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Short-term effects of drought and salinity on mineral nutrient distribution along growing leaves of maize seedlings

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Abstract

The objectives were to study the effect of drought and salinity on the spatial distribution of mineral nutrients along the growing leaves of maize. Maize plants were grown in a greenhouse in soil under drought and saline conditions for 23 days after sowing. At harvest, the spatial distribution of fresh weight and dry weight contents and mineral nutrient concentrations along growing leaves 4 and 5 of maize was determined. Drought and salinity reduced the fresh weight content regardless of leaf number and caused a similar reduction. However, they affected the dry weight content differently, resulting from the reduction in the relative water content by drought. The results showed that the change in ion concentration along the growing leaf axis for most ions is independent of treatments. Although both drought and salinity cause a low nutrient availability in soil and low nutrient transport in plants, this study showed that except for Na^+, there was no difference in the concentrations of most ions at any given location between plants in the control and either of the drought or saline treatments. Thus, reduction in leaf growth under drought and saline conditions may be due to other causes rather than the limitation of nutrients in a short-term period of drought and salt stresses.

Keywords: Drought; Growing leaves; Maize; Mineral nutrients; Salinity

1. Introduction

Maize is one of the major food crops in most of the countries where drought and salinity problems exist or may develop. In the early growth stages, leaf growth is one of the most sensitive processes to drought and salinity (e.g. Tardieu et al., 2000; Neves-Piestun and Bernstein, 2005). Because drought and salinity both lower the soil water potential, similar physiological mechanisms such as the water deficit or osmotic effect in plants might explain the reduction in plant growth. Therefore, considerable attention has been focused on comparing the differential responses of plant growth under drought and salinity that are mediated by the lowered soil water potential (e.g. Shalhevet and Hsiao, 1986; Schmidhalter and Oertli, 1991; Munns, 2002). Under drought stress, nutrient uptake by the roots is reduced, in part because the decline in soil moisture results in a decreased rate of diffusion of nutrients from the soil matrix to the absorbing root surface (Viets, 1972; Pinkerton and Simpson, 1986). Moreover, nutrient transport from the roots to the shoots is also restricted by the reduced transpiration rates and impaired active transport and membrane permeability, altogether resulting in a reduced root adsorbing power of crop plants (Hsiao, 1973; Kramer and Boyer, 1995). Thus, the reduced nutrient availability is one of the most important factors limiting plant growth under drought. Under saline conditions, however, soils contain extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and $Cl^-/NO_3{}^-$, leading to specific ion toxicities (e.g. Na^+ and Cl^-) and ionic imbalance (Grattan and Grieve, 1999).

To better understand the physiological mechanisms involved in both stresses, it is important to examine both conditions. In grasses such as maize, the elongation of the growing leaves is restricted to a small region at the base of the blade enclosed by sheaths of older leaves (Kemp, 1980). Along the leaf elongation zone, there is a gradient of cell development, which causes spatial distributions of nutrients along the leaf axis. Studies have shown that water-soluble carbohydrates, macronutrients (N, P, K^+, Ca^{2+} and Mg^{2+}) and micronutrients (Fe, Mn and Zn) are spatially distributed along the grass leaves (Schnyder and Nelson, 1987; Bernstein et al., 1995; Meiri et al., 1992; Hu and Schmidhalter, 1998a; Hu et al., 2000; De Lacerda et al., 2003;

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Neves-Piestun and Bernstein, 2005), and that the growing tissues are a strong sink for nutrients. Therefore, metabolic or nutritional changes associated with control and stress conditions should be much more closely linked with the most actively growing tissues than with the whole or non-growing tissues. Although previous studies reported the effect of salinity on macro- and micronutrient distribution along the growing leaves of sorghum (Bernstein et al., 1995; De Lacerda et al., 2003), wheat (Hu and Schmidhalter, 1998a; Hu et al., 2000) and maize (Neves-Piestun and Bernstein, 2005), there is no information available for the spatial distributions of these nutrients in the growing leaves of grasses under drought conditions and for the comparative responses of different species to drought and salinity stresses.

Therefore, to more fully understand the nutrient disturbance in plants under drought and salinity, the objectives of this study were to investigate the effect of these conditions on the spatial distribution of macro- and micronutrients along the growing leaves of maize and to compare the ion distribution in the growing leaves under drought and salinity.

2. Materials and methods

2.1. Plant materials and growth conditions

Maize (*Zea mays* L. cv. Rasant) seeds were pre-germinated for 1 day, after which 10 seeds of maize were sown in 7-l pots filled with loamy soil. One week after sowing, the seedlings were thinned to seven per pot. The experiment was carried out in a greenhouse. The daily air temperature ranged from 37 °C (maximum at day) to 10 °C (minimum at night), with the daily average temperature being about 20 °C. Relative humidity fluctuated between 30 and 85%; the average value was about 60%.

Loamy soil was collected from the soil surface (0–15 cm), air-dried, ground, passed through a 5-mm mesh screen, and thoroughly mixed. The soil consisted of 23% clay, 48% silt and 29% sand, and the organic matter content was 1.66%. The pH ($CaCl_2$) was 5.7. The air-dried soil, with a gravimetric water content of 8%, was filled layer-wise in six layers in 7-l pots. To obtain the final value of 20% soil gravimetric water content, the nutrient solution with or without NaCl was added to each layer. Nitrogen was applied as 0.2 g NH_4NO_3 per pot. Both the water content and amount of nutrient was optimal for plant growth according to our previous tests. For the salinized treatment, the final concentration of 100 mM NaCl was obtained by adding NaCl to the nutrient solution and applying it to the top soil layer 10 days after sowing. To reduce evaporation, 400 g of coarse sand (2 mm in diameter) was placed on the soil surface for all treatments. For the control and salinized treatments, the pots were weighed daily and the water loss was replaced by adding tap water during the experiment as necessary. The drought stress was started at day 18 after sowing by replacing only 1/4 of water loss after this time. During drought period, the soil matric potentials decreased from −0.2 bars at day 19 to −4 bars at day 23 after sowing. Salinity treatment at 100 mM NaCl caused a soil osmotic potential of about −4 bars. Ideally, to compare drought and salinity effects, similar soil water potentials for the two treatments should be imposed. Practically, it was difficult to achieve this. Thus, we compared the physiological effect of these two stresses at harvest time when the growth of plants showed a similar reduction as compared with control plants.

2.2. Analysis of plant growth and tissue sampling of growing leaves

The accumulation of evapotranspiration and evaporation were determined by respectively weighing the pots with and without the plants daily. Maize plants were harvested at day 23 after sowing. Shoot fresh weight (FW) was determined. At the final harvest, leaves 4 and 5 were still expanding. These two youngest leaves were carefully removed from the shoot, which was enclosed in the older leaf sheath.

The growing leaves of the maize plants were cut into different segments along the leaf axis to study the effect of drought and salinity on the mineral elements present in the different tissues. A growing grass plant consists of several functional zones as defined by characteristics of tissues. According to the age of a growing leaf, these zones include the growth, secondary deposition (enclosed mature tissues in the old leafs sheath), and photosynthetic zones (exposed mature tissues) (Evequoz, 1993). Thus, decisions regarding the lengths and positions of the leaf segments must be based on the tissue age and functions in the growing leaf. Leaves 4 and 5 were cut at the ligule with a razor blade and divided into four additional segments: (1) the growth zone (3 cm above the ligue: seg1), (2) the remaining part of the leaf enclosed by sheath (seg2), (3) the first 6 cm of the exposed part of the leaf (seg3), and (4) the remainder of the exposed leaf (leaf distal; seg4). To ensure that sufficient material was available for ion analysis, six segments at the same position were combined into one sample. The length of the growth zone for maize (about 3 cm) was determined following studies by Evequoz (1993). After FW of the segments were determined, samples were dried at 60 °C for 2 days. Dry weights (DW) were determined and the materials were stored for the analysis of ion concentrations. Relative water content (RWC) (%) was calculated from: $RWC = 100 \times (FW - DW)/FW$.

Besides the separated youngest leaves 4 and 5, other plant material was also oven-dried at 60 °C for 2 days and the dried samples were weighed. The shoot DW was calculated by the total DW of leaves 4 and 5 plus the DW of other plant materials.

2.3. Analysis of ion concentrations

Oven-dried samples of leaves and sheathes at harvest were ground to pass through a 1-mm diameter sieve. The concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Mn, Fe, Zn, and S were determined using an Inductively Coupled Plasma Emission Spectrometer (ICP model Liberty 200, Varian Australia Pty. Ltd., Mulgrave Victoria, Australia). Before the analysis, 50 mg of ground dry material was digested by adding 2 ml concentrated HNO_3 (65%) and 1 ml H_2O_2 (30%) for 30 min at 2600 kPa (80 psi) in a MDS-2100 microwave oven (CEM Corp., Matthews, NC). After digestion, each sample was brought up to the final volume of 25 ml with deionized water.