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Relation between Sugarbeet Traits and Water use Efficiency in Water Stressed Genotypes

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Abstract: Drought stress is one of the major problems affecting sugarbeet crop production in semiarid regions of the world. In this study, 12 sugar beet lines differed in drought tolerance were evaluated in field experiments for water use efficiency, root yield, sugar content, sugar yield, white sugar yield, purity and impurities with adequate water and under drought stress in Karaj in 1998. Water stress was initiated at about the six-leaf stage. The stress was continuous throughout the growing season. Some physiological characters such as biomass, root dry weight and the ratio of root/top were also included in the stress trial. Analysis of variance was conducted to identify genotypic differences. The relationship between water use efficiency (WUE) with root yield (RY), sugar yield (SY), purity, root dry weight, biomass and impurities such as sodium (Na), potassium (K) and α-amino nitrogen (α-N) was determined in the stress trial. Significant differences were found between lines for Na, K, α-N, purity and molasses sugar (MS) under well-watered condition and for root yield, sugar yield, sugar content, K, α-N, water use efficiency, root dry weight and biomass in stress experiment. Root yield and sugar yield exhibited large differential genotypic responses to drought stress. Genotypes 12, 1 and 4 demonstrated high sugar yield as well as high water use efficiency under stress condition as compared to the other genotypes. These genotypes could be useful for developing productive varieties in the stress environments. There was close associations between WUE with root yield, sugar yield, root dry weight and biomass in the stress trial. Drought generally increased the content of impurities such as sodium (Na), potassium (K) and α-amino nitrogen (α-N) which could affect the quality of beet process in the factory. Under stress condition, very drought tolerant lines contained lower concentration of sodium (Na) than the susceptible ones, although exceptional genotypes were distinguished. These observations indicated that drought tolerance is still very complex and sugarbeet breeders need more efficient techniques, under either dry or wet environments, to improve water use efficiency in this crop.

Key words: *Beta vulgaris* L., drought, stress, water use efficiency, relationship, genotype

INTRODUCTION

Water deficit is a major limiting factor affecting sugarbeet production in semi-arid regions of the world. Drought stress is also one of the major problems of sugarbeet production in some parts of Europe. Jaggard *et al.*[1] estimated the yield loss of sugarbeet due to drought in three agro-climatic regions of the UK and determined on average an annual loss of about 141000 t of sugar or 10.5% of production.

Effect of selection for drought tolerance on performance of tropical maize (*Zea mays* L.) under a range of nitrogen (N) levels was examined and significant differences were found between genotypes under sever N stress[2]. A strong association was found between grain yield and harvest indexes of tropical maize in drought stress[3]. In common bean, seed and pod number exhibited a large differential genotypic response to water stress and a negative correlation between relative water content (RWC) in the plant and yield components was found[4]. Comparison of sorghum hybrids and their parents under drought stress in the field showed that above-ground dry matter accumulation in hybrids were significantly greater than in the parents at harvest time[5]. Ehdaie[6] studied each component trait of spring wheat cultivars contributing to the variation of water use efficiency. In this study, significant genotypic variations were found for WUE (ratio of grain yield to water used), evapotranspiration efficiency (ratio of total dry matter to water used) and harvest index (ratio of grain yield to total dry matter).

Clarke *et al.*[7] investigated the physiological basis of the sugar beet responses to drought stress. They used relative water content (RWC) and the ratio of variable fluorescence (F_v) to the maximal fluorescence (F_m) as a measure of photosynthetic efficiency in the leaves of young sugar beet plants for the classification of different varieties. During the stress sugarbeet accumulated amino acids and glycinebetaine. Unfortunately these, together with sodium and potassium were the principal impurities,

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which could reduce beet quality for processing. Schittenhelm[8] compared the agronomic performance of root chicory, jerusalam artichoke and sugarbeet in stress and non-stress environments. The results revealed that the yield of storage organ of chicory and sugarbeet was less affected by water deficit stress than that of jerusalam artichoke. It indicated that root crops were capable of avoiding drought by developing deep rooting system.

Rover and Buttner[9] reported the effects of periodically and permanently shortage water on sugarbeet plants and concluded that either periodic or permanent stress increased significantly the content of important non-sugar compounds (impurities) such as potassium, sodium, α-amino nitrogen and glycinebetaine and consequently increased sugar in molasses. Genotypes of sugarbeet can be categorised into four groups according to their performance in drought and favourable conditions: genotypes with high performances in both conditions, genotypes with higher yield in non-stress conditions, genotypes with a relatively good yield in stress conditions and genotypes with a poor yield in both conditions[10]. The genotypes with high performances in both stress and non-stress conditions were selected for breeding purposes. A study was carried out in the field as well as in the greenhouse by Clover *et al.*[11] where sugarbeet plants were exposed to drought stress by either withholding irrigation or covering the experimental plots with automated rain filters. Drought stress greatly reduced total dry matter yield of sugarbeet. That was due to reductions in the yield of both storage roots and foliage of plants around 29 and 20%, respectively. In addition, it consistently increased the concentration of amino-nitrogen in the storage root. Drought tolerance or high water use efficiency should be considered essential breeding or agronomy objectives in areas where the sugarbeet crop is likely to encounter a water deficit during the growing season[12,13].

The objectives were conducted to study the relation between water use efficiency (WUE), agronomic and physiological characters of sugarbeet genotypes differed in drought tolerance. Genotypes under drought and well-watered experiments were also compared for WUE and beet characteristics.

MATERIALS AND METHODS

Two field experiments separated by 5 m were planted at the experimental field of Sugar Beet Seed Institute, Karaj, Iran, 1998. A total of 12 diverse sugarbeet lines were used in each experiment. A Randomised Complete Block Design with two replicates was laid out. Plots consisted of three rows, 8 m in length, inter row spacing was 50 cm and interplant spacing was 20 cm. A furrow irrigation system was applied. In each irrigation, input and runoff water was measured by W.S.C. flume in both experiments. It was supposed that plots received equal water for each experiment. After thinning at the seedling stage, a desired density of 100000 plants ha^{-1} was obtained. One of the experiments was irrigated with the adequate water until the plants harvested. In this experiment the irrigation started when 60% of the available water depleted. In the other experiment, drought stress performed by withholding irrigation until the soil water content at a depth of 0 to 60 cm reached to the wilting point (100% of available water depleted). Moisture content of the soil was measured using a Troxler instrument, model Sentry 2000 (TDR).

Important agronomic characters such as root yield (RY), sugar content (SC), sugar yield (gross sugar per hectare), white sugar yield (WSY), yield of extractable sugar (purity), non-sugar compounds (impurities) as sodium (Na), potassium (K), α-amino nitrogen (α-N), molasses sugar (MS) were determined[13]. Water use efficiency (WUE) defined as the ratio of WSY to total water used[6] in cereals grain yield was considered instead of WSY. The total water included both transpiration and soil evaporation water. In addition, top (foliage parts) dry weights (TDW), root dry weights (RDW), biomass and the root/top ratio were calculated for each plot in the stress trial.

All variables at each experiment were subjected to analysis of variance (ANOVA) using SAS procedure[14]. A regression model was applied to explain the relationship between WUE with RY, SC, SY, biomass and impurities (K, Na and α-N) for different genotypes in the stress experiment. Lines were also compared for RY, SY, SC and WUE in stress and non-stress experiments.

RESULTS AND DISCUSSION

No significant differences were found among the 12 lines of the well-watered (control) experiment for important economic traits such as RY, SY, WSY and WUE. It indicated that lines had similar performances for those characters under an optimal condition. Impurities (Na, K, α-N, Na/K and MS), SC and PUR were also varied significantly among genotypes in the well-watered experiment (Table 1). It means that enough genetic variations exist within the 12 lines for the characters (SC and PUR) which increase the quality of sugarbeet. Traits decreasing purity or extractable sugar were also of vital importance. In contrast to the control trial, water deficit increased genetic variances for RY, SY, WSY and WUE (Table 2). Drought also had statistically significant effects on the RDW, biomass, SC, K and α-N.

Table 1: Mean squares estimated for root yield (RY), sugar yield (SY), white sugar yield (WSY), water use efficiency (WUE), sugar content (SC), potassium (K), sodium(Na), alfa-amino nitrogen(α-N), Na/K, purity (PUR) and mollasses sugar (MS) in the non-stress experiment

S.O.V.	df	RY	SY	WSY	WUE	SC	K	Na	α-N	Na/K	PUR	MS
Replication	1	158.62	6.05	4.103	0.043	0.476	0.14	0.035	0.398	0.000	0.053	0.017
Genotype	11	73.78	2.06	1.307	0.015	0.476*	0.24*	0.153*	0.386*	0.003*	3.947**	0.088**
Error	11	96.09	2.65	1.823	0.019	0.224	0.05	0.063	0.189	0.001	1.248	0.020
CV.(%)		21.45	20.14	19.610	20.140	2.660	3.80	13.960	26.170	12.980	1.310	5.390

* and ** significant at 0.05% and 0.01% probability levels, respectively

Table 2: Mean squares estimated for root yield (RY), sugar yield (SY), whit sugar yield (WSY), water use efficiency (WUE), sugar content (SC), potassium (K), sodium (Na), nitrogen(α-N), Na/K, purity (PUR) and molasses sugar (MS), top dry weight (TDW), root dry weight (RDW), biomass, and root/top (R/T) in the stress experiment

S.O.V.	df	RY[a]	SY	WSY	RDW[b]	Biomass	R/T	WUE	SC	K	Na	α-N	Na/K	PUR	MS
Replication	1	25.856	0.548	0.531	0.950	1.541	0.350	0.008	1.425	0.348	0.015	2.331	0.000	1.019	0.001
Genotype	11	37.502*	2.069**	1.661**	2.416*	4.288*	0.246	0.030**	4.029*	0.451*	0.064	0.570*	0.008*	1.340	0.240
Error	11	13.978	0.478	0.388	1.397	3.018	0.664	0.007	1.883	0.312	0.076	0.520	0.005	3.696	0.140
CV.(%)		13.290	12.710	13.000	17.350	18.170	27.750	12.710	7.100	10.180	18.210	34.910	24.160	2.190	16.800

* and ** significant at 0.05% and 0.01% probability levels, respectively; a = weight of fresh root and b = weight of dried root

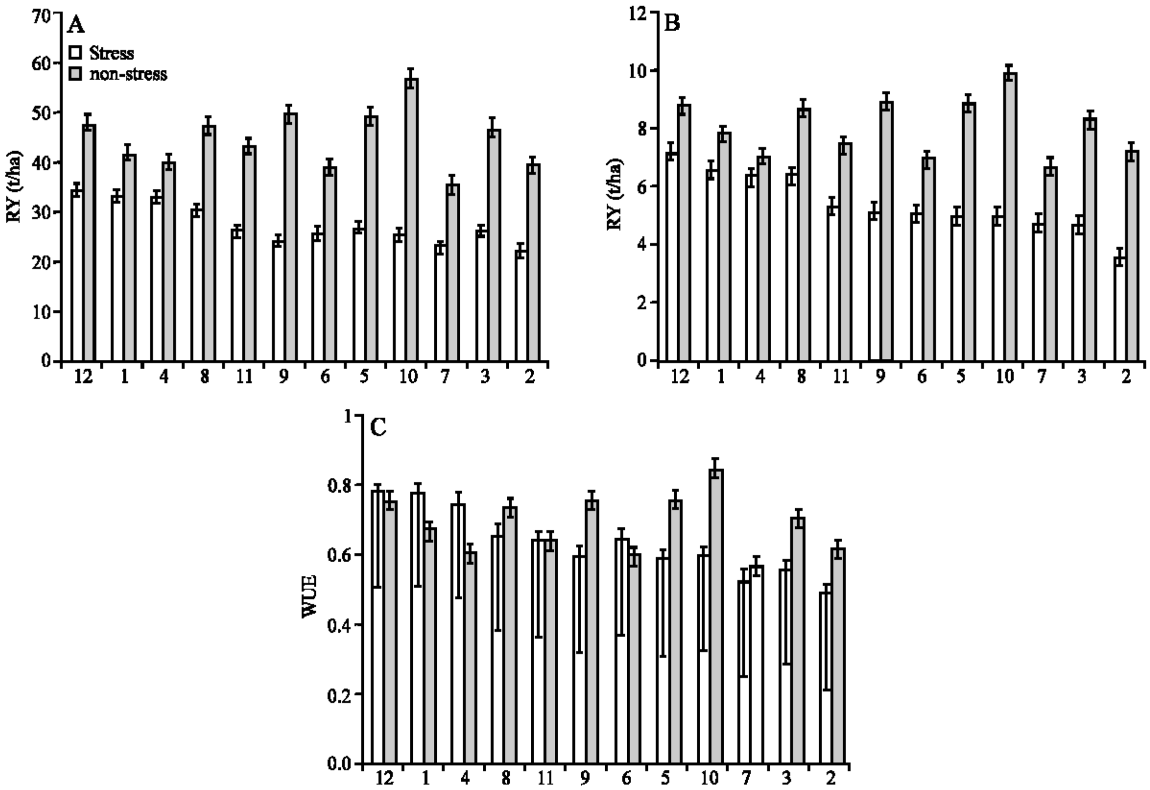

Fig. 1: Comparison of 12 sugar beet lines for root yield (A), sugar yield (B) and water use efficiency © under stress and non-stress conditions. ⊥ shows the error bar

The impact of water on the performance of genotypes was assessed in Fig. 1A and B. Root and sugar yield consistently decreased due to the drought and more than 50% yield losses occurred for the sensitive genotypes (lines 10, 9 and 5). Yield increases due to irrigation depend on the several factors. Soil holding capacity and precipitation are the two most important. Adequate soil fertility also plays an essential role in achieving the higher yield potential under irrigation. Since sugar beet has long taproots it is capable in exploiting water from the lower soil horizons. When irrigation water was sufficient and evenly distributed in the sugarbeet field, a rapid growth of storage root would be occurred[8]. The patterns of WUE in the drought and non-drought experiments were not consistent (Fig. 1C). Mean values of WUE were not significantly different between the two experiments (data not shown). But drought tolerant lines (12, 1 and 4) presented the highest WUE in the dry experiment,

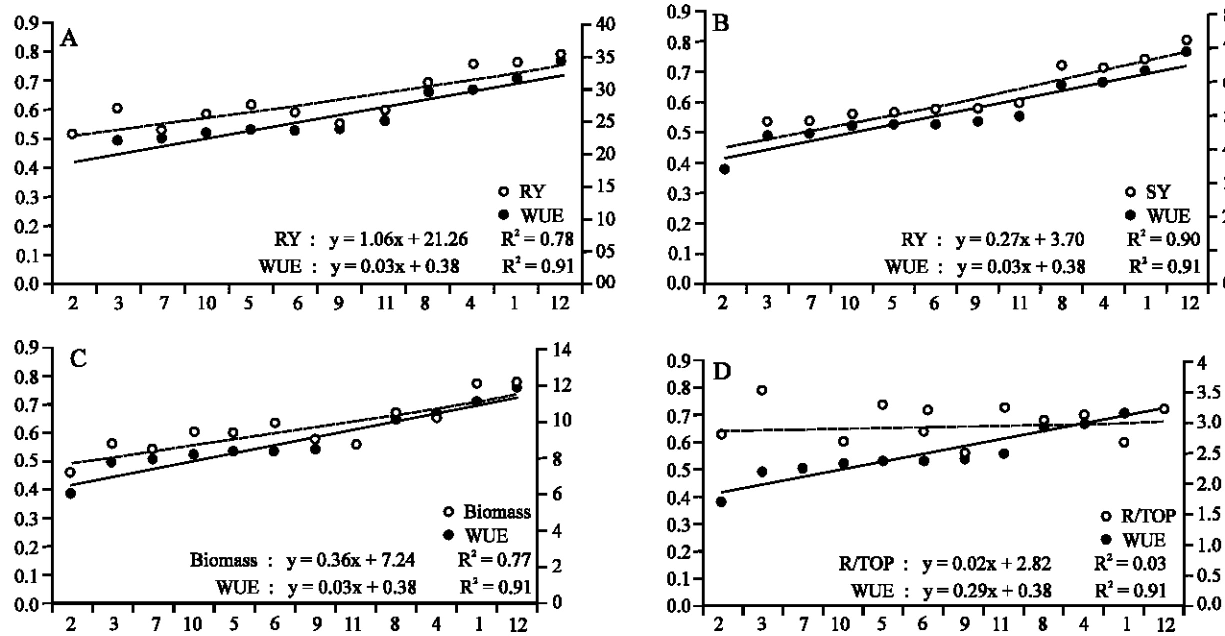

Fig. 2: The regression line of water use efficiency (WUE) was compared with that of root yield (A), sugar yield (B), biomass (C) and ratio of root/top (D) for 12 sugarbeet genotypes in the drought stress experiment

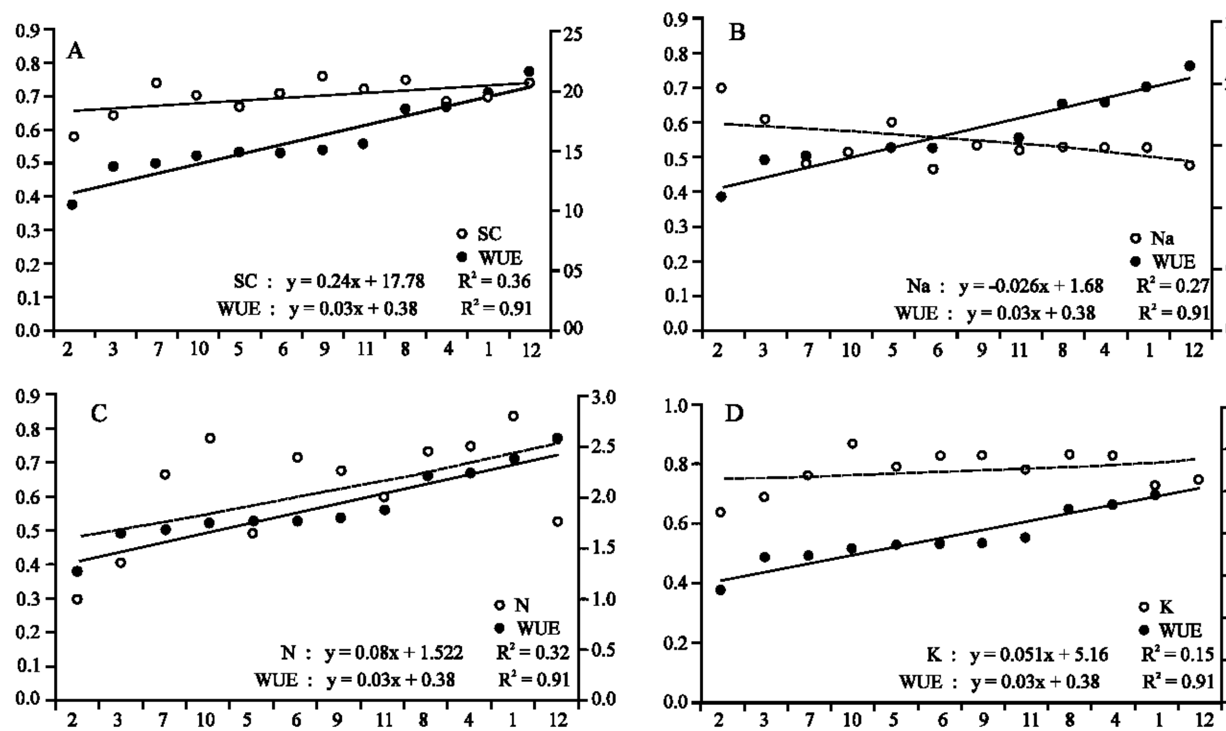

Fig. 3: The regression line of water use efficiency (WUE) compared with that of sugar content (A), sodium (B), alfa-amino Nitrogen (C) and potassium (D) for 12 sugarbeet genotypes in the drought stress experiment

indicating that genotypes having the highest WUE in the dry trial could produce highest storage root and sugar yield in water deficit condition. In contrast to our results, Ehdaie *et al.*[6] observed a negative correlation between WUE and aboveground dry matter and grain yield in wheat. It was suggested that root crops such as sugarbeet and chicory were capable of avoiding drought by developing deep rooting systems in the soil[8]. It seems that the relationship between WUE and yield have varied among studies and have been depending on particular crops and environmental factors. Indeed, storage organs of photosynthetic matters, root distribution and root water uptake capacity and efficiency may affect the WUE of plants.

In the present study, WUE was consistently associated with RY, SY and total biomass in the dry experiment (Fig. 2A-C). At final harvest, high WUE values of genotypes were accompanying with increases of total dry matter yield in the stress condition. A very poor relation between WUE and the R/T ratio indicated that increases of WUE had no positive or negative effects on the top yields (Fig. 2D). Clover *et al.*[11] reported drought stress generally decreased mean leaf size of sugarbeet by 17% and consequently resulted in a considerable reduction of total foliage cover in the field. Reduction of mean total cover and early leaf senescence were also observed in the droughted field (data not shown) but a poor canopy structure was not reasonably related to a low WUE or low dry matter yield.

The regression line of WUE was compared with that of SC and impurity components such as Na, K and α-N for 12 genotypes in the stress trial (Fig. 3). Although the genotypes displayed significant differences in the sugar content of their storage root (Table 2) but an increase of WUE was related to a relatively small increase of sugar content (Fig. 3A). Accumulation of sodium (Na) in the root was not strongly correspondent to the WUE obtained for various genotypes; nevertheless, Na concentration had a rather small and negative relation with WUE (Fig. 3B). However, genotypes having high WUE may comparatively assimilate lower amount of Na in the dry condition. The pattern of potassium (K) was more or less similar to that of SC for stressed genotypes (Fig. 3D). Although genotypes that were characterised containing both greater yield potential and higher WUE values, their potassium concentration was increased slightly. However, high WUE was not necessarily achieved by a rapid increase of K.

Among the impurities (K, Na and α-N) measured in this study, the regression line of alfa-amino nitrogen accumulation showed similar tendencies to WUE in the stressed genotypes (Fig. 3C). Genotypes showed both the highest productivity and WUE absorbed more N fertilizer from the soil as compared to other genotypes, i.e. increased α-N concentration was pronounced in the lines 12, 1 and 4. Previous studies represented that drought consistently influenced the quality of sugarbeet by increasing impurities such as alfa-amino nitrogen, sodium, potassium and glycinebetaine and decreasing extractable sugar[9-11,15]. Clover *et al.*[11] claimed that drought had a remarkable effect on the concentration of α-amino nitrogen in the storage root but had little effect on potassium and sodium contents. Sadeghian *et al.*[10] reported potassium had the highest variation in sugarbeet germplasm under stress conditions as compared to other impurities. Biomass and N accumulation were closely related in corn and selection under well-fertilized soil could not define precisely genotypic effects for drought tolerance[2]. Maximum sugar yields generally attained at the highest level of N fertilization in beet[8] and both water shortage and nitrogen stress reduces considerably storage organs of beet and chicory. Therefore, high accumulation of N fertilizer is most likely attributable to the ability of water and N uptake capacity of roots in sugar beet genotypes.

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