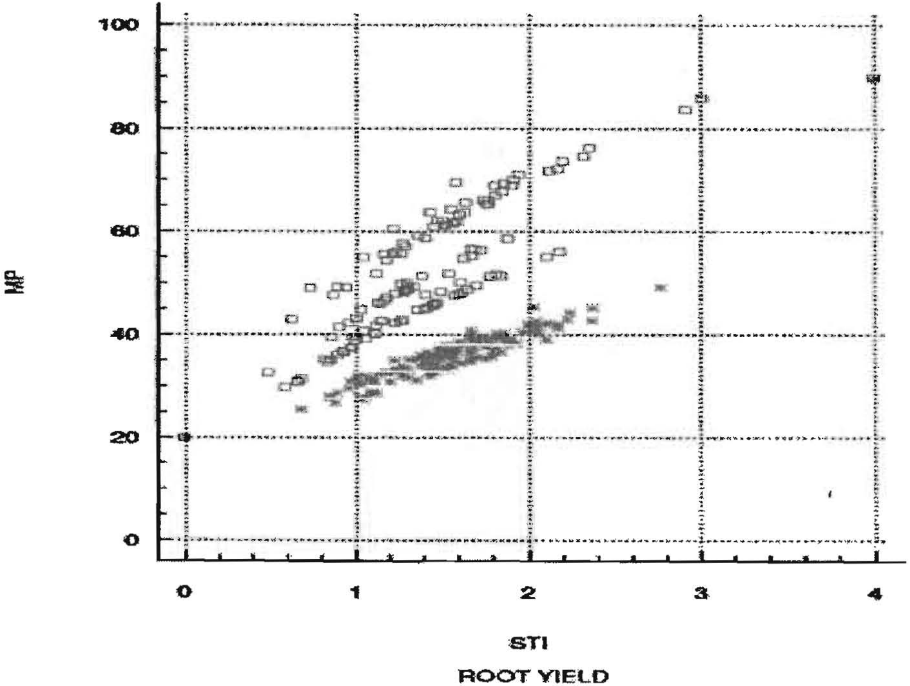


Figure 1B1: The relationship between two drought tolerance indexes, SSI and STI, and means under stress (MEAN2) and non-stress conditions (MP) are presented for root yield and sugar yield. B1-B4 shows the relationship between STI, and MP and MEAN2. * and □ are data from Karadj and Mashhad trials, respectively.

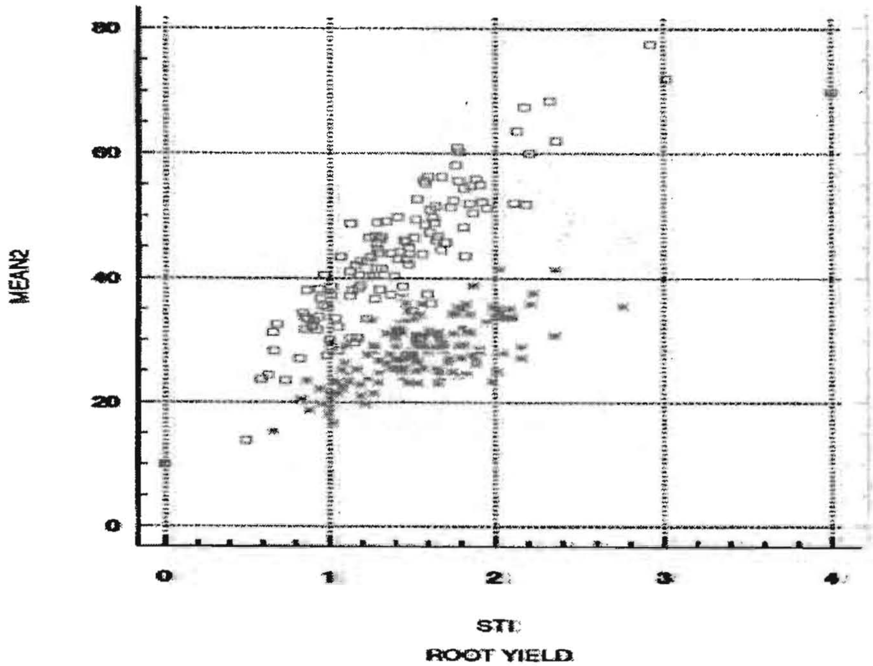
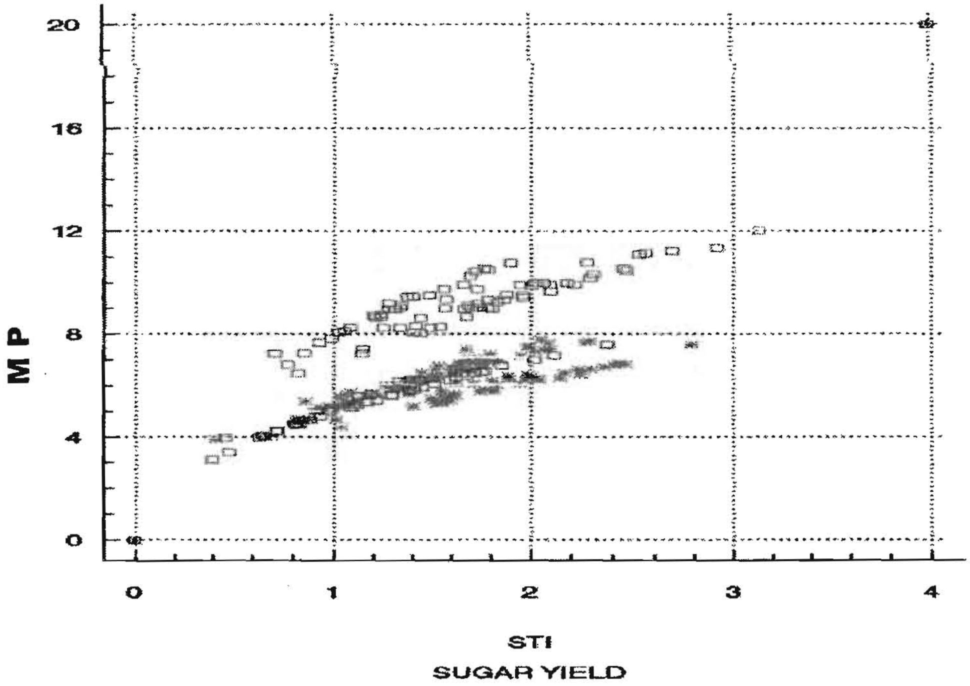


Figure 1B2: The relationship between two drought tolerance indexes, SSI and STI, and means under stress (MEAN2) and non-stress conditions (MP) are presented for root yield and sugar yield. B1-B4 shows the relationship between STI, and MP and MEAN2. * and □ are data from Karadj and Mashhad trials, respectively.



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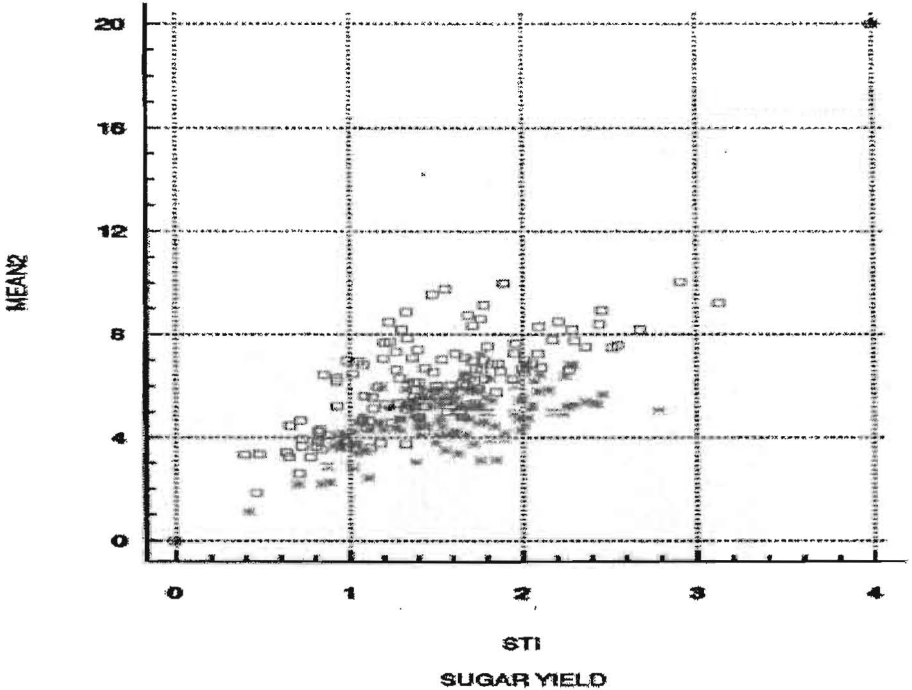

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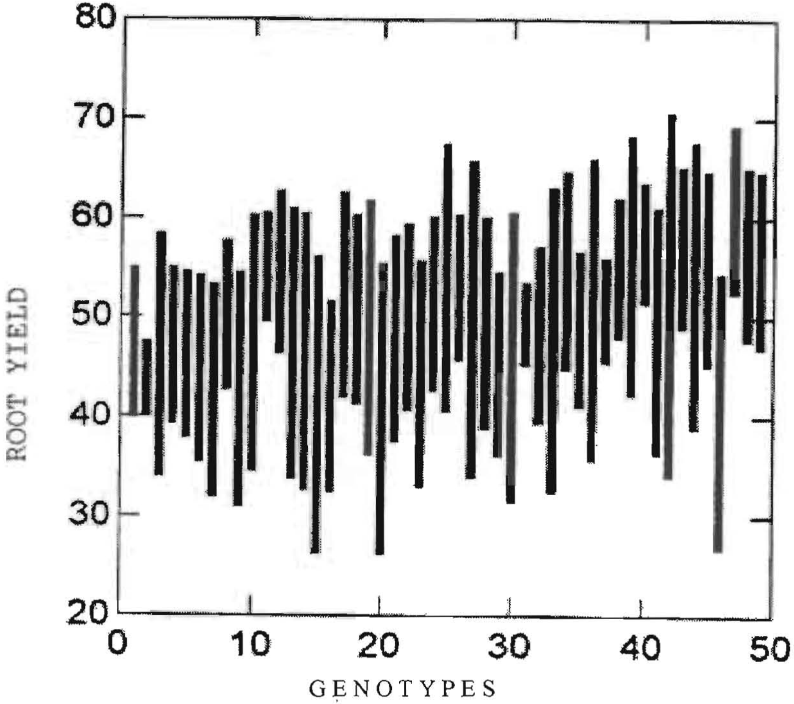


Figure 2A1: Root yield and white sugar yield of 49 sugarbeet lines under drought and well watered conditions, in 1996 (A), 1997 (B), and 1998 (C). In 1998 only data from Karadj was used. Each bar represents the range for each genotype mean, combined over locations (Karadj and Mashhad).

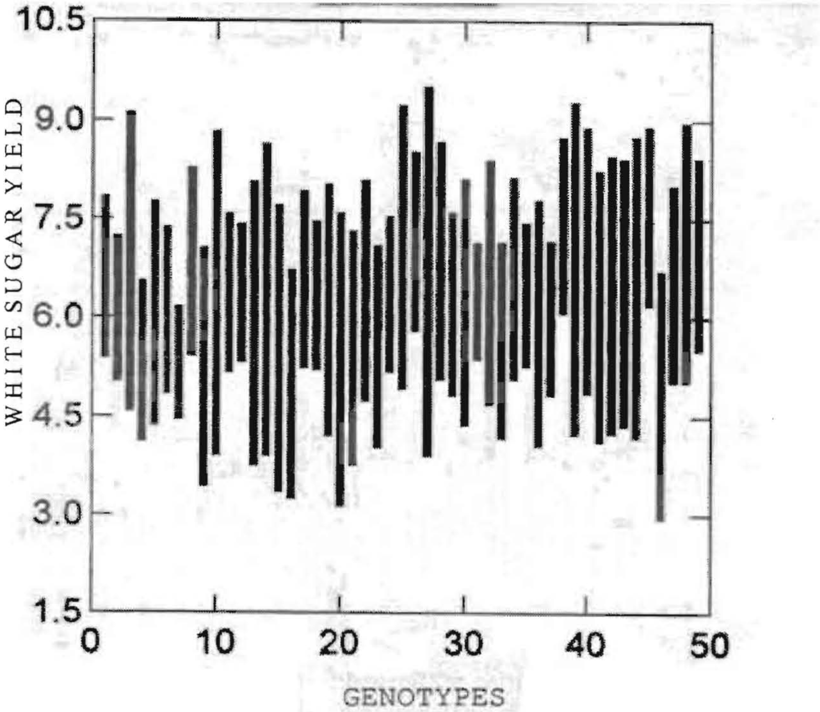


Figure 2A2: Root yield and white sugar yield of 49 sugarbeet lines under drought and well watered conditions, in 1996 (A), 1997 (B), and 1998 (C). In 1998 only data from Karadj was used. Each bar represents the range for each genotype mean, combined over locations (Karadj and Mashhad).

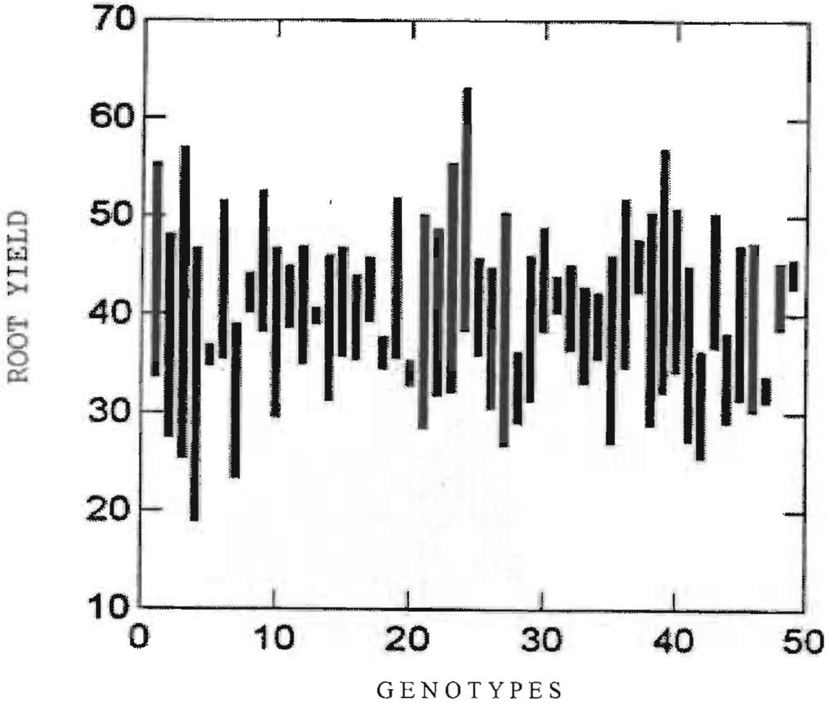
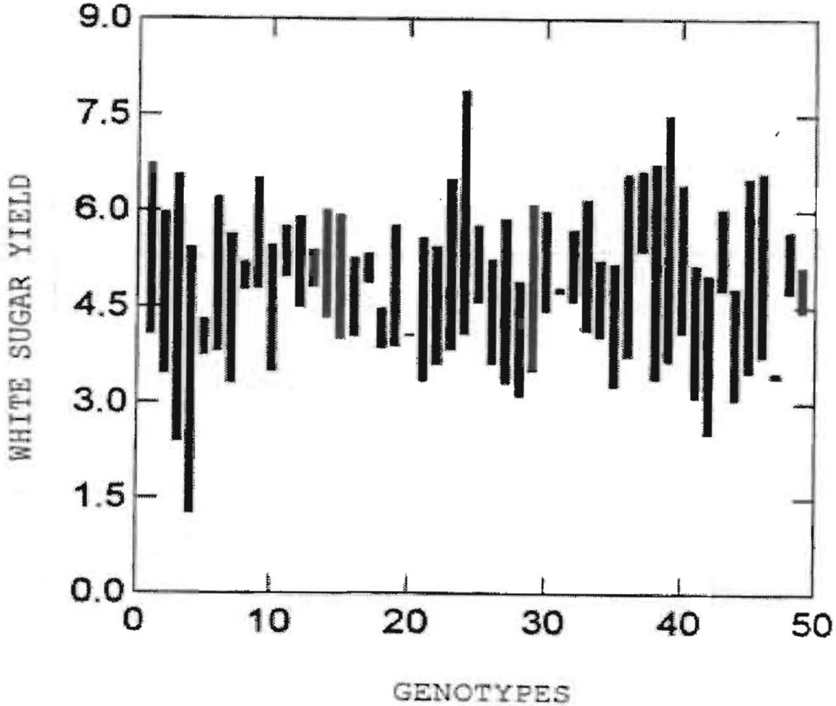


Figure 2B1: Root yield and white sugar yield of 49 sugarbeet lines under drought and well watered conditions, in 1996 (A), 1997 (B), and 1998 (C). In 1998 only data from Karadj was used. Each bar represents the range for each genotype mean, combined over locations (Karadj and Mashhad).



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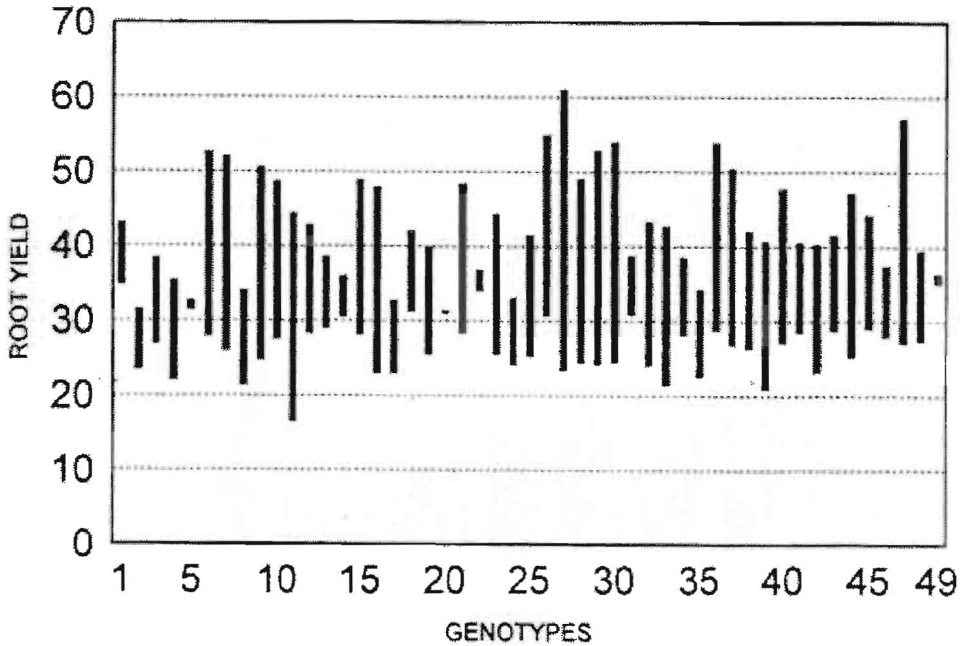

Figure 2C1: Root yield and white sugar yield of 49 sugarbeet lines under drought and well watered conditions, in 1996 (A), 1997 (B), and 1998 (C). In 1998 only data from Karadj was used. Each bar represents the range for each genotype mean, combined over locations (Karadj and Mashhad).

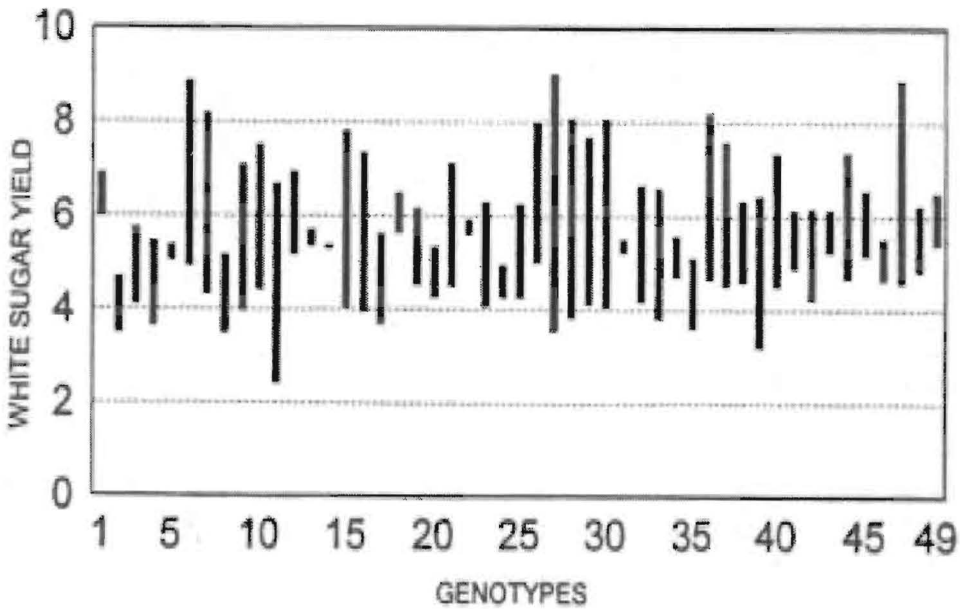

Figure 2C2: Root yield and white sugar yield of 49 sugarbeet lines under drought and well watered conditions, in 1996 (A), 1997 (B), and 1998 (C). In 1998 only data from Karadj was used. Each bar represents the range for each genotype mean, combined over locations (Karadj and Mashhad).

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