Effect of Salinity on Growth and Leaf Photosynthesis of Two Sugar Beet (*Beta vulgaris* L.) Cultivars

A. Dadkhah[1]

ABSTRACT

This study investigated the variation between two sugar beet (*Beta vulgaris* L.) cultivars with respect to growth parameters and photosynthetic rates of individual attached leaves during salinization. Sugar beet plants grown in sand culture were gradually exposed to different levels of salinity (0, 50, 150 , 250, and 350 mM, NaCl+CaCl$_2$ in 5:1 ratio). Salt concentrations significantly decreased all growth traits. At the highest level of salinity (350 mM), cv 7233- P$_{29}$ showed a significantly higher leaf area and total dry matter than Madison after eight weeks of salt treatment commencment. Net photosynthesis (A$_{CO2}$) and stomatal conductance (g$_s$) were strongly affected by salinity. The Na$^+$ and Cl$^-$ concentrations in shoots significantly increased as salt concentration increased. Net photosynthesis (A$_{CO2}$) was plotted against computed leaf internal CO$_2$ concentration (C$_i$), and the initial slope of this A$_{CO2}$-C$_i$ curve was used as a measure of photosynthetic ability. Leaves from plants exposed to 50 mM salinity showed little change in photosynthesis, whereas those treated by high levels of salinity had up to 91.5% inhibition in photosynthetic rates and an increase in CO$_2$ compensation point. Leaf chlorophyll content increased with increasing salinity. Although partial stomatal closure occurred with salinization, reductions in photosynthesis were partly non-stomatal at high levels of salt treatment.

Keywords: Gas exchange, Plant growth, Salt stress, Sugar beet.

INTRODUCTION

Growth of higher plants in saline soil depends on salt tolerance of the plant species. The decrease in plant growth due to salinity includes a reduction in the leaf area of the plant. The reduction in growth is a consequence of several physiological responses including modification of ion balance, water status, mineral nutrition, stomatal behaviour and photosynthetic efficiency (De-Herraled *et al*., 1998; Hester *et al*., 2001; Ghoulam *et al*., 2002; Al-Khateeb, 2006; Koyro, 2006).

Photosynthesis, as one of the most important physiological processes, provides 90% of the plant dry matter (Steduto *et al*., 2000). Several researchers have published convincing evidence showing that photosynthetic carbon metabolism is affected by reduced plant water potentials (Sultana *et al*., 1999; Steduto *et al*., 2000; Hester *et al*., 2001; Koyro, 2006). The photosynthetic capacity of plants grown under saline conditions is depressed depending on type of salinity, duration of treatment, species and plant age (Sultana *et al*., 1999; Steduto *et al*., 2000; Hester *et al*., 2001; Koyro, 2006).

Many studies have concluded that the reduction in photosynthesis in response to salinity is to some extent the result of reduced stomatal conductance and, consequently, restriction of the availability of CO$_2$ for carboxylation (Everard *et al*., 1994; Chartzoulakis *et al*., 1995; Koyro, 2006). Reduction in transpiration rate under salinity is another evidence for interference

---
[1] Department of Agronomy, College of Agriculture, Ferdowsi University of Mashhad, Islamic Republic of Iran. e-mail: dadkhah@um.ac.ir

of salinity to stomatal conductance. Although reduction of photosynthesis by salinity is partly due to a reduced stomatal conductance, non-stomatal inhibition of photosynthesis, caused by direct effects of NaCl on the photosynthetic apparatus, has been reported for some species (Seemann and Sharkey, 1986; Delfine *et al.*, 1998; Sultana *et al.*, 1999; Steduto *et al.*, 2000). These non-stomatal factors consist of a reduced efficiency of RuBP carboxylase, reduction of RuBP regeneration, the sensitivity of photosystem II to NaCl and a reduction in chlorophyll pigments to absorb enough light (Ball and Farquhar 1984; Ball and Anderson 1986; Seemann and Sharkey, 1986).

Since information on phisiological changes occurring during salt stress is lacking for sugar beet, which is relatively tolerant of saline environments, the aim of this study was to compare the response to salinity of two cultivars of sugarbeet. The different varieties were chosen according to preliminary information on their growth under saline conditions (Dadkhah and Griffiths, 2006). In this paper, the effect of different levels of salinity treatment on gas exchange, stomatal conductance and chlorophyll content of two sugar beet cultivars are discribed.

MATERIALS AND METHODS

Plant Materials and Growth Conditions

A pot experiment was carried out based on randomized complete block design with six replications to investigate the effect of salt stress on growth and gas exchange of two sugar beet (*Beta vulgaris*) cultivars, one of Iranian origin (7233-P_{29}) and a British (Madison) cultivar, which were chosen according to preliminary information on their growth under saline conditions (Dadkhah and Grifiths, 2006).

Seeds were sown 5 mm deep in plastic containers (40×20×10 cm) filled with vermiculite. After emergence, seedlings were transplanted to 15 cm diameter plastic pots (one seedling per pot) containing washed sand, with a saucer under them to prevent leaching after irrigation, and transferred to controlled conditions. The growth conditions were 26±1°C/16±1°C (day/night), while relative humidity was between 45-55%. Photon flux density (PFD) was about 350 μmol m^{-2} s^{-1} at canopy height with 16-h photoperiod. Five levels of salinity (0, 50, 150, 250, 350 mM NaCl+CaCl$_2$ in 5:1 molar ratio) were imposed through irrigation from the time most plants were at the 4-leaf stage and continued for 8 weeks. Salts were added to modified Hoagland nutrient solution (Maas and Poss, 1989). The pots were flushed out with saline water containing nutrients every week to ensure homogeneity of salinity and nutrient supply in the growth medium. To prevent shock to plants, irrigation started with 50 mM saline water and was increased by 50 mM every other day until reaching each salinity level.

Growth was measured as leaf area, number of leaves, and dry matter accumulation. Plants were harvested after 8 weeks of salt treatment and were separated into leaf lamina, petioles, stem, and roots. These components were dried for 48h at 70°C in a convection oven and weighed.

Data Collection

Gas exchange patterns in sugar beet leaves were studied in the presence of salinity under controlled environmental condition. Net photosynthesis (A$_{CO2}$) of the attached youngest fully expanded leaf (youngest leaf over 50% full size) and the oldest leaf were measured by enclosing the middle part of leaf in the cuvette of a Combined Infra Red Gas Analysis System (CIRAS-1 Portable photosynthesis system) at week 8 after commencement of salinity tretment. The area of cuvette that caught full illumination was 2.5 cm^2. Measurements and results were displayed on the analyzer display panel and also recorded on the data storage system. In order to study photosynthetic efficiency,

photosynthetic rates of individual attached leaves were measured at ambient CO_2 concentration and different levels of external CO_2 concentrations ranging from approximately 70 to 1,500 μ mol CO_2 mol^{-1} air and saturated light intensity (1,500 μ mol photon m^{-2} s^{-1}).

Extraction of chlorophyll pigments from the finely ground leaf samples was carried out using 80% acetone. The absorbance of optically clear filtrates was measured at 664 and 647 nm using a Beckman spectrophotometer. The chlorophyll *a*, *b* and total chlorophyll (μg per cm^2) were computed using the equations given by Porra *et al*. (1984).

Leaf chlorophyll fluorescence measurements were made on the youngest fully expanded leaves (youngest leaf over 50% full size) at week 8 by using the Plant Efficiency Analyser (PEA) (Hansatech, Norfolla England). Measurement of maximum and minimum chlorophyll fluorescence (F_m and F_0, respectively) was used to assess photosynthetic tolerance to environmental constraints. The F_v (variable fluorescence)/F_m ratio ($F_v = F_m – F_0$) gives an indication of the status of the photosynthetic apparatus, since fluorescence emission is inversely proportional to the amount of light utilized for photosynthesis. Determination of F_v/F_m ratio was made on dark- adapted leaves from all treatments.

The concentrations of Na^+ and K^+ in leaves blade that were used for gas-exchange measurement, were determined by flame photometer (JENWAY, PEP-7).

Leaf Cl^- content was measured by ion-exchange chromatography using DIONEX Model DX 500, fitted with a CD20 conductivity Detector, IP 25 pump and AS 14 Ion Exchange Column.

The experiment was carried out based on randomized complete block design with six replications. The measurements were made on six plants in each treatment. The data for all characters was analysed using the analysis of variance procedure of Statistical Analysis System (SAS) software, version 6.12. Means were compared by Duncan's multiple range tests at the 0.05 probability level for all comparisons.

RESULTS AND DISCUSSION

Impacts of Salinity on Growth

Plant growth was measured as shoot and root dry matter, number of leaves, and total plant leaf area. All growth characters were significantly decreased by increasing salinity. However, the sensitivity of the different characters to salinity varied. Total leaf area was reduced by 57.6% (average of the 2 cultivars) in plants grown at high level of salinity (350 Mm) compared to the leaf area of non-stressed plants after 8 weeks of salinization (Table 1). Leaf number per plant was significantly decreased as salinity increased in both cultivars. However, low level of salt treatment (50 mM) slightly increased leaf number per plant. This increase was not statistically significant.

Table 1. Mean live leaf area (cm^2 per plant) at different levels of salinity and percentage of reduction (compared to the control) . Each number is the average of six replications.

Salinity (mM)	0		50		150		250		350	
cvs	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%
Madi	41± 851	0.0	31± 801	5.90	29± 499	38.50	20± 320	60.50	20± 286	66.40
P_{29}	35± 813	0.0	50± 813	0.00	18± 570	29.89	31± 450	44.70	15± 420	48.34
Avg.	832.0	0.00	807.0	3.00	534.0	35.80	385.0	53.73	353.0	57.60

The values are the Mean±SE of six plants. The difference among treatments is significant at the 5% level according to Duncan's multiple range test.

Table 2. Mean number of leaves per plant at different levels of salinity and percentage of reduction (compared to the control). Each number is the average of six replications.

Salinity (mM)	0		50		150		250		350	
cvs	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%
Madi	1 ± 14	0.0	1.7 ± 16	-14.3	1.2 ± 13	7.10	1 ± 12	14.3	0.6 ± 10	28.60
P_{29}	0.6 ± 11	0.0	1.1 ± 11.7	-6.40	0.6 ± 10.5	4.50	1 ± 10	9.10	1.5 ± 9.2	16.40
Avg.	12.5	0.00	13.85	-10.8	11.75	6.0	11.0	12	9.6	23.2

The values are the Mean$\pm$SE of six plants. The difference among treatments is significant at the 5% level according to Duncan's multiple range test.

Cultivar Madison had greater reduction in leaf numbers due to salinity after 8 weeks of salt treatment (Table 2). However, leaf number of Madison was higher than cv P_{29} at all levels of salinity but its total leaf area was less than P_{29}. Therefore, it can be concluded that Madison genetically produces more, but smaller, leaves. The results show that the leaf number was less affected than leaf area by salinity. It suggested that most of the reduction in plant leaf area due to salinity was caused by the inhibition of leaf expansion. This is consistent with the result of previous research, which showed that high levels of salinity decreased leaf area due to a combination of a decrease in cell number and cell size (De-Herralde *et al.*, 1998). Witkwski and Lamont (1991) reported that plants might reduce water loss by reducing their evaporation surface. Therefore, leaves tend to be smaller and thicker in saline conditions.

Salt stress significantly reduced dry matter production (Table 3). Total plant dry matter at the highest salinity (350 mM) was decreased by 50.6% (mean of both cvs) compared to dry matter of non-stressed plants after 8 weeks of salinity treatment. At the highest salinity, cv P_{29} had greater dry weight than Madison. Shoot dry weight was significantly reduced by salinity. Shoot dry weight at the highest salinity (350 mM) decreased by 43.55% (mean of 2 cvs)

Table 3: Total dry weight, shoot dry weight, and root dry weight (gr per plant) and percentage of reduction (compared to the control) of sugar beet cultivars at different levels of salinity after 8 weeks of salinization. Each number is the mean of six replications.

Salinity (mM)	0		50		150		250		350	
					Total dry weight (gr per plant)					
cvs	Actual	%	Actual	%	Actual	%	Actual	%	Actual	%
Madison	0.02 ± 9.1	0.0	0.2 ± 7.99	12.2	0.4 ± 5.8	36.3	0.4 ± 4.57	49.45	0.3 ± 3.70	59.30
P_{29}	0.4 ± 7.9	0.0	1.0 ± 8.00	-1.3	0.9 ± 6.4	18.99	0.7 ± 5.02	36.20	0.2 ± 4.70	40.40
Avg.	8.5	0.00	8.0	5.90	6.1	28.24	4.80	43.53	4.20	50.60
					Shoot dry weight (gr per plant)					
Madison	0.07 ± 6.4	0.0	0.3 ± 6.2	3.13	0.50 ± 4.4	31.25	0.4 ± 3.5	45.31	0.04 ± 3.1	51.60
P_{29}	0.2 ± 6.0	0.0	1.0 ± 6.8	-13.30	0.8 ± 5.4	10.00	1.0 ± 4.1	31.70	0.3 ± 3.9	35.00
Avg.	6.20	0.00	6.50	-4.84	4.90	20.0	3.80	38.70	3.50	43.55
					Root dry weight (g per plant)					
Madison	0.09 ± 2.7	0.0	0.1 ± 1.8	33.3	0.1 ± 1.4	48.1	0.04 ± 1.07	60.4	0.4 ± 0.59	78.2
P_{29}	0.2 ± 1.9	0.0	0.4 ± 1.2	36.8	0.1 ± 1.0	47.4	0.03 ± 0.94	50.5	0.1 ± 0.79	50.5
Avg.	2.30	0.00	1.50	34.80	1.20	47.83	1.00	56.52	0.69	70.0

compared to non-stressed plants. Shoot dry weight of cv Madison decreased compared to its control at the same time (Table 3). Salt stress also had a significant negative effect on root dry weight. The effect of salinity on root dry weight was greater than shoot dry weight because root dry weight of both cvs decreased even at the lowest level of salinity. Root dry weight at the lowest level (50 mM) of salinity decreased by 34.8% compared to root dry weight of non-stressed plants (Table 3). This might be due to the type of sugar beet root (storage root) and also water deficiency caused by concentration of salt in the growth medium. Abdollahian-Noghabi (1999) found that shoot/root ratio of *Beta vulgaris* increased under drought stress condition. The root percentage reduction of cv P_{29} was less than that of Madison at high level of salinity (Table 3), although both were severely influenced. A possible reason for dry matter reduction could be the greater reduction in uptake and utilization of mineral nutrients by plants under salt stress. Pessarakli and Tucker (1985, 1988) reported that total nitrogen uptake of cotton plants decreased with increasing salinity, reflecting primarily a dry matter reduction. The uptake of nitrogen (N) in salt stressed plant might be competitively limited by Cl^- (Aslam *et al.*, 1984; Ward *et al.*, 1986).

Leaf Gas Exchange

Net Photosynthesis (A_{CO2}) significantly ($P \leq 0.001$) decreased with increasing salt concentration (Figure 1-a). Plants grown at low and high levels of salinity had rates that were , respectively, 80% and 8.3% of the controls. Analysis of variance revealed that there were no significant differences between the two cultivars in the rates of net photosynthesis, but cv Madison had higher net photosynthesis than P_{29}. Net photosynthesis rate generally decreased with leaf age (Figure 1-b) and this was paralleled by a lower stomatal conductance. Net photosynthesis rate of cv Madison was
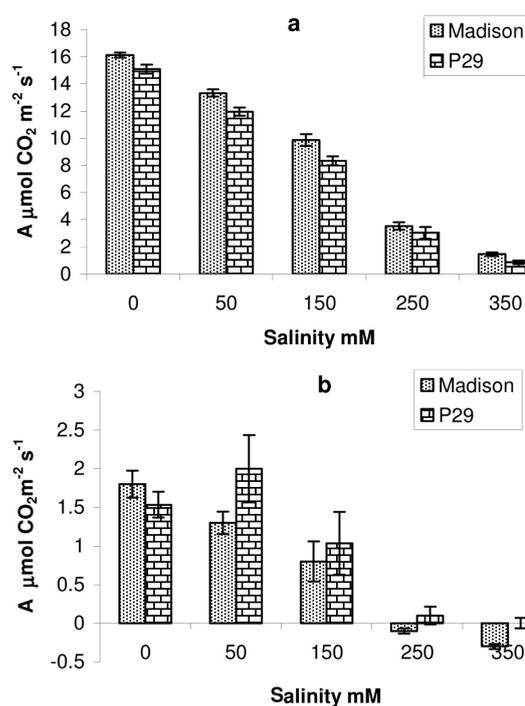

Figure 1. Net photosynthesis rates of the youngest fully expanded (a) and old leaves (b) of two sugar beet cultivars at different levels of salt concentration. Each bar is the average of six measurements. Vertical lines are standard error of the means.

significantly decreased at the lowest level of salinity (50 mM), while P_{29} had a higher net photosynthesis rate compared to its control at the same salt concentration but this was not significant. The photosynthetic rates of old leaves of Madison plants grown at 250 mM salt concentration were below the compensation point, while P_{29} still maintained rates above the compensation point. The photosynthetic rates of old leaves of plants grown at 350 mM of salt concentration were at the compensation point and below it for, respectively, P_{29} and Madison cultivars (Figure 1-b). Therefore, old leaves of these plants were effectively parasitic, whereas old leaves of non-stressed plants and those grown at low levels of salinity still made a positive contribution to the carbon economy of the plant.

The adverse effects of salinity on net photosynthesis (A_{CO2}) was associated with a significant ($P \leq 0.001$) decrease in stomatal

conductance (g_s) (Figure 2). Stomatal conductance of plants irrigated with low level of salinity (50 mM) decreased by 31% compared with the controls. At high level of salinity, stomatal conductance was very low (91.3% decrease compared to the controls).

The ratio of intercellular to ambient CO_2 concentration (C_i:C_a) decreased up to 150 mM salinity compared to the controls (Figure 3). In spite of decreasing A_{CO2} and g_s with increasing levels of salinity, the C_i:C_a
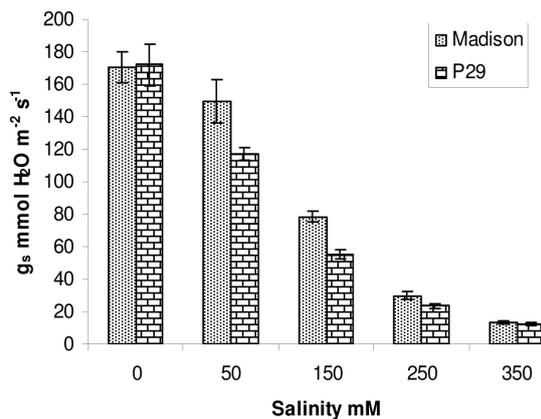

Figure 2. Stomatal conductance (g_s) of youngest expanded leaf (youngest leaf over 50% full size) of two sugar beet cultivars at different levels of salt concentration. Each bar is the average of six measurements. Vertical lines are standard error of the means
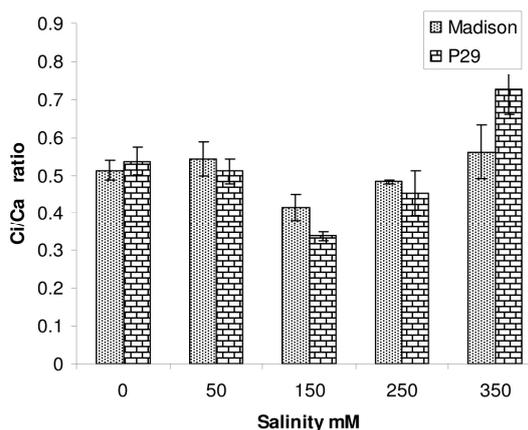

Figure 3. Ratio of intercellular to ambient CO_2 concentration (C_i:C_a) of youngest fully expanded leaves of two sugar beet cultivars at different levels of salinity. Each bar is the average of six measurements. Vertical lines are standard error of the means.

ratio not only showed no significant reduction at 250 mM but also increased at 350 mM. In the control conditions, there was no significant difference in C_i:C_a ratio between the two cultivars.

Salinity and Leaf Ion Concentration

The concentration of salt in the rooting medium induced a subtantial increase in Na^+ concentration in leaves (P≤ 0.001) (Figure 4-a). There were significant differences in leaf sodium concentration between the two cultivars at different levels of salinity. Cultivar P_{29} had significantly higher Na^+ content in its leaves at the lowest salinity (50 mM) than cv Madison (Figure 4-a). However, at the highest salinity level, cv P_{29} had significantly lower leaf sodium content compared to Madison. Leaf K^+ concentration decreased significantly by increasing salinity to around half of the control values at 350 mM (Figure 3-b). Choloride (Cl^-) contents in leaves of both cultivars increased with increasing salt concentration (Figure 3-c). There were no significant differences in leaf Cl^- concentration between the two cultivars in the control plants. At high levels of salinity, cv P_{29} had significantly lower Cl^- content in leaves than Madison. There is substantial evidence that accumulation of inorganic ions, predominantly Na^+ and Cl^-, has an important role in the process of osmotic adjustment. (Ashraf and Ahmad, 2000; Ghoulam *et al*., 2002). The increase in Na^+ and Cl^- concentrations in salinized expanded leaves of the two cultivars was not similar. Cultivar P_{29} (salt tolerant) accumulated less Na^+ and Cl^- in its cells at high levels of salinity compared to cv Madison. Schachtman and Munns (1992) reported that lower rate of Na^+ accumulation in expanding leaves of *Triticum* species might be due to higher leaf expansion and/or a mechanism that limits the transport of roots uptake of Na^+. The lower Na^+ and Cl^- contents in P_{29} at high levels of salinity could be attributed to the higher rates of leaf expansion at high
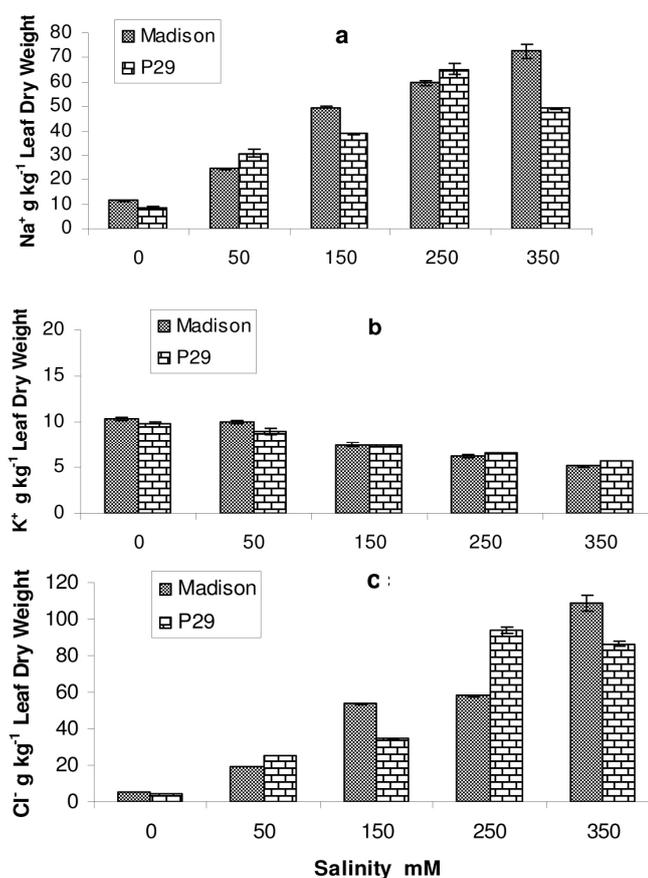
Figure 4. Leaf sodium (Na^+), potassium (K^+) and chloride (Cl^-) concentrations (g kg^{-1} dry weight) after 8 weeks exposure to different salt concentrations. Each bar is the average of six replications. Vertical lines are standard error of the means.

level of salinity in this cultivar. Another possibility might be that cv P_{29} absorbs Na^+ and Cl^- up to a threshold level and, then, acts as a salt excluder.

Leaf Chlorophyll Content and Chlorophyll Fluorescence Analysis

Leaf chlorophyll a, chlorophyll b and total chlorophyll content generally increased with increasing salinity (data not shown). The ratio of chlorophyll a/b was unaffected by salinity up to 150 mM in both cultivars. The amount of leaf total chlorophyll and photosynthetic rate showed a weak negative correlation in the presence of salinity. This could be due to the inverse effect of salinity

on photosynthesis and its positive effect on chlorophyll content.

The ratio of variable to maximum fluorescence (F_v/F_m) was significantly reduced by increasing salt concentration, but not between the controls and the 50 mM salt treatment (Figure 5). The maximum level of fluorescence (F_m) was lower under salinity treatments than in the controls, which suggests that there might have been some damage due to salinity to photosystem II reaction centres, or, in transfer of excitation energy from the antenna to the reaction centres.

Photosynthesis and Stomatal Parameters

The present study indicated substantially lower rates of net photosynthesis and stomatal conductances with increasing salinity. Similar results have been obtained
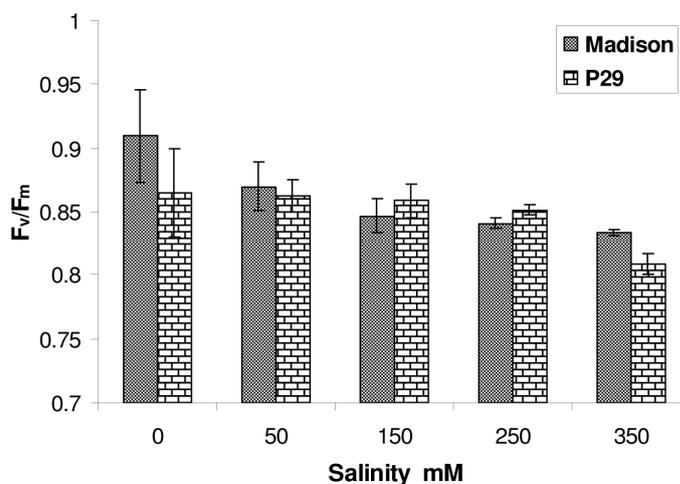
Figure 5. Chlorophyll fluorescence: ratio F_v/F_m of youngest expanded leaves of two sugar beet cultivars at different levels of salinity. Each bar is the mean of six measurements. Vertical lines are standard error of the mean.

with other plant species (Everard *et al.*, 1994; Delfine *et al.*, 1998; Sultana. 1999; Steduto *et al.*, 2000).

Everard *et al.* (1994) reported that, at intermediate salinity (100mM), photosynthesis in celery (*Apium graveolens* L.) was limited by a decrease in stomatal conductance, while at the highest level of salinity (300mM), carboxylation capacity (by measuring C_i) and electron transport (fluorescence) were the apparent prevailing limitations to photosynthesis.

Comparing rates of net photosynthesis under the control conditiond (Figure 1a) revealed that the two cultivars did not have significant differences in gas exchange characteristics. Lower rates of net photosynthesis at higher levels of salinity were associated with a decreased stomatal conductance (Figure 2). Decreased stomatal conductance had relatively little effect on intercellular CO_2 concentration, which responded in a complex manner. If stomatal closure was the main reason for decreased rates of net photosynthesis at high levels of salinity (250 and 350 mM), it would be expected that there would be lower intercellular CO_2 concentrations. The absence of such an observation in plants exposed to salinities above 150 mM

suggests that a non-stomatal effect limited photosynthesis at higher salinities.

Photosynthesis and Non-stomatal Parameters

A reduction in the rate of photosynthesis as a consequence of non-stomatal inhibition of photosynthesis by salt has also been observed previously (Seeman and Sharkey, 1986; Lloyd *et al.*, 1987: Delfine *et al.*, 1998). Such alterations in photosynthetic capacity must be the result of either a change in the leaf content of photosynthetic machinery and/or alteration in the efficiency with which this machinery operates.

Total chlorophyll contents in both cultivars increased under saline conditions. However, a negative relationship (R^2= -0.52) was observed between photosynthetic rate and total chlorophyll content in both sugar beet cultivars under salinity. This negative correlation may be due to the contrasting effects of salinity on photosynthesis (photosynthesis decreased with increasing salt concentration). In contrast, chlorophyll content was increased with increasing salinity. This increase in chlorophyll can be due to an inverse effect of salinity on specific leaf area (SLA), which is considered

a measure of leaf density or thickness (Hunt, 1982; Cramer *et al.*, 1994). As leaves of stressed plants became thicker than non-stressed plants, and thicker leaves contain more cells per unit leaf area, both photosynthesis and chlorophyll concentration were expressed per unit leaf area. Thus, chlorophyll content could not be a limiting factor for photosynthesis in the presence of salinity. An increase in chlorophyll content with salinity is not sufficient to counter the adverse effects of decreasing g_s and non-stomatal factors that may have influenced net carbon gain.

The initial slope of the *A-C$_i$* curve is a convenient measure of photosynthetic efficiency and is often defined as the carboxylation efficiency (CE). In this study, greater decreases in carboxylation efficiency were observed under increased salinity levels (Figure 6). Changes in carboxylation efficiency with salinization have been reported previously (Bethke and Drew, 1992) and may indicate a lower activity of Rubisco, because the initial slope of the *A-C$_i$* curve is thought to be controlled mainly by the ability of the enzyme to fix CO_2 (von Caemmerer and Farquhar; 1986). The Madison cultivar grown at 350 mM had the lowest initial slope. Commensurate with the change in carboxylation efficiency, the CO_2 compensation point also increased with severity of salt treatment. Comparable changes in CO_2 compensation point have been reported previously for salinized barley (Rawson, 1986). Another limiting factor could be RuBP regeneration, which could limit electron capture and transport for quinone reduction (Long and Hällgern, 1993). Chlorophyll fluorescence measurements could represent the differences in the efficiency of photosystem II in sugar beet cultivars in the presence of salinity.

The fluorescence data suggested that the rate of energy translocation or light capture might be limited by salinity (Long and Hällgern, 1993). Relating fluorescence and gas exchange data in stressed plants suggested that these plants might be experiencing some degree of photoinhibition (Figure 5). Salt stress is accompanied by oxidative damage in plants (Hernandez *et al.*, 1993; Streb *et al.*, 1993; Gosset *et al.*, 1994). Lower F_v/F_m in the salt stressed compared to the control plants indicated that RuBP regeneration, which needs adequate electron translocation from photosystem II to electron acceptors, might be disturbed by salinity. However, in this study, although there were significant differences in F_v/F_m in different salt treatments, values of F_v/F_m were relatively high for both the control and salt stress treatments (0.80-0.91) (Figure 5).
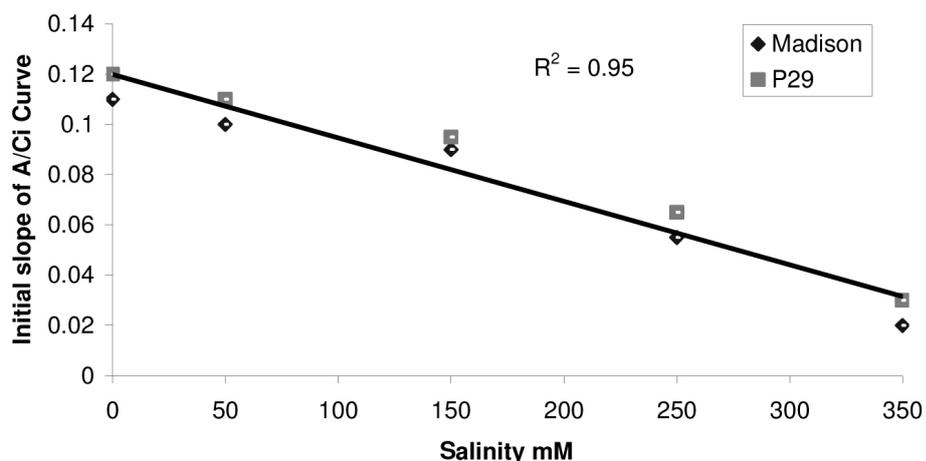

Figure 6. Correlation between the initial slope of the *A/C$_i$* curve and different levels of salt treatment in two sugar beet cvs.

Similar values of F_v/F_m were found by Belkhodja *et al.* (1994) and Kafi (1996) for barley and wheat, respectively, grown in the presence of salinity.

In this experiment, C_i:C_a ratio decreased up to 150 mM salinity. However, at 250 and 350 mM, despite reduction in A_{CO2} and g_s, the C_i:C_a ratio actually increased. It is likely that the increased intercellular CO_2 concentration (C_i) was mainly associated with the decreased CO_2 fixation of mesophyll cells due to the decreased CO_2 assimilation capacity (Lu and Zhang 1998).

CONCLUSIONS

The present assessment of the effect of salinity on performance of two sugar beet cultivars allows us to conclude that increasing the levels of salinity decrease most of the growth and physiological parameters. Salinity had greater effect on root dry weight than shoot dry weight. Data also revealed that salinity significantly decreased photosynthesis of leaves in both cultivars. The ratio of intercellular to ambient CO_2 concentration (Ci/Ca) decreased up to 150 mM salinity compared to non- stressed plants. However, *Ci/Ca* ratio increased at higher levels of salt treatment. This shows that at high levels of salt concentrations (250 and 350 mM) non-stomatal parameters have a greater effect on photosynthesis.

ACKNOWLEDGEMENTS

REFERENCES

1. Abdollahian-Noghabi, M. 1999. Ecophysiology of Sugar Beet Cultivars and Weed Species Subjected to Water Deficiency Stress. Ph.D. Dissertation, The University of Reading, Reading.

2. Al-Khateeb, S. A. 2006. Effect of Salinity and Temperature on Germination, Growth and Ion Relations of *Panicum turgidum* Forssk. *Bioresource Technol.,* **97:** 292-298.

3. Ashraf, M. and Ahmad, S. 2000. Influence of Sodium Chloride on Ion Accumulation, Yield Components and Fiber Characteristics in Salt-tolerant and Salt-sensitive Lines of Cotton (*Gossypium hirsutum* L.). *Field Crop Res.,* **66:** 115-127.

4. Aslam, M., Huffaker, R. C. and Rains, D.W. 1984. Early Effects of Salinity on Nitrate Assimilation in Barley Seedlings. *Plant Physiol.,* **76:** 321-325.

5. Ball, M. C. and Farquhar, G. D. 1984. Photosynthetic and Stomatal Responses of Two Mangrove Species *Ageceras corniculatum* and *Avicennia marina*, to Long-Term Salinity and Humidity Conditions. *Plant Physiol.,* **74:** 1-6.

6. Ball, M. C. and Anderson, J. M. 1986. Sensitivity of Photosystem II to Nacl in Relation to Salinity Tolerance of the Salt Tolerant Mangrove, *Avicennia martina*, and the Salt Sensitive Pea, *Pisum sativum. Aust. J. Plant Physiol.,* **13:** 689-699.

7. Belkhodja, R., Morales, F., Abadia, A., Gomez-Aparisi, A. J. and Abadia, J. 1994. Chlorophyll Fluorescence as a Possible Tool for Salinity Tolerance Screening in Barley (*Hordeum vulgare* L.). *Plant Physiol.,* **104:** 667-673.

8. Bethke, P. C. and Drew M. C. 1992. Stomatal and Non-stomatal Components to Inhibition of Photosynthesis in Leaves of *Capsicum annuum* during Progressive Exposure to NaCl Salinity. *Plant Physiol.,* **99:** 219-226.

9. Brugnoli, N. and Lauteri, M. 1991. Effect of Salinity on Stomatal Conductance, Photosynthesis Capacity and Carbon Isotope Discrimination of Salt Tolerant (*Gossypium hirsutum* L.) and Salt Sensitive (*Phaseolus vulgaris* L.) C$_3$ Non-halophytes. *Plant Physiol.,* **95:** 628-635.

10. Chartzoulakis, K. S., Therios, I. N., Misopolinos, N. D. and Noitsakis, B. I. 1995. Growth, Ion Content and Photosynthetic Performance of Salt-stressed Kivi Fruit Plants. *Irrigation Sci.,* **16:** 23-28.

11. Cramer, G. R., Alberico, G. J. and Schmidt, C. 1994. Leaf Expansion Limits Dry Matter Accumulation of Salt-stressed Maize. *Aust. J. Plant Physiol.,* **21:** 663-674.

12. Dadkhah, A. R. and Grifiths, H. 2006. The Effect of Salinity on Growth, Inorganic Ions and Dry Matter Partitioning in Sugar Beet Cultivars. *J. Agric. Sci. Technol.,* **8:** 199-210.

13. De Herralde, F., Biel, C., Save, R., Morales, M. A., Torrecillas, A. and Alarcon, J. J. 1998. Effect of Water And Salt Stresses on the Growth, Gas Exchange and Water Relations in *Argyranthemum Coronopiflium* Plants. *Crop Sci.,* **139:** 9-17.

14. Delfine, S., Alvino. A., Zacchinig, M. and Loveto, F. 1998. Consequence of Salt Stress on Conductance to CO_2 Diffusion, Rubisco Characteristics and Anatomyof Spinach Leaves. *Aust. J. Plant Physiol.,* **25:** 395-402.

15. Everard, J. D., Gucci, R., Kang, S. C., Flore, J. A. and Leoscher, W. H. 1994. Gas Exchange And Carbon Partitioning In The Leaves of Celery (*Apium graviolens* L.) at Various Levels of Root Zone Salinity. *Plant Physiol.,* **106:** 281-292.

16. Ghoulam, C., Foursy, A. and Fares, K. 2002. Effects of Salt Stress on Growth, Inorganic Ions and Proline Accumulation in Relation to Osmotic Adjustment in Five Sugar Beet Cultivars. *Environ. Exp. Bot.,* **47:** 39-50.

17. Gosset, D. R. and Millhollan, E. P. 1994. Antioxidant Response to Nacl Stress in Salt-Tolerant and Salt-sensitive Cotton Cultivars. *Crop Sci.,* **34:** 706-714.

18. Hernandez, J. A., Corpas F. J., Gomez, M., Del Rio, L. A. and Sevilla, F. 1993. Salt-induces Oxidative Stress Mediated by Activated Oxygen Species in Pea Mitochondria. *Physiol. Plantarum,* **89:** 103-110.

19. Hester, M. W., Mendelssohn, I. A. and Mckee, K. L. 2001. Species and Population Variation to Salinity Stress in *Panicum hemitomon*, *Spartina patens*, and *Spartina alterniflora*: Morphological and Physiological Constraints. *Environ. Exp. Bot.,* **46:** 277-297.

20. Hunt, R. 1982. Plant growth Curves: An Introduction to the Functional Approach to Plant Growth Analysis. Edward Arnold, London.

21. Kafi, M. 1996. Effect of Salinity on Aspect of the Physiology of Wheat (*Triticum aestivum* L.). Agricultural and Environment Science. Newcastle upon Tyne, University of Newcastle.

22. Koyro, H. W. 2006. Effect of Salinity on Growth, Photosynthesis, Water Relations and Solute Composition of the Potential Cash Crop Halophyte *Plantago coronopus* (L.). *Environ. Exp. Bot.,* **56:** 136-146.

23. Lloyd, J., Syvertsen J. P. and Kriedemann P. E. 1987 Salinity Effects on Leaf Water Relations and Gas Exchange of Valencia Orange (*Citrus Sinensis*) (L.) Osbeck on Rootstocks with Different Salt Exclusion Characteristics. *Aust. J. Plant Physiol.,* **14:** 605-617.

24. Long, S. P. and Hallgern, J. E. 1993. Measurement of CO_2 Assimilation by Plants in the Field and the Laboratory. In: "*Photosynthesis and Production in a Changing Environment*", (Eds.): Hall, D. O., Scurlock, J. M. O., Bolhar-Nordenkampf, H. R., Leegood, R. C. and Long, S. P.. Chapman and Hall, London, PP. 129-167.

25. Lu, C. and Zhang, J. 1998. Change in Photosynthesis II Function during Senescence of Wheat Leaves. *Physiol. Plantarum,* **104:** 239-247.

26. Maas, E. V. and Poss, J. A. 1989. Salt Sensitivity of Wheat at Various Growth Stages. *Irrigation. Sci.,* **10:** 29-40.

27. Munns, R., and Termaat, A. 1986. Whole-plant Responses to Salinity. *Aust. J. Plant Physiol.,* **13:** 143-160.

28. Pessarakli, M. and Tucker, T. C. 1985. Uptake of Nitrogen-15 by Cotton under Salt Stress. *Soil Sci. Soc Am. J.,* **49:** 149-152.

29. Pessarakli, M. and Tucker, T. C. 1988. Dry Matter Yield and Nitrogen-15 Uptake by Tomatoes under Sodium Chloride Stress. *Soil Sci. Soc. Am. J.,* **52:** 698-700.

30. Porra, R. J., Thompson, W. A. and Kriedeman, P. E., 1984. Determination of Accurate Extinction Coefficients and Simultaneous Equations for Assaying Chlorophylls a and b Extracted with Four Different Solutions: Verification of the Concentration of Chlorophyll Standards by Atomic Absorption Spectroscopy. *Biochim. Biophys. Acta.,* **975:** 384-394.

31. Rowson, H. M. 1986. Gas Exchange and Growth in Wheat and Barley Grown in Salt. *Aust. J. Plant Physiol.,* **13:** 475-489.

32. Schachtman, D. P. and Munns R. 1992. Sodium Accumulation n Leaves of Triticum Species that Differ in Salt Tolerance. *Aust. J. Plant Physiol.,* **19:** 331-340.

33. Seemann, J. R. and Sharky, T. D. 1986. Salinity and Nitrogen Effects on Photosynthesis, and Ribylose-1, 5-bisphosphate Carboxylase and Metabolite Pool Size in *Phaseolus vulgaris. Plant Physiol.,* **82:** 555-560.

34. Steduto, P., Albrizio, R., Giorio, P. and Sorrentino, G. 2000. Gas-exchange Response and Stomatal and Non-stomatal Limitations to Carbon Assimilation of Sunflower under Salinity. *Environ. Exp. Bot.,* **44:** 243-255.

35. Streb, P., Micheall-Knauf, A. and Feierabend, J. 1993. Preferential Photoinactivation of Catalase and Photoinhibition of PS II are Common Early Symptoms under Various Osmotic and Chemical Stress Conditions. *Physiol. Plantarum,* **88:** 590-598.

36. Sultana, N., Ikeda, T. and Itoh, R., 1999. Effect of NaCl Salinity on Photosynthesis and Dry Matter Accumulation in Developing Rice Grains. *Environ. Exp. Bot.,* **42:** 211-220.

37. Von Caemmerer, S. and Farquhar, G. D. 1986. Relation between Steady-state Gas Exchange, *in Vivo* Ribulose Biophosphate Carboxylase Activity, and Some Carbon Reduction Cycle Intermediates in *Raphanus sativus. Aust. J. Plant Physiol.,* **13:** 669-688.

38. Ward, M. R., Aslam M. and Huffaker, R. C. 1986. Enhancement of Nitrate Uptake and Growth of Barley Seedling by Calcium under Saline Conditions. *Plant Physiol.,* **80:** 820-824.

39. Witkowski, E. T. F. and Lamont, B. B. 1991. Leaf Specific Mass Confounds Leaf Density and Thickness. *Oecologia,* **88:** 486-490.

تاثیر تنش شوری بر رشد و فتوسنتز دو واریته چغندر قند (.Beta vulgaris L)

ع. دادخواه

چکیده

این تحقیق به منظور مطالعه تاثیر تنش شوری بر پارامترهای رشد و میزان فتوسنتز برگ دو واریته چغندر قند (مادیسون و P_{29} – ۷۲۳۳) انجام شد. بذور چغندر قند در محیط شن کاشته شدند و پس از سبز شدن، به گلدان های پر شده از ماسه شسته منتقل شدند. گیاهان پس از استقرار به مدت هشت هفته تحت پنج سطح شوری صفر، ۵۰، ۱۵۰، ۲۵۰ و ۳۵۰ میلی مولار مخلوط نمکهای کلرور سدیم و کلرور کلسیم به نسبت مولی پنج به یک قرار گرفتند. تنش شوری صفات رشد را بطور معنی داری کاهش داد. واریته P_{29} در سطح شوری ۳۵۰ میلی مولار نسبت به واریته مادیسون سطح برگ و ماده خشک بیشتری تولید کرد. تنش شوری همچنین میزان فتوسنتز خالص و هدایت روزنه ای برگ را بشدت تحت تاثیر قرار داد. با افزایش غلظت شوری، میزان یون های سدیم و کلر در برگ افزایش یافت. منحنی فتوسنتز خالص و غلظت گاز کربنیک داخل برگ رسم و شیب منحنی به عنوان ظرفیت فتوسنتزی استفاده شد. در تیمار شوری ۳۵۰ میلی مولار، میزان فتوسنتز برگ ۹۱/۵ درصد نسبت به شاهد (عدم اعمال شوری) کاهش نشان داد. با افزایش شوری میزان کلروفیل برگ افزایش یافت. اگرچه کاهش فتوسنتز تا حدی مربوط به کاهش هدایت روزنه ای برگ بود اما در تیمار های بالا شوری عوامل غیر روزنه ای در کاهش فتوسنتز تاثیر زیادی داشتند.