The effect of salinity on plant available water

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Abstract
Salinity acts to inhibit plant access to soil water by increasing the osmotic strength of the soil solution. As the soil dries, the soil solution becomes increasingly concentrated, further limiting plant access to soil water. An experiment was conducted to examine the effect of salt on plant available water in a heavy clay soil, using a relatively salt tolerant species, wheat 'Kennedy', and a more salt sensitive species, chickpea 'Jimbour'. Sodium chloride was applied to Red Ferrosol at 10 rates from 0 to 3 g/kg. Plants were initially maintained at field capacity. After 3 weeks, plants had become established and watering was ceased. The plants then grew using the water stored in the soil. Once permanent wilting point was reached plants were harvested, and soil water content was measured.

The results showed that without salt stress, wheat and chickpea extracted approximately the same amount of water. However, as the salt concentration increased, the ability of chickpea to extract water was severely impaired, while wheat's ability to extract water was not affected over the range of concentrations examined.

Growth of both wheat and chickpea was reduced even from low salt concentrations. Possible explanations for this are that the effect on growth is due to Cl^- toxicity and that this occurs at lower concentrations than the osmotic effect of salinity, or that the metabolic demands of maintaining plant water balance and extracting soil water under saline conditions result in reduced growth.

Key Words
Salinity, plant available water, Red Ferrosols, wheat

Introduction
Salinity has a dual effect on plant growth via an osmotic effect on plant water uptake, and specific ion toxicities. By decreasing the osmotic potential of the soil solution, plant access to soil water is decreased, because of the decrease in total soil water potential. As the soil dries, the concentration of salt in the soil solution increases, further decreasing the osmotic potential. In order to maintain water uptake from a saline soil, plants must osmotically adjust. This is done either by taking up salts and compartmentalizing them within plant tissue, or synthesizing organic solutes. Plants which take up salts generally have a higher salt tolerance and greater ability to store high salt concentrations in plant tissue without affecting cell processes, and are know as halophytes. Plants which synthesise organic solutes are known as glycophytes, and they try to prevent excess salt uptake because they can tolerate much lower concentrations of salt in plant tissues before cell processes are adversely affected. In most cases glycophytes tend to be salt sensitive, although this is not always the case (Bernstein 1975; Marschner 1995; Orcutt and Nilsen 2000). While these are the two extremes, most plants utilize a combination of these strategies, and differences exist between varieties (Chhipa and Lal 1995; Saneoka *et al.* 1999). Even with complete osmotic adjustment, a reduction in growth may occur due to the metabolic demands of maintaining osmotic adjustment (Bernstein 1975; Marschner 1995).

While increased uptake of salts may contribute to osmotic adjustment, Na^+ and Cl^- toxicity may result. A range of symptoms have been described, with chlorosis on the tips of older leaves, developing to necrosis, followed by death of leaves, common across many species (Eaton 1966; Grundon 1987; Kurniadie and Redmann 1999; Xu *et al*. 2000).

Accumulation of excess Na^+ may cause metabolic disturbances in processes where low Na^+ and high K^+ or Ca^{2+} are required for optimum function (Marschner 1995). A decrease in nitrate reductase activity, inhibition of photosystem II (Orcutt and Nilsen 2000), and chlorophyll breakdown (Krishnamurthy *et al.* 1987) are all associated with increased Na^+ concentrations. Cell membrane function may be compromised as a result of Na^+ replacing Ca^{2+}, resulting in increased cell leakiness (Orcutt and Nilsen 2000).

While symptoms of Cl^- toxicity are frequently documented (Grundon *et al.* 1987; Manchanda and Sharma 1989; Kurniadie and Redmann 1999; Xu *et al.* 2000), much less information regarding the specific effects of high Cl^- is available. High concentrations of Cl^- in leaf tissue may disrupt photosynthetic function through the inhibition of nitrate reductase activity (Xu *et al.* 2000). Once the capacity of the cell to store salts is exhausted, salts build up in the intercellular space, leading to cell dehydration and death (Munns 1993).

A better understanding of the dominant effects involved in plant response to salinity will facilitate development of improved varieties and crop management practices.

Materials and Methods

A pot trial was conducted to examine the effect of salt on plant available water due to osmotic stress. Concurrent experiments were conducted with wheat 'Kennedy' and chickpea 'Jimbour' grown in soil contaminated with NaCl. Ten rates of NaCl were used, from 0 to 3 g/kg (0, 0.125, 0.25, 0.375, 0.5, 0.75, 1.0, 1.5, 2, 3), with 3 replicates.

The soil used for this experiment was a Red Ferrosol. While a soil of this kind is not generally associated with salinity problems, it was used for this study because adding NaCl would not alter the physical properties of the soil and no dispersive response to NaCl was observed. Therefore the effect of salt on plant water uptake was not confounded with the effect of altered soil physical properties on root proliferation and soil water capacity.

Straight sided, 15cm pots were used in this experiment, lined with plastic bags. Each pot had two layers of soil, the salt treatment and half the basal nutrient application was applied to 3kg of soil in the lower layer, while the remaining basal nutrient application was applied to the 500g surface layer. In each case the nutrients and salt were added to enough water to bring the soil to field capacity, which was then added as one solution. This was allowed to incubate for 1 week.

Each pot was planted with 5 seeds, and then thinned to 3 plants after 1 week. Pots were maintained at field capacity until 3 weeks after planting. From this point, water loss was monitored by weighing pots, and plant growth and foliar symptoms were monitored. The soil surface was covered in a layer of white beads to minimize evaporative losses. Plants were harvested when they reached permanent wilting point, as determined by early morning observations to ascertain whether plants had recovered turgor overnight. Plants were harvested, dried, and weighed, and final soil water content was measured.

Results

A variation in growth between treatments was evident from the early stages of the experiment, while other foliar symptoms took longer to develop. Initially wheat appeared water stressed, before developing chlorosis on the tips and margins of the oldest leaves. This developed to necrosis and affected progressively younger tissue. In mature plants, stems were short and heads had few grains. Foliage that had not developed chlorosis was a dull grey-green colour and leaves were short and stiff. Stems and leaves appeared to be coated in a waxy substance.

While wheat appeared water stressed before developing foliar symptoms, the reverse was true for chickpea. Initially the tips of the oldest leaves were affected by chlorosis, followed by necrotic lesions. Senescence of these leaves quickly followed. Plants grown in soil with >1.0g/kg NaCl had reduced leaf size.

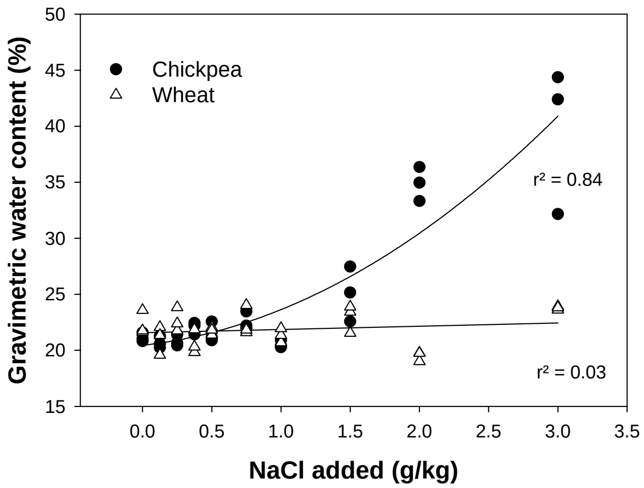


Figure 1. Gravimetric water content of soil at harvest.

The water content of the soil at harvest is shown in Figure 1. Water extraction by wheat was not affected by increasing salt content of the soil, while water extraction by chickpea was severely reduced at salt additions above 1.5g/kg.

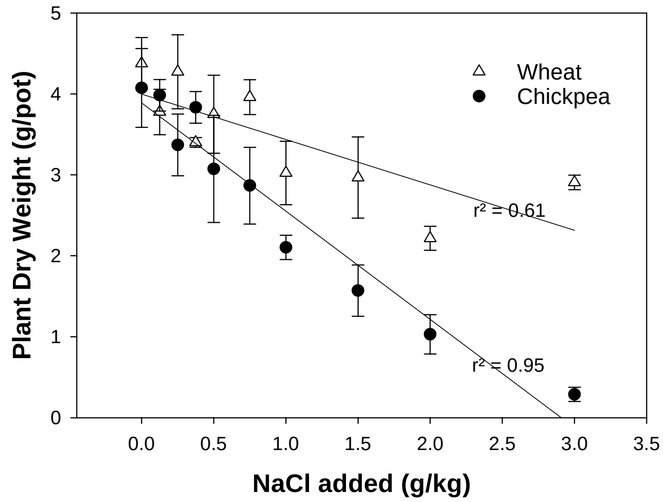
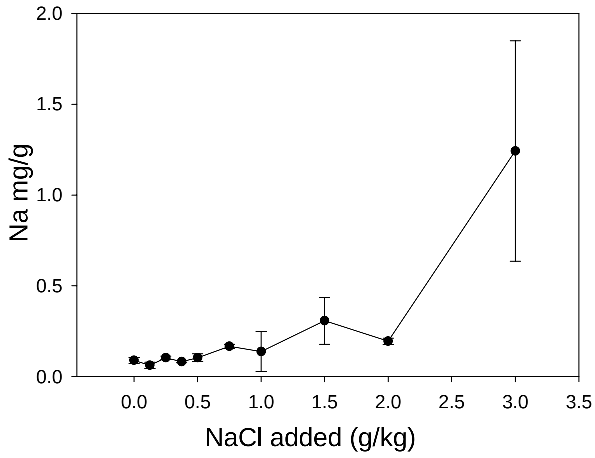


Figure 2. Plant dry weight (per pot).

While the effect of NaCl on final soil water content was only evident for chickpea at salt additions above 1.5g/kg, growth of both wheat and chickpea was affected from much lower salt contents (Figure 2). A 10% reduction in growth occurred at 0.5g/kg for chickpea and 1.0 g/kg for wheat.

a)



b)

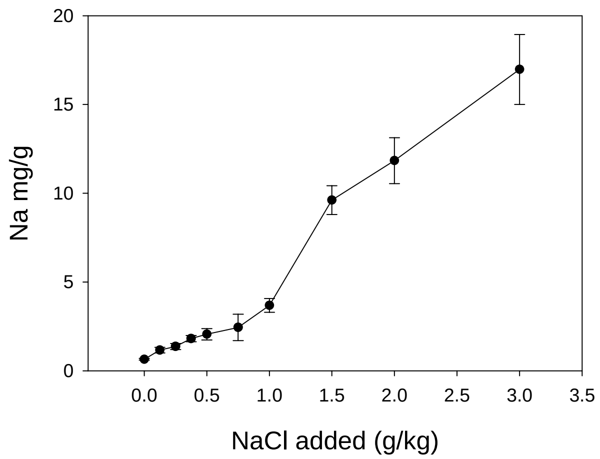


Figure 3. The Na^+ concentration in plant tissue of a) Wheat, and b) Chickpea.

Accumulation of Na^+ in the plant tissue of chickpea was approximately ten times greater than Na^+ accumulation in wheat (Figure 3). Wheat was also able to exclude Na^+ at higher external salt concentrations. These results indicate that wheat is able to effectively exclude Na^+ up to external concentrations of 2g/kg, while Na^+ uptake in chickpea increases sharply above 1g/kg NaCl.

Discussion

The foliar symptoms observed for both wheat and chickpea were consistent with those described in the literature for salt stress, or Na^+ or Cl^- toxicity (Eaton 1966; Grundon 1987; Kurniadie and Redmann 1999; Xu *et al.* 2000). The development of toxicity symptoms on the oldest plant tissues is consistent with accumulation of salts in the plant tissues until toxic levels are reached (Krishnamurthy *et al.* 1987; Marschner 1995).

The differences between wheat and chickpea in the way foliar symptoms developed may be linked to the accumulation of Na^+ in plant tissues. Wheat appeared water stressed before developing salt stress symptoms, and had much lower accumulation of Na^+. This indicates that while wheat was able to exclude Na^+, maintaining osmotic adjustment in order to take up water was less successful. Conversely, chickpea was initially able to maintain water uptake, but accumulated large amounts of Na^+ quickly. This early accumulation of salt may have also served to decrease the osmotic potential of the plant tissues and facilitate water uptake.

As plant growth progressed, the effects of early salt uptake, or exclusion, further impacted on plant growth and water extraction. Because wheat was able to prevent toxic levels of Na^+ accumulating, it could maintain growth and water uptake, which resulted in uniform water extraction across all treatments, and less impact on growth than occurred in chickpea. Meanwhile, accumulation of high concentrations of Na^+ in chickpea appear to have resulted in a severe reduction in growth. At rates of NaCl greater than 1.5g/kg plant growth was so severely reduced that water extraction ceased.

From this evidence it seems likely that wheat may be reasonably tolerant of saline conditions, provided that sufficient water supply is maintained. Chickpea however, is intolerant of saline conditions.

Conclusions

The results of this experiment indicate that the most significant impact of increased NaCl on growth of wheat is the osmotic effect in reducing plant water uptake, while growth of chickpea is most affected by accumulation of salts in plant tissues. Further investigation of this subject is currently in progress.

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