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Foliar Fertilization Applied to Droughted and Salinized Wheat and Maize Seedlings

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Abstract

Drought and salinity are very important factors that limit crop productivity world-wide. Causal relations between drought and salinity and growth are still little known. Leaf growth in monocotyledonous species reacts most sensitively to drought and salinity. Previous research has demonstrated that nutrient deficiencies or imbalances may be primary events involved in the onset of leaf growth reductions. Foliar application of nutrients represents a possibility to counteract such situations. This was tested with four different foliar treatments applied to droughted, salinized and control plants of maize and wheat at the seedling stage. The treatments included foliar applications of tap water, NPK, NK, applied daily, and NPK applied twice during the 5-day period. Various growth components and the nutrient status of the plants were measured. The results demonstrate the positive effects of foliar fertilization on growth of droughted and salinized plants. Foliar fertilization significantly affected plant height of wheat and maize plants regardless of the treatments. Plant height of droughted wheat and salinized maize seedlings was significantly increased by the foliar treatment NK daily as compared with the other treatments. Foliar fertilization increased the leaf length of salinized maize seedlings. No such effects were observed for shoot fresh weight or evapotranspiration. The results show the positive effects of foliar fertilization

on various growth parameters. The potential for foliar fertilization to obtain better insight into limiting factors under drought and salinity is illustrated.

Introduction

Drought and salinity pose serious limitations to crop productivity. Both stresses may reduce growth by decreasing water uptake from the soil due to the decreased soil water potential. High salt concentrations in the soil may further cause toxic effects or nutrient imbalances. There is no doubt that in the long term, excessive salt accumulation in plant tissues inhibits growth of salinized plants and that lack of water accounts for decreases in growth of droughted plants. However, so far there is no clear evidence which factors might be involved in the onset of growth reductions.

Growth in monocotyledonous plants occurs predominantly unidirectionally and is confined to a distinct zone at the leaf base which is enclosed by the sheaths of older leaves (Kemp, 1980). In young plants of maize and wheat, this zone is about 3 cm long, followed by a non-growing region, which is still enclosed within the sheaths and therefore photosynthetically not active in contrast to the following zone outside the sheath. Previous studies conducted with drought stressed maize seedlings (Schmidhalter *et al.*, 1998) and salinized wheat plants (Hu *et al.*, 1997; Hu, 1996) indicated that leaf growth is very sensitive to these stresses. Reductions in leaf extension of droughted maize plants, became visible before decreases in transpiration, water status of non-meristematic zones, and photosynthesis became evident (Schmidhalter *et al.*, 1998; Évéquoz, 1994). Similar observations have been made with salt-stressed wheat plants (Hu, 1996; Hu and Schmidhalter, 1998a).

Besides the maintenance of osmotic adjustment, nutrients also serve many specific roles in plant metabolism. Previous studies tried therefore to elucidate which solutes might be causally involved in growth reductions. Detailed investigations of nutrient concentrations on a millimetre scale along the leaf blade allowed some nutrients to be excluded as being responsible for eventual growth reductions. A mechanistic understanding of growth could be obtained by a kinematic analysis of growth (Silk, 1984; Evéquoz, 1994; Schmidhalter, 1995; Hu and Schmidhalter, 1998a, b). It seems that organic solutes play a minor role in growth reductions of droughted maize and salinized wheat plants, whereas it was found that inorganic nutrients might limit growth (Evéquoz, 1994; Schmidhalter, 1995; Hu and Schmidhalter, 1998a). In salinized wheat plants, it seemed unlikely that the fairly small Na contents found in the meristematic zone caused leaf reduction. However, a competitive effect of NO_3^- and Cl^- might account for the observed reductions (Hu and Schmidhalter, 1998a). In droughted maize plants such a role was also postulated for NO_3^- (Evèquoz, 1994; Schmidhalter, 1995).

An alternative way to better interpret nutrient deficiencies or imbalances might be to supplement potentially limiting nutrients by foliar fertilization or direct injection of nutrients into tissues. In this study we investigated the influence of foliar fertilization on shoot and leaf growth of salinized and droughted wheat and maize plants. This study reports the observed general growth effects. On-going detailed studies of the nutrient status in meristematic and non-meristematic growth zones will complement this information to verify whether nutrients might play a primary role in the onset of drought and salt stress induced reductions in monocotyledonous plants.

Materials and Methods

The experiment was carried out in a greenhouse with removable roofs. Plants could therefore be subjected to natural ambient conditions which were recorded. Maximum and minimum air temperatures varied between 37 °C (day) and 10 °C (night) with daily averages of 20 °C. Relative humidity oscillated between 30 and 85 %. Average values were 60 %.

Seeds of wheat *(Triticum aestivum* var. Star) and maize (*Zea mays* L. var. Rasant), were pre-germinated for one day, then sown in 7-L pots filled with 6 kg loamy soil. The soil consisted of 23 % clay, 48 % silt and 29% sand, pH ($CaCl_2$) was 5.7, organic matter content was 1.66 %. The initially air-dried soil (gravimetric water content 8%) was filled layer-wise in six layers in the pots and appropriate amounts of nutrient solution or nutrient solution plus added salts were given to each layer to obtain desired moisture contents and salt levels in the soil. A previously established soil water retention curve allowed soil matric suctions ranging from –0.025 to –0.03 MPa to be achieved. This is considered to be optimal for growth. The topmost soil layer was not salinized until 10 days after sowing to facilitate seedling emergence. All other layers received 120 g water per kg air-dried soil containing 1.17 g NaCl. All soil layers received additionally 0.2 g NH_4NO_3 120 mL tap water^{-1} or salinized solution for the drought and salinized treatment, respectively. The soil was adequately supplied with P and K, so there was no need to fertilize with these elements.

Pre-germinated seeds were sown on May 18, 1998 in pots with soil. Each pot contained 7 maize plants or 19 wheat plants. Four and five replications were chosen for maize and wheat, respectively. On May 27, 400 g coarse sand (2 mm in diameter) was placed on the soil surface to reduce evaporation. On the same day, the topmost soil layer of the salinized treatment was salinized as described previously. Thereafter, all pots were watered daily to replace the water lost until June 4, 1998. After that day, one fourth of the water use of the drought treatments was daily replaced until the desired leaf growth stages were reached, whereas the control treatment and the salt stress treatments received full irrigation every day.

Foliar fertilization started on June 5 and lasted for five days. Four different foliar sprays were used: (i) tap water sprayed daily, (ii) NPK solution (7.5 g KNO_3 + 1.5 g KH_2PO_4 + 1 g K_2HPO_4 L tap water^{-1}) sprayed twice during the experiment on day 1 and 4 after beginning the foliar treatments, (iii) NPK solution applied daily, and (iv) N solution applied daily (7.5 g KNO_3 L tap water^{-1}).

The measurements included daily recordings of maximum shoot length and of water use by plants determined by weighing the pots. Evaporation was determined by weighing unplanted control pots of the three different main treatments. Maize plants were harvested on June 10, 1998. Salinized and well-watered wheat plants were harvested on June 12 and droughted wheat plants on June 14, 1998. At harvest, shoot fresh weight was determined. The three youngest leaves (leaf 3, 4 and 5) were carefully removed from the shoot including the leaf sheath. The total length of the leaf blade and the length of the sheath were determined. Leaves were additionally separated, if present, in to (i) leaf sheath, (ii) growing zone (3 cm in length from the leaf base), (iii) leaf segment between the end of the growing zone and the beginning of the exposed part of the leaf (non-exposed zone), (iv) exposed part of the leaf, 6 cm in length (exposed zone), and (v) the rest of the exposed leaf blade (leaf tip). The length of the respective parts was measured and fresh and dry weight determined by gravimetric weighing. For dry weight determination, plant material was oven dried at 60 °C for two days. Thereafter, the plant material was finely ground by hand and wet ashed at 120 psi pressure for 20 minutes. Plant material was then analyzed for mineral elements by ICP (K, Ca, Mg, Na, Mn, Fe, Zn, total P, total S), and water-soluble anions by ion chromatography (NO_3, PO_4, Cl), and total N by elementar analyzer. Results were analyzed by ANOVA and means separated by least significant differences using the JMP version of the SAS programme and by SAS (1990).

Results

Cumulative and daily evapotranspiration

The three main treatments, control, drought and salinity differed significantly in cumulative (Figure 1) and daily evapotranspiration (Tables 1 and 2). Control treatments showed markedly higher evapotranspiration than drought treatments. Drought strongly reduced evapotranspiration. Salinization resulted in decreased growth and reduced evapotranspiration as compared to the control and drought treatments. At the end of the experiment, however, evapotranspiration of salinized treatments reached the levels of drought treatments. This shows that drought stress reduced most markedly evapotranspiration. Evaporation from unplanted pots was comparatively small (Figure 1) and did not markedly differ for the three main treatments.

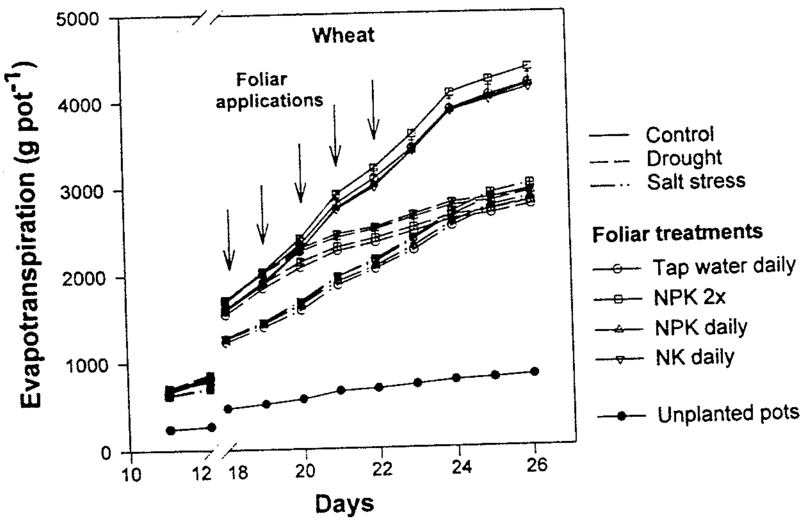

Figure 1. Cumulative evapotranspiration of droughted, salinized and control seedlings of wheat plants to which four different foliar treatments (tap water daily, NPK 2x, NPK daily, NK daily) were applied during day 18 to 23. Evaporation from unplanted pots is also indicated. Error bars represent standard errors and are not shown if smaller than symbol size.

Foliar treatments did not result in differences in daily evapotranspiration of wheat and maize plants (Tables 1 and 2).

Table 1. Main treatment and foliar treatment effects on daily evapotranspiration, shoot height and shoot fresh weight, fresh weight and dry matter contents of leaves 3, 4 and 5 in droughted, salt-stressed and control wheat seedlings.

	Main treatments	**Foliar treatments**			
		Tap water	NPK 2x	NPK daily	NK daily
Daily evapotranspiration (g)		ns*	ns	ns	Ns
Drought	a**	ns	ns	ns	Ns
Salt stress	b	ns	ns	ns	Ns
Control	c	ns	ns	ns	ns
Shoot height (cm)		a	b	b	c
Drought	a	a	ab	b	c
Salt stress	b	a	ab	c	ab
Control	c	a	b	ab	a
Shoot fresh weight (g)		ns	ns	ns	ns
Drought	a	ns	ns	ns	ns
Salt stress	b	ab	b	a	a
Control	c	a	b	b	b
Fresh weight of leaves 3, 4 and 5 (g)		ns	ns	ns	ns
Drought	a	ns	ns	ns	ns
Salt stress	a	ns	ns	ns	ns
Control	b	ns	ns	ns	ns
Dry matter content of leaves 3, 4 and 5 (%)		ns	ns	ns	ns
Drought	a	a	ab	b	ab
Salt stress	b	ns	ns	ns	ns
Control	b	ns	ns	ns	ns

* ns = non significant

**Mean separation within main treatments and foliar treatments by Student test. Differences among treatments are indicated by different letters.

Table 2. Main treatment and foliar treatment effects on daily evapotranspiration, shoot height and shoot fresh weight, length, fresh weight and dry matter contents of leaves 3, 4 and 5 in droughted, salt-stressed and control maize seedlings.

	Main treatments	Foliar treatments			
		Tap water	NPK 2x	NPK daily	NK daily
Daily evapotranspiration (g)		ns*	ns	ns	Ns
Drought	a**	ns	ns	ns	Ns
Salt stress	b	ns	ns	ns	Ns
Control	c	ns	ns	ns	Ns
Shoot height (cm)		ns	ns	ns	Ns
Drought	a	a	b	c	C
Salt stress	b	a	b	ab	C
Control	c	ns	ns	ns	Ns
Shoot fresh weight (g)		ns	ns	ns	Ns
Drought	a	ns	ns	ns	Ns
Salt stress	b	ns	ns	ns	Ns
Control	c	ns	ns	ns	Ns
Length of leaves 3, 4 and 5 (cm)		ns	ns	ns	Ns
Drought	a	a	b	b	B
Salt stress	b	a	b	ab	Ab
Control	c	a	b	ab	Ab
Fresh weight of leaves 3, 4 and 5 (g)		a	ab	a	B
Drought	a	a	ab	a	B
Salt stress	b	ns	ns	ns	Ns
Control	c	ns	ns	ns	Ns
Dry matter content (%) of leaves 3, 4 and 5		ns	ns	ns	Ns
Drought	a	a	ab	a	B
Salt stress	b	ns	ns	ns	Ns
Control	c	ns	ns	ns	Ns

- ns = non significant
- **Mean separation within main treatments and foliar treatments by Student test. Differences among treatments are indicated by different letters.

Shoot height

Both stresses, especially drought, reduced shoot height in wheat and maize seedlings. Salt-affected plants were smaller at the beginning of the drought treatment, but reached nearly the same level at the end of the experiment. Shoot height of wheat and maize seedlings subjected to control, drought and salt stress conditions was significantly affected by foliar fertilization.

Two foliar applications of NPK increased plant height of control wheat plants as compared to daily applications of NK and tap water. In droughted wheat plants, a marked increase in shoot height was observed in the treatment NK daily, as compared to the other three treatments (Figure 2). Tap water resulted in the smallest shoot height. No marked differences except for NPK applied daily were found among the different foliar treatments in salt stressed wheat plants.

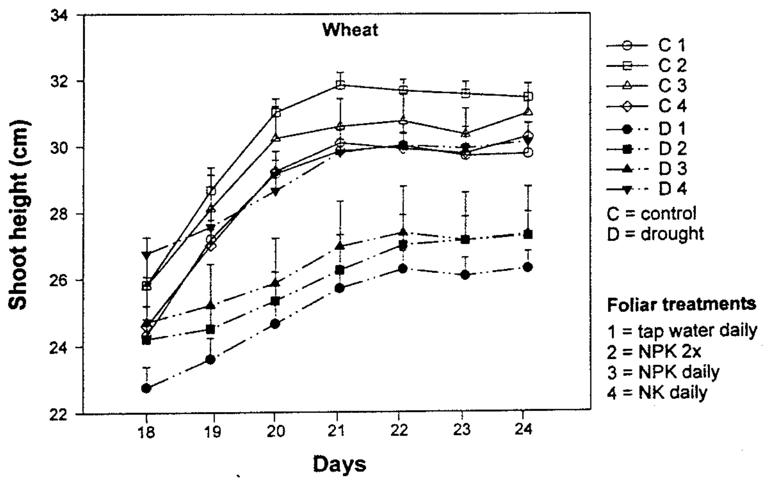

Figure 2. Plant height of droughted and control wheat seedlings to which four different foliar treatments were applied. For details see text.

Different foliar treatments did not affect shoot height of maize plants in the control treatment, Foliar fertilization with NK daily, increased shoot height of salinized maize seedlings as compared to the other treatments (Figure 3). Significant differences among the different treatments were found in droughted maize plants (Table 2). Tap water resulted in maximum plant height (data not shown).

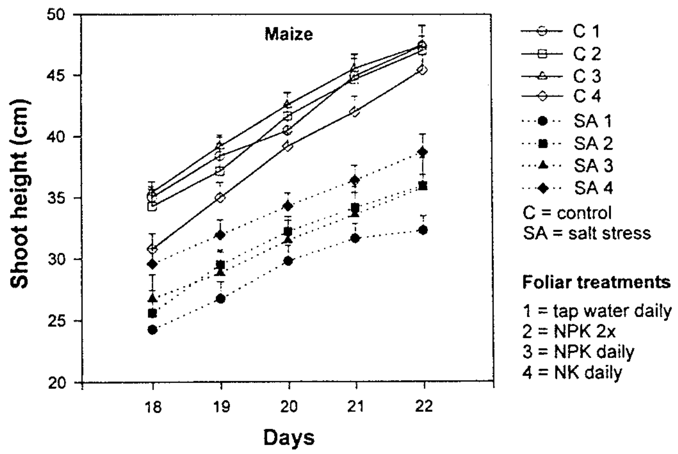

Figure 3. Plant height of salinized and control maize seedlings to which four different foliar treatments were applied.

Shoot fresh weight

Similarly to plant height, shoot fresh weight of wheat plants was markedly higher under control conditions than under stress conditions (Figure 4). Nutrient application influenced the shoot fresh weight of control plants positively as compared to tap water. Foliar treatments did not affect droughted wheat plants, whereas a positive effect of two applications of NPK was observed in salinized wheat plants.

Drought and salinity reduced shoot fresh weight in maize as compared to the control treatment. No significant differences among the different foliar treatments were found.

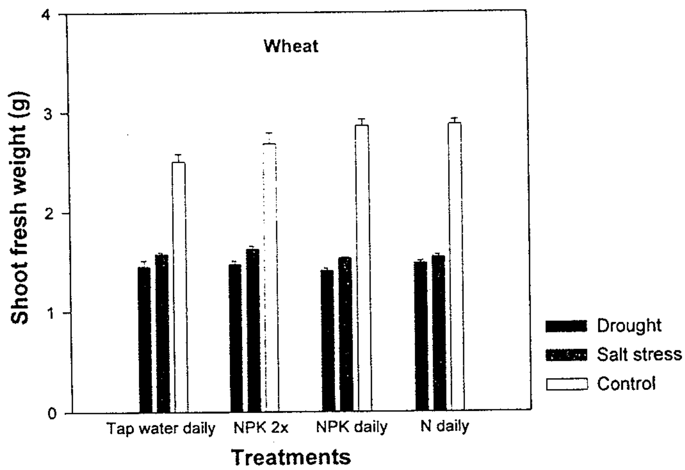

Figure 4. Shoot fresh weight of droughted, salinized and control wheat plants to which four different foliar treatments were applied. Pot values are expressed per plant and represent 7 and 19 plants per pot (n=4 and 5 for maize and wheat, respectively).

Length of leaves 3, 4 and 5 in maize seedlings

Foliar treatments did not affect leaf sheath length of leaf 3, the youngest fully developed leaf, and of leaf 4, the second youngest leaf, in maize plants (data not shown). Leaf 5 was only partly extended out of the older leaf's sheath and the sheath did not appear. In drought affected maize plants, leaf blade length of leaves 3 and 4 was slightly increased by tap water as compared to the other treatments. An opposite effect was observed in salt stressed leaf blades of leaves 4 and 5 where the length was highest with daily applications of NK, followed by NPK daily, NPK twice and tap water applied daily. This sequence seemed to be reversed in control leaf blades of leaf 3. Daily application of NK resulted in smaller blades of leaves 4 and 5 in the control treatment as compared to the other treatments.

Fresh weight of leaves 3, 4 and 5

Leaf fresh weight was determined separately for the leaf sheath, growing zone, non-exposed leaf segment, exposed leaf zone and leaf tip as defined in the "Materials and Methods" section.

Tap water increased leaf tip fresh weight of leaf 3 in droughted wheat seedlings (data not shown). In contrast, foliar fertilization of salinized maize seedlings increased significantly fresh weight of leaf tips in leaves 4 and 5 (Figure 5), fresh weight of the leaf sheath in leaves 3 and 4 (data not shown), and fresh weight of non-exposed zone of leaf 5 (Figure 5). The increase was most marked with daily applications of NK, followed by NPK daily, and NPK twice. NK daily decreased fresh weight of leaf tips in leaves 3 and 4 as compared to the other treatments (data not shown).

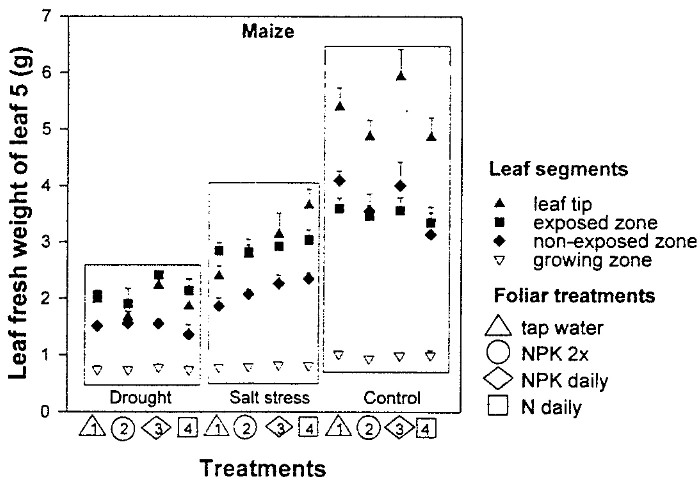

Figure 5. Leaf fresh weight separately indicated for growing zone, non-exposed zone, exposed zone and tip of leaf 5 in droughted, salinized and control maize seedlings to which four different foliar treatments were applied. For details see text. Replicate measurements (n=4 and 5 for maize and wheat, respectively) represent 7 and 4 plants per pot for maize and wheat, respectively.

Foliar fertilization also positively influenced fresh weight of leaf blades 3 and 5 in control wheat seedlings. The application of foliar fertilizers or tap water hardly influenced salt stressed wheat seedlings. Some positive effects of foliar fertilization on the leaf tip fresh weight of leaf 5 were noticed. The most puzzling, but also variable results were obtained with droughted wheat seedlings. Foliar fertilization increased the fresh weight of the sheath and blade of leaf 4. In leaf 3, foliar fertilization with daily applications of NPK and NK increased strongly leaf blade fresh weight and decreased leaf sheath fresh weight as compared to daily applications of tap water and NPK applied twice daily. Foliar fertilization seemed to exert a positive effect on fresh weight of the growing zone and the non-exposed zone.

Dry matter contents of leaves 3, 4 and 5

Dry matter contents of leaves 3, 4 and 5 were significantly increased in drought- affected wheat plants by daily applications of NPK as compared to tap water (Table 1). Daily application of NK increased dry matter contents in droughted maize leaves (Table 2).

Discussion and Conclusion

Foliar fertilization with macronutrients has not widely been used as a technique to alleviate the negative effects of salt and drought stress. Under non-stressed conditions, where more information is available, the application of N seems most promising, since a significant fraction of a plant's basic requirement can be met by foliar application. Application of foliar nutrients might be more promising in the early stages of development. Foliar applications of N, P, K, and S, applied at the four- or five-leaf stage, significantly increased the N and P contents of maize seedlings at a critical growth stage and resulted in yield increases of both silage and grain (Giskin and Efron, 1986). Foliar absorption rates for younger leaves are more favourable than for older leaves (Wittwer and Teubner, 1959) and nutrient demand for the production of a smaller biomass has to be fulfilled. It is well known that salinity and drought can markedly decrease leaf growth of wheat plants in the early developmental stages. Leaf growth in these stages strongly influences tiller number, an important determinant of yield potential. On drying soil, water uptake and concomitantly, nutrient uptake is reduced. Nutrients are preferably located in the top soil. Drying out of the upper soil horizon may even more influence nutrient uptake than water uptake, especially when some roots already access lower soil horizons with reduced nutrient availability. Saline soils are frequently characterised by extreme ratios of Na/K, Na/Ca and Cl/NO_3. Under such conditions, nutrient imbalances or deficiencies may occur. Foliar application of nutrients to droughted or salt stressed wheat and maize seedlings might therefore offer a way to alleviate stress. Both water and N sprays slightly increased growth in droughted cotton seedlings. However, N was of no more benefit to the plants than water alone (Holman *et al.*, 1992). More positive results were obtained in this study. The results from this study make it clear that species- and stress-specific reactions may be involved.

On-going analyses will provide the basis to better interpret the positive effects of foliar fertilization on growth parameters. The results support the hypothesis that nutrient deficiencies or nutrient imbalances are involved in early reductions in plant growth due to drought and salinity. There are hardly any studies which have addressed the potential to study basic mechanisms of plant growth interactions with drought and salinity stress by means of foliar fertilization. Our results show that foliar fertilization is a useful tool to study nutrient interactions with drought and salinity.

References

Evéquoz, M. 1993. Adaptation osmotique et propriétés rhéologiques des parois cellulaires: Critères pour la selection du mais à la sécheresse. PhD thesis, ETH Zürich, No. 10234.

Giskin, M. and Y. Efron. 1986. Planting date and foliar fertilization of corn grown for silage and grain under limited moisture. *Agronomy Journal* 78, 426-429.

Holman, E. M., D. M. Oosterhuis and R. G. Hurren. 1992. Foliar fertilization of droughted cotton seedlings. *Arkansas Farm Research* 41, 4-5.

Hu, Y. and U. Schmidhalter. 1998a. Spatial distribution of inorganic ions and sugars contributing to osmotic adjustment in the elongating wheat leaf under saline conditions. *Australian Journal of Plant Physiology* 25(6), 591-597.

Hu, Y. 1996. Growth response of wheat to salinity in hydroponics and soil. PhD thesis, ETH Zürich, No. 11619.

Hu, Y. and U. Schmidhalter. 1998b. Spatial distribution and net deposition rates of mineral elements in the elongating wheat (*Triticum aestivum* L.) leaf under saline soil conditions. *Planta* 204(2), 212-219.

Hu, Y., Oertli, J. J. and U. Schmidhalter. 1997. Interactive effects of salinity and macronutrient level on wheat: Part 1. Growth. *Journal of Plant Nutrition* 20 (9), 1155-1167.

Kemp, D. R. 1980. The location and size of the extension zone of emerging wheat leaves. *New Phytologist* 84:729-737.

SAS/STAT, 1990. User's Guide, Volume 2, Version 6, Fourth Edition, SAS Institute Inc., Cary, NC.

Schmidhalter, U. 1995. Does soil nutrient uptake control drought perception in plants? In: Proceedings International Congress on Drought Tolerance of

Higher Plants. Montpellier, France, IIIA. 5 pages.

Schmidhalter, U., M. Evéquoz, K.-H. Camp and C. Studer. 1998. Sequence of drought response of maize seedlings in drying soil. *Physiologia Plantarum* 104(2), 159-168.

Silk, W. K. 1984. Quantitative description of development of expansive growth. *Annual Review Plant Physiology* 35, 479-518.

Wittwer, S. H. and F. G. Teubner. 1959. Foliar adsorption of mineral nutrients. *Annual Review Plant Physiology* 10, 13-32.