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Effects of Salinity and pH on Gas Exchange and Growth of Wheat under Hydroponic Conditions

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Abstract: The experiment was conducted on SARC-1 wheat in plastic pots in solution culture. Two salt-stress levels (0 mol m^{-3} NaCl (control) and 100 mol m^{-3} NaCl), and two pH levels (pH 5.8 and 8.5) were tested. Salt stresses were created by adding calculated amounts of commercial NaCl to the nutrient solution. pH 8.5 was created by adding 1.0 M KOH. Data provide some evidence that the effects of salinity on net photosynthesis (Pn) and growth were greater at high pH than at low pH. Percentage decreases in root, shoot weight and leaf area due to salinity were greater at high pH than at low pH. pH 8.5 in combination with 100 mol m^{-3} NaCl proved very harmful for gas exchange and plant growth.

Key words: Salinity, pH, saline, sodic, wheat, gas exchange, photosynthesis

Introduction

The increasing demand for cereals and other food crops has necessitated the utilization of brackish waters and marginal lands having high salinity and alkaline pH. In many arid regions of the world, including Pakistan, soils are mostly saline sodic and have a pH of 8.5 or more along with salt stress. These conditions cause nutrient imbalances in such soils, and the deleterious effects of salinity become more hazardous (Bandyopadhyay and Singh, 1990). Soil pH is an important factor influencing the growth of most field crops and pastures through its effects on the solubility and availability of plant nutrients. Wheat and barley are reported to suffer a reduction in growth at pH 8.5 and 9.0 respectively (Hewitt, 1966).The effects of high salinity of the solution culture on different growth and gas exchange parameters have also been reported by different workers (Richards, 1969; Iqbal, 1992). Alam (1981) studied the effects of different pH levels in solution culture on rice growth and reported that growth was affected adversely at high pH. Optimal dry matter accumulation was noted at pH levels between 5.5 and 6.5, and maximum reduction in growth occurred at both pH 3.5 and 8.5. It was also found that Fe^{2+} contents in the plants decreased with increasing solution pH while the concentration of other elements increased progressively. Leidi *et al.* (1991) studied the effect of high pH and salinity on wheat under NO_3^- and NH_4^+ nutrition. A decrease in wheat growth was reported with an increase in pH of the nutrient solution. Shoot dry weight declined with increasing NaCl concentration of the nutrient solution. Plant growth also decreased with an increase in pH. Findenegg *et al.* (1989) have reported an increase in free ammonium in sugar beet leaves at increased pH of the nutrient solution and suggested that ammonium accumulation could have been responsible for the growth depression at high pH.

The length of root hairs of wheat growing in Long Ashton nutrient solution was affected by pH and the concentration of Ca^{2+}. The pH limits were about 3.0-3.5 for severe injury and 3.5-4.0 for marked depression in growth, and at about 9.0 and 8.5 respectively at the upper end for wheat and barley in water culture (Hewitt, 1966). Uptake of N, P, K^+, Ca^{2+}, Mg^{2+}, Zn^{2+}, Mn^{2+}, Cu^{2+} and Fe^{2+} were reduced by salinity and/or sodicity in wheat (Padole, 1991).

The majority of efficient nutrient solutions used in solution culture studies, have pH values between 5 and 6; which do not represent the saline-sodic soil conditions (alkaline pH) encountered in the field. Research regarding the salt tolerance of wheat has been extensive, but the effect of high pH in combination with salt stress has been mostly ignored. The purpose of this experiment was to study the effects of salinity at high (alkaline) and low (acidic) pH and find out if the pH of the hydroponic culture medium influences responses of wheat to salt stress.

Materials and Methods

Plastic pots of 10 litre capacity with expanded polystyrene tops, were used for growing the plants. The pots as well as the lids were painted black to discourage any fungal growth. Twelve holes were bored in the polystyrene lids to hold the seedlings. The experiment was conducted in a glasshouse at University College of North Wales, Bangor, UK. The average maximum and minimum daily temperatures in the glasshouse during the course of this study were 30.1 ± 1.1 and 8.1 ± 0.5°C respectively. During the same period, average sunshine hours at the farm were 6.4 ± 0.6 hours.

Seeds of SARC-1 variety of wheat were germinated on capillary matting placed over a plastic pot which was filled to the top with tap water. After germination, 12 healthy seedlings were transplanted into each polystyrene lid and held in place with pieces of foam.

Nutrient solution was introduced 3 days after transplanting. The nutrient solution contained 5.0 g of Phostrogen per 10 litre water to which trace elements were added according to modified Long Ashton formula (Hewitt, 1966). Iron was added as Fe-EDDHA from a stock solution (instead of Fe-EDTA) at 4.0 mg l^{-1} to the nutrient solution in the pots to improve the iron availability to the plants under alkaline pH conditions (Leidi *et al.*, 1991).

Two salt stress levels i.e. 0 mol m^{-3} NaCl (control) and 100 mol m^{-3} NaCl were tested. At each stress level, two pH levels i.e. pH 5.8 (pH of freshly prepared nutrient solution) and 8.5 were imposed. Salt stress levels were produced by adding calculated amounts of commercial NaCl to the nutrient solution. pH levels were adjusted to 8.5 by adding 1.0 M KOH. Salt was added starting 7 days after transplanting at the rate of 25 mol m^{-3} NaCl per day and was raised up to 100 mol m^{-3}. The two pH levels were imposed at the time when the salt stressed plants were at 100 mol m^{-3} NaCl. The treatments thus produced were as follows:

1. 0 mol m^{-3} NaCl at pH 5.8 (control)
2. 0 mol m^{-3} NaCl at pH 8.5
3. 100 mol m^{-3} NaCl stress at pH 5.8
4. 100 mol m^{-3} NaCl stress at pH 8.5

The experiment was laid out in a completely randomized design with five replications. Nutrient solutions were kept under constant aeration and were changed after every week (Leidi *et al.*, 1991). pH 8.5 was maintained daily with 1.0 M KOH while the lower pH level was left undisturbed. The pots were topped daily with tap water to make up the loss due to evapotranspiration.

Gas exchange measurements were made using a portable Infra-red gas analyser (IRGA-Model LCA-2), on the sixth, fully expanded leaves on the main stem, 45 days after sowing (DAS); at a PPFD of 1000 ± 30 μmol m^{-2} s^{-1} by shifting the plants to a growth room. The measurements of net photosynthesis (Pn), stomatal conductance (g_s), transpiration (E) and sub-stomatal carbon dioxide (Ci) were made on four plants in each treatment from each replication. After measuring gas exchange, the remaining plants were harvested to record agronomic data i.e. number of tillers, leaf area, shoot dry weight and root dry weight. The samples of shoot and root were dried in an oven at 80°C for 72 hours and dry weights were then recorded. ANOVA and LSD were calculated at 0.05 level of probability unless otherwise stated.

Results and Discussion

Gas Exchange Parameters: Both salinity and high pH resulted in significant decreases in Pn (LSD = 0.61) and g_s (LSD = 0.04). The effects of salinity were greater than the effects of high pH. The salinity x pH interaction was not significant.

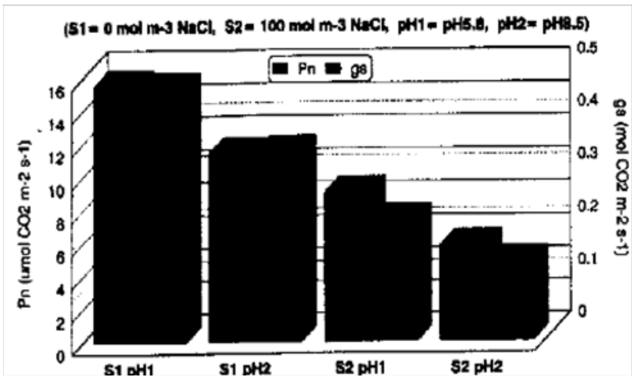

Fig. 1: Effect of salinity and pH on net photosynthesis (Pn) and stomatal conductace (gs)

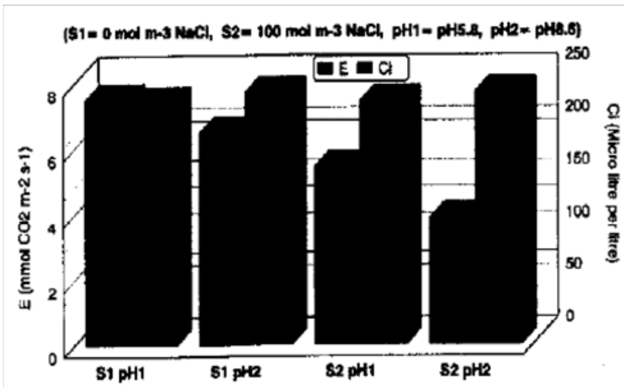

Fig. 2: Effct of salinity and pH on transpiration (E) and sub-stomatal CO_2 (Ci) in wheat

At 0 mol m^{-3} NaCl net photosynthesis (Pn) decreased by 26% as a result of increase in pH from 5.8 to 8.5 (Fig. 1). At 100 mol m^{-3} stress, the decrease in Pn was 42%. The lowest rate of Pn was observed at 100 mol m^{-3} NaCl in association with pH 8.5. Stomatal conductance (g_s), was affected in a similar way. Compared to the control, g_s was decreased by 26, 53 and 70% at pH 8.5, 100 mol m^{-3} NaCl stress and 100 mol m^{-3} stress + pH 8.5 respectively.

The decreases in transpiration rate (E) were smaller than the decreases in Pn and g_s but again the effects of salinity were greater than the effects of high pH (Fig. 2). Compared to the control, E was decreased by 14, 28 and 48% at pH 8.5, 100 mol m^{-3} NaCl stress and 100 mol m^{-3} stress + pH 8.5 respectively.

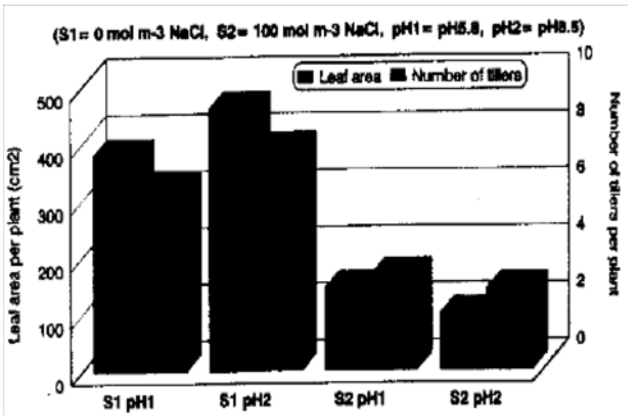

Fig. 3: Effect of salinity and pH on leaf area and number of tillers per plant

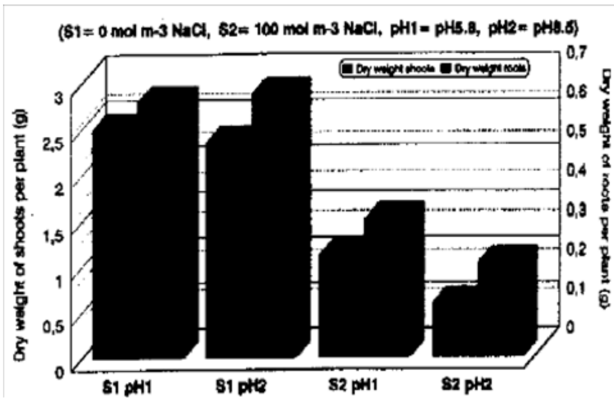

Fig. 4: Effect of salinity and pH on dry weight of shoot and roots per plant

The effects of salinity and pH were highly significant (LSD = 0.40) but their interaction was non-significant. Sub-stomatal CO_2 (Ci) was significantly higher (Fig. 2) at pH 8.5 than at pH 5.8 (LSD = 6.45). The effect of salinity and salinity x pH interaction were non-significant.

The decrease in g_s with salinity and no changes in Ci indicated that decreases in Pn were mostly due to an increase in stomatal and mesophyll resistance (Kingsburg and Epstein, 1984; Rawson, 1986). High pH of the growth medium may be responsible for a significant increase in Ci which might be due to inhibition in CO_2 fixation at chloroplast level (Lauchli and Epstein, 1984). The decreases in Pn, g_s and E caused by salinity were greater than those caused by high pH. In contrast to this, Leidi *et al.* (1991) found that in NH_4^+ fed plants, E decreased at high NaCl concentration and increased with an increase in pH of the nutrient solution. In this study, there was no effect of NaCl salinity on the Ci while a significant increase was caused by high pH. This indicates that high pH may be responsible for slowing down the photosynthetic process which caused an increase in Ci due to the presence of some internal resistance in the plants grown at high NaCl concentration in combination with high pH (Leidi *et al.*, 1991). Decrease in chlorophyll content of the leaves might also be responsible for a decrease in Pn at high pH in this study. Khan (1996) however, reported non-significant decreases in Pn at high ESP of the soil which had a pH greater than 8.5 (Richards, 1969).

Agronomic Data: An increase of 22% was noted in leaf area per plant at pH 8.5, while 62% decrease occurred at 100 mol m^{-3} NaCl (Fig. 3). At 100 mol m^{-3} stress + pH 8.5, the leaf area was affected more adversely and a decrease of 74% was noted in this case. The effects of salinity and salinity x pH were highly significant (LSD = 40.6 and 56.3 respectively) but the effects of pH were non-significant.

The effects of salt stress and pH on the number of tillers per plant at 45 DAS, are presented in Fig. 3. At pH 8.5, there was a 22% increase in this parameter compared to the control. At 100 mol m^{-3} NaCl, there was a 49% decrease in the number of tillers, while at 100 mol m^{-3} NaCl+pH 8.5 the effect was most severe and the decrease was 56% compared to the control. The effects of salinity, pH and their interaction were significant (LSD = 0.42, 0.42 and 0.59 respectively).

Dry weight of shoots was decreased by 6% due to an increase of pH alone but by 55% due to 100 mol m^{-3} NaCl stress (Fig. 4). The decrease was highest (77%) at 'pH 8.5+100 mol m^{-3} NaCl stress. The effects of salinity and pH were highly significant (LSD = 0.30***), while those of salinity x pH were non-significant.

The effects pH on dry weight of roots per plant were also small compared to the effects of salinity (Fig. 4). Averaged over the two pH levels, salinity decreased root dry weight by 56%. The decrease was 63% at 100 mol m^{-3} NaCl+pH 8.5. The effects of salinity were highly significant (LSD = 0.06) while those of pH and salinity x pH interaction were non-significant. Salinity reduced growth of plants through its effect on the shoot and root growth, decrease in leaf area, number and length of tillers and dry matter accumulation (Munns and Termaat, 1986).

The effects of salinity on these parameters were considerably greater at high pH than at low pH, and also substantially greater on leaf area than on the number of tillers. It is clear from this, that decrease in total leaf area per plant was due to a decrease in the number of tillers as well as a decrease in the area of individual leaves. An increase in the number of tillers and leaf area per plant at pH 8.5 in the absence of NaCl stress might be due to higher K^+ level in this treatment and comparatively better nutrition because KOH solution was added to raise the pH of the nutrient solution. However, this is unlikely as K^+ in leaf sap was lower at pH 8.5 than at pH 5.8. In contrast to the above, Leidi *et al.* (1991) did not observe this trend in their experiment on wheat.

Salinity is responsible for reduction in leaf growth which mainly occurs under salt stress and in this way it affects yield adversely (Iqbal, 1992). An increase in root zone salinity lowers the overall water status of the plants and thus aggravates this effect. With increase in age and build up of the salt concentration other symptoms of salt injury may appear. The effects of salinity on leaf and other growth parameters could be due to excessive transport of Na^+ and Cl^- and decreased uptake of K^+, Ca^{2+}, Mg^{2+}, NO_3^- or SO_4^{2-} ions (Munns and Termaat, 1986). The adverse effects of salinity may be further aggravated at high pH of the growth medium (Srivastava *et al.*, 1988; Leidi *et al.*, 1991). A growth inhibition was observed by Findenegg *et al.* (1989) in sugar beet both at high pH and at increased Cl^- concentration.

It can be concluded from the results obtained in this study that the deleterious effects of salinity on different gas exchange and growth parameters were further enhanced at high pH of the growth medium.

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