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Potential of applied potassium in improving salt tolerance of Maize (*Zea mays* L.) hybrids

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Abstract

Hydroponic experiment was performed to evaluate the response of three maize hybrids to potassium supply under salinity stress. Potassium was applied at the rate of 9 and 18mm K under saline (120mm L^{-1} NaCl) and non-saline condition in half strength Hoagland solution. Results revealed that salt stress negatively affected the root length, shoot length, root fresh and dry weight, shoot fresh and dry weight, relative water content, membrane stability index, K^+, K^+/Na^+ ratio in all maize hybrids while reverse is true in case of Na^+. However, K application significantly alleviates the hazardous effect of salinity. The prominent effect of K application was observed @ 18mm K in maize hybrid YH relative to other levels of K and maize hybrids respectively under both saline and non-saline condition.

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Introduction

Pakistan is situated in arid to semi-arid climate region of world. This nature of climate is encouraging to the accumulation of salts that are causing severe salinity problems (Ashraf *et al.*, 2002, Abbasi *et al.,* 2012). Addition to climatic factors, poor quality irrigation water and improper drainage systems are the major causes for the formation of saline soils in arid and semi-arid regimes (Kiani, Rasouli, 2014). Pakistan's total cultivated area is about 20.2 million hectares out of which about 6.67 million is affected by salinity (Murtaza *et al.*, 2011). In Punjab 2.67 million hectare is affected by salinity (Anonymous, 2002). A loss of about US $300 million each year estimated due to salinity in Punjab province (Athar, Ashraf, 2009).

Soil salinity hinders the plant growth and reduces the yield by mainly three ways; first the salts accumulate around the plant roots and reduce the plant's internal water potential that causes the decrease in water movement from soil to the plant and stops ions or nutrient transport towards the plant. Secondly through transpiration pathway these excess soluble salts when enters into plants body damage the leaves and thereby reduce the process of photosynthesis (Arraouadi *et al.,* 2011). In a third way, salinity causes reduction in plant growth is the ionic imbalance that is caused by excess chloride and sodium ions and reduced uptake of other cations and anions like Ca^{+}, K^{+}, P (Munns, 2005; Abbasi *et al.*,2015). Salinity adversely affects plant's all growth stages including germination, seedlings, vegetative and maturity stages (Nawaz *et al.*, 2010; Abbasi *et al.*, 2015). From its drastic effects the reduction in internodal distance and fewer leaves per plant are common in plants grown under salt stress (Zhu, 2001). Defoliation is another adverse effect of salinity (Akca, Samsunln, 2012). Plants grown under salt stress feel disturbance in their different physiological pathways i.e. respiration, nitrogen fixation, photosynthesis and carbohydrates metabolism caused by ionic toxicity and osmotic stress throughout their growth period (Chen *et al.*, 2005; Abbasi *et al.*, 2016). Maize plant is moderately sensitive to salinity but high salt concentration in the root zone drastically affects maize growth and governs great loss in yield (Munns, 2002) by inducing low osmotic potential, inhibiting enzyme activities, creating ionic imbalance, disturbing solute accumulation and changing the internal plant metabolic activities (Lewis, 2002; Flowers, 2004). The salinity induced effects differ with the stage of plant growth with the changes in biochemical and physiological attributes (Najafi *et al.*, 2007). Potassium is an essential plant nutrient that is considered effective osmoticum which play an important role in restricting the uptake of sodium by adjusting the osmotic potential and stomatal activity under salinity (Mengel, Kirkby, 2001). Maintenance of adequate potassium levels is much important for survival of plants in saline medium (Abbasi *et al.*, 2014). Potassium is observed with the ability to alleviate the adverse effects of salinity (Sanjakkara *et al.*, 2001) by regulating K^{+}/Na^{+} ratio. Keeping in view the favorable possessions of potassium towards salinity, present study was planned to explore the tendency of applied potassium in improving salt tolerance mechanism of maize hybrids.

Materials and methods

Experiment Details and Treatments

Experimental Material

A hydroponic experiment was conducted in the Wire House of Department of Soil Science, University College of Agriculture & Environmental Sciences, the Islamia University of Bahawalpur. Two maize hybrids seeds (Yousufwala hybrid and YH 1898 hybrid) were collected from Maize and Millet Research Institute (MMRI), Yousafwala, Sahiwal, Pakistan, while the 3rd hybrid maize Agroman-6619 seeds were collected from local market. Sufficient number of healthy maize seeds of each hybrid was germinated in sand culture.

At two-leaf stage, seedlings of uniform size were wrapped with foam at root shoot junction and then transplanted in holes of thermo pole sheets floating over 50 L tubs containing half strength Hoagland's nutrient solution (Hoagland and Arnon, 1950).

Treatments

To investigate the salinity tolerance, maize hybrids were exposed to 120mm NaCl (T_2) alone and with the application of two levels of potassium (T_5: 9mm K and T_6: 18mm K). Both potassium levels were also applied as alone without any stress (T_3: 9mm K and T_4:18mm K). A control treatment (T_1) was also checked for comparison.

Harvesting and Measurements

After 4 weeks of stress plants were harvested manually and following morphological and physiological parameters were recorded. Maize plants shoot & root length, shoot & root fresh weights were taken through electrical weighing balance just after harvest. Shoot & root dry weights were obtained placing the weighed sample of shoot and root in an oven at 65°C for 48 hours till the constant weight obtained. Relative water contents were measured according to the method described by Weatherley (1950) and the membrane stability index was measured according to the procedure described by Premchandra (1990) and Sairam (1994).

Determination of Na^+ and K^+ concentration

Na^+ and K^+ concentration from leaf sap was determined by using Sherwood 410 Flame photometer.

Statistical Analysis

The data collected for the maize hybrid growth, physiological and ionic attributes was subjected to the statistical analysis at 1% probability.

Results

Effect of salinity and potassium on morpho-physiological attributes of maize hybrids

Maize hybrids showed significant differences under the salinity stress. Addition of sodium chloride caused significant decrease in shoot length as compared to control in all three maize hybrids (Fig. 1). The shoot length was decreased up to 60.31% in the treatment where NaCl was applied at the level of 120mm as compared to the control. Among the three maize hybrids YH hybrid was found more tolerant to salinity with least decrease in shoot length (38.58%) as compared to the Agroman-6619 and YH-1898 hybrids. Application of potassium significantly improved the shoot length by inducing tolerance in all maize hybrids. Up to 24.21% improvement in shoot length was observed in the treatment where potassium was applied @ 18mM under salt stress (T_6). Maximum shoot length (124cm) was recorded in case of YH hybrid in the treatment where potassium applied @ 18mM without salt stress (T_4).

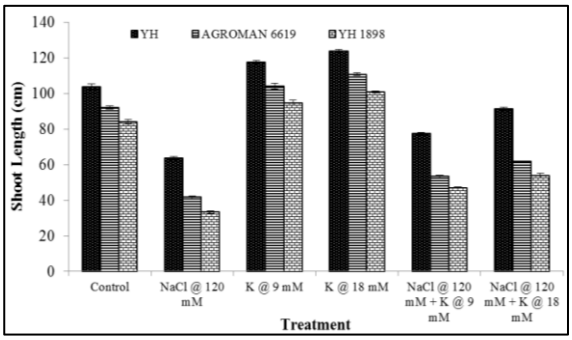

Fig. 1. Effect of potassium and salinity on shoot length (cm).

Root length for maize hybrids was also drastically decreased under the salinity stress. Data regarding root length (Fig. 2) showed that salinity stress exerted strong negative impact on root length of maize hybrids. However, the impact of salinity differed significantly between maize hybrids. Minimum effects of salinity on root length were observed in maize hybrid Agroman-6619 with minimum decrease in root length (28.44%) at 120mm NaCl level when compared with control. While maize YH-1898, on the other hand, showed much larger sensitivity to sodium chloride application with 32.99% decrease in root length over the control. Application of potassium @ 18mm K significantly improved the root length under saline condition and this effect was more prominent in maize hybrid YH.

Data regarding shoot fresh and dry weights of maize hybrids, showed a significant variation in the tolerance to salinity and significant positive response to the applied potassium as presented in Fig. 3 & Fig. 4 respectively. The highest reduction in shoot fresh weight (53.37%) was observed in case of Agroman-6619 hybrid followed by the YH-1898 hybrid with 53.12% decrease in the treatment where NaCl was applied at the level of 120mm as compared to the control. While in case of shoot dry weight, YH-1898 was severely affected by salinity with decrease in shoot dry biomass up to 60.61% when compared to control. Application of potassium improved the both shoot fresh and dry weights when applied at the level 18mM under salinity up to 16.23% for fresh and 52.81% for shoot dry weight in maize hybrid YH.

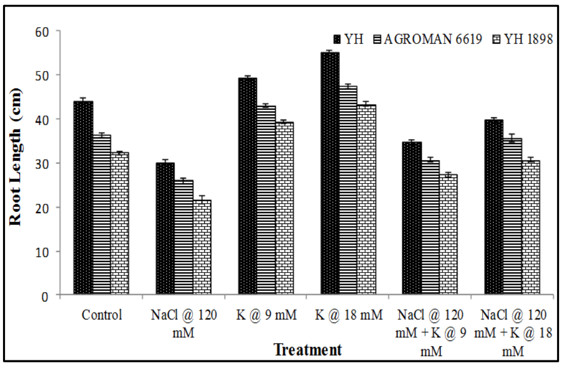

Fig. 2. Effect of potassium and salinity on root length (cm).

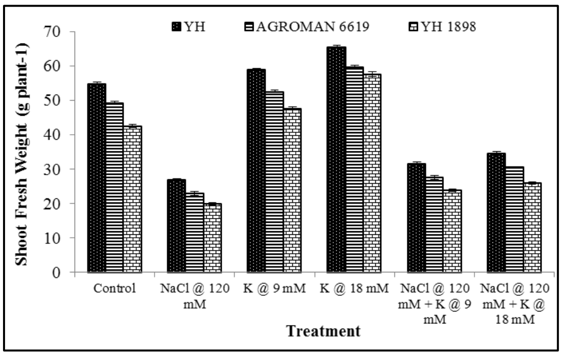

Fig. 3. Effect of potassium and salinity on shoot fresh weight (g plant-1).

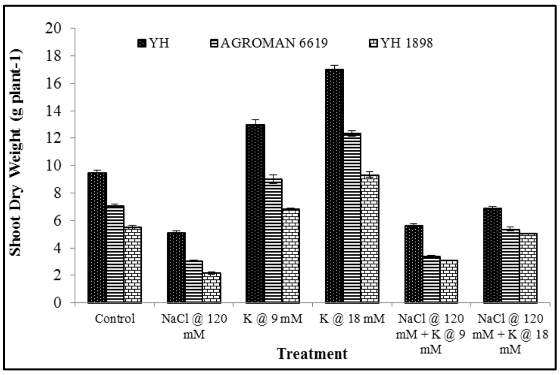

Fig. 4. Effect of potassium and salinity on shoot dry weight (g plant-1).

Same pattern of root fresh and dry weight reduction was observed as in case of shoot fresh and dry weights. Root fresh and dry weights for maize hybrids were also drastically decreased under the salinity stress. The impact of salinity differed significantly between maize hybrids. Minimum effects of salinity on root fresh and dry weight were observed in maize hybrid YH with minimum decrease in root fresh and dry weights (38.88% for fresh and 49.35% for dry) as compared to the control treatment at 120mm NaCl level. While maize YH-1898, on the other hand, showed much larger sensitivity to sodium chloride application with 54.55% decrease in root fresh weight and 61.90% decrease in root dry weight as presented in Fig. 5 and Fig. 6 respectively. Addition of potassium @ 18mm K shows prominent response in maize hybrid YH both under saline and non-saline condition.

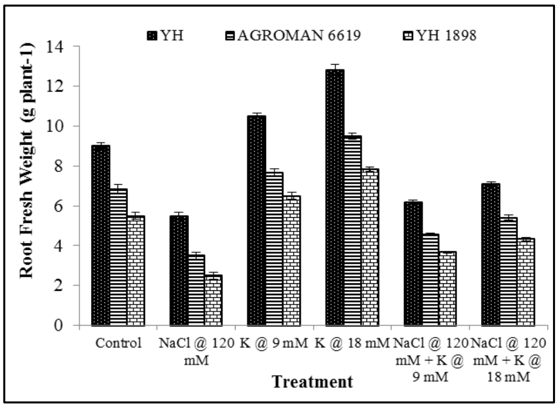

Fig. 5. Effect of potassium and salinity on root fresh weight (g plant-1).

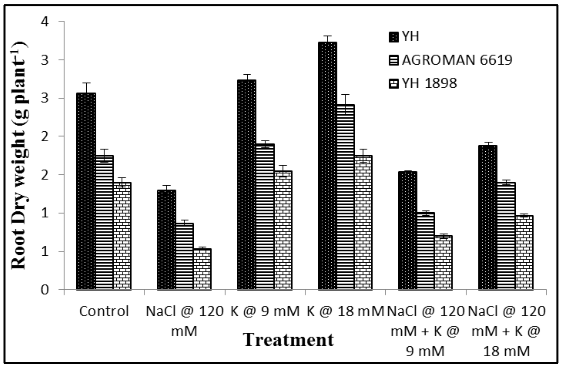

Fig. 6. Effect of potassium and salinity on root dry weight (g plant-1).

Effect of salinity and potassium on physiological attributes of maize hybrids

Physiological attributes of maize hybrids were also influenced under the salinity. Membrane stability index (MSI) and relative water contents (RWC) was significantly reduced in all three maize hybrids under the 120mm NaCl level (Fig. 7 & Fig. 8). Maize hybrid YH-1898 was severely affected by salinity by showing least MSI and RWC and found to be most salt sensitive hybrids followed by Agroman- 6619 hybrid and YH hybrid. Potassium application under saline and non-saline condition improved the both physiological attributes. Prominent response to potassium application at @ 18mm K was observed in maize hybrid YH while least response was noted in YH-1898 maize hybrids under saline and non-saline condition. The response of Agroman-6619 maize hybrid was intermediate between these two maize hybrids.

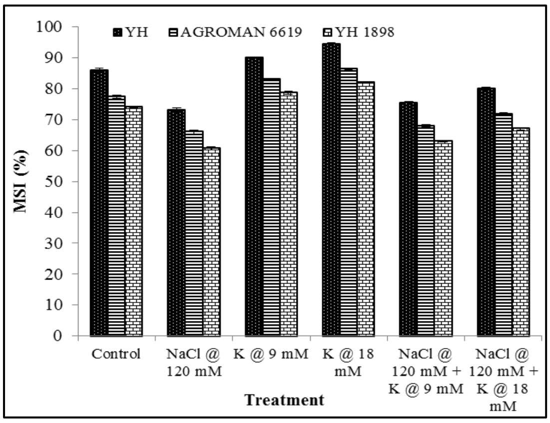

Fig. 7. Effect of potassium and salinity on membrane stability index (%).

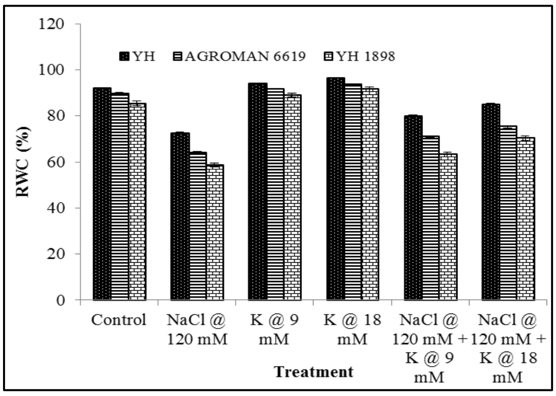

Fig. 8. Effect of potassium and salinity on relative water contents (%).

Effect of salinity and potassium on ionic attributes of maize hybrids

Data regarding sodium concentration in the leaf sap of three maize hybrids grown under saline and non-saline condition revealed that salt stress had a significant effect on the leaf sodium concentration (Fig. 9). Na^+ concentration differed significantly between control and 120mm NaCl. Under saline condition, the highest concentration of sodium (148 mol m^{-3}) was found in YH-1898 followed by Agroman-6619 (138 mol m^{-3}), whereas the lowest sodium concentration was observed in YH (107 mol m^{-3}) as compared to the control. The addition of potassium @ 18mm K decreased the sodium concentration in leaf sap of maize hybrids especially in YH followed by other two maize hybrids. Salinity also reduced the potassium concentration in the leaves of all maize hybrids. The maize hybrid YH had highest potassium concentration (86.30 mol m^{-3}) followed by Agroman-6619 (73.00 mol m^{-3}) and YH-1898 had the lower concentration (66.00 mol m^{-3}) of potassium under 120mm level of NaCl. Addition of potassium @ 18mm K significantly alleviates the harmful effect of salinity by improving potassium concentration in leaf sap of all maize hybrids. This effect was more prominent in maize hybrid YH followed by other hybrids as depicted in Fig. 10.

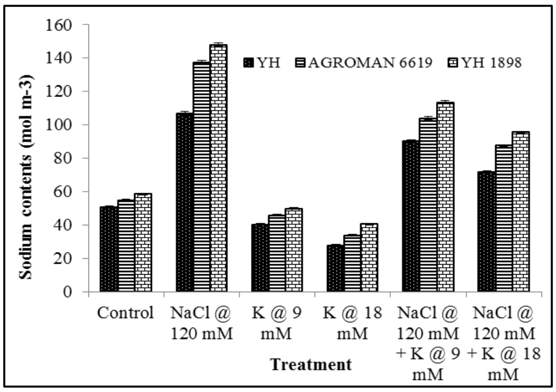

Fig. 9. Effect of potassium and salinity on sodium concentration (mol m^{-3}).

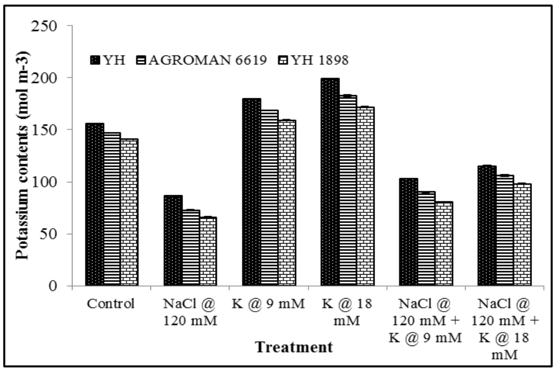

Fig. 10. Effect of potassium and salinity on potassium concentration (mol m^{-3}).

Leaf potassium to sodium ratio decreased significantly with the salinity stress (Fig.11). Increased uptake of sodium resulted in a valuable decrease in potassium to sodium ratio. The maize hybrid YH maintained better level of potassium to sodium ratio (0.76) followed by Agroman- 6619 (0.50) and YH-1898 (0.40) under 120mm level of NaCl concentration. The minimum potassium to sodium ratios were observed in YH-1898 in all the treatments under saline as well as non-saline medium in the solution.

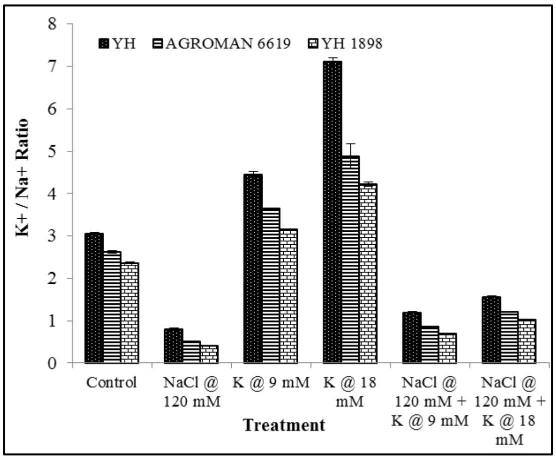

Fig. 11. Effect of potassium and salinity on K^+ / Na^+ ratio.

Discussion

Characterization of germplasm of different crops for salt tolerance, transfer of genes for salinity tolerance into adapted cultivars and suitable regulation of mineral nutrients are needed to enhancement the chemical and engineering approaches to sustain crop production on salt affected soils (Abbasi *et al.*, 2015; 2016). Result of present study revealed that salinity induced reduction in the root length, shoot length, root fresh and dry weight, shoot fresh and dry weight. Salinity reduces the ability of plant to absorb water from soil solution resulting in osmotic stress which restricted the plant growth (Munns *et al.*, 2006). Salinity induced osmotic stress mainly causes less leaf growth and it is the major factor for growth reduction in most of the salt sensitive species (Munns, Tester, 2008). Under high level of salts, the water potential of root surrounding environment is reduced that makes the plant unable to absorb water from the soil solution by roots (Abbasi *et al.*, 2014). Salt stress reduces the plant growth attributes because of ion toxicity especially sodium (Agong *et al.*, 2004). Application of potassium under saline medium increased the crop growth parameters (Gadallah *et al.*, 2007 and Akram *et al.*, 2007; Abbasi *et al.*, 2015). The present experiment depicts that the addition of potassium under salinity increased the shoot length, root length, shoot fresh weight and root fresh weight. Application of potassium in the saline environment improves the root length and plant height in plants (Bar-Tal *et al.*, 2004; Maqsood, 2009; Abbasi *et al.*, 2014). Plants with lower concentration of sodium produce greater shoot length and biomass (Munns, James 2003; Keshavarz *et al.*, 2004)

Accumulation of toxic salts may leads to the alteration in the cell membrane stability index and its structure which causes the disturbance in plant cell metabolism (Hasegawa *et al.*, 2000). This may further leads to the retarded plant growth as a result of reduced protein synthesis due to the reduced activity of photosynthetic enzymes as phosphoenolpyruvate carboxylase and Rubisco (Yang *et al.*, 2002). Permeability of plasma membrane disturbed due to the low water uptake reducing the cell elongation and growth that is directly related to turgor potential and the reduction in osmotic potential within plant cell (Munns, Tester, 2008). This study also depicts that salinity severely disturbed the MSI and RWC in maize plants. Potassium played an important role in maize hybrids water relation under salinity stress and helped the plants to absorb more water to attain turgidity and membrane stability (Abbasi *et al.*, 2016)

High sodium accumulation under salinity stress in maize hybrids (YH-1898) could be one of the reasons of its sensitivity to salt stress, while more potassium concentration in the case of maize hybrids (YH) must have contributed towards its discriminating tolerance to salinity stress. Ion toxicity is another deleterious effect of salinity on plant growth which results in the accumulation of toxic ions like sodium and chloride that reduces the availability of other plant essential nutrients like Ca^{2+} and K^+ (Lefevre *et al.*, 1989). Ion toxicity is mainly hampered by the sodium ions in plant metabolic system directly (Munns, 2002).

High concentration of salts in the root zone enhances the Na^+ and Cl^- concentration in leaf (Piestun, Bernstein (2005). High Na^+/K^+ ratio results in disturbing the metabolic process, inhibiting the enzymatic activities and reduces the plant photosynthesis activities (Chesnes, Montague, 2001).

Conclusion

The reduction in growth of maize hybrids under salinity stress was due to imbalance in ionic attributes especially the toxicity of Na^+ and its imbalances with K^+. The maize hybrid YH showed a strong affinity for potassium over the sodium and exhibited relatively less reduction in shoot length; shoot fresh and dry weight root fresh and dry weight, MSI, RWC and K^+/Na^+ ratios. Addition of potassium in saline environment created marked difference in plant morpho-physiological and ionic attributes and this effect was more prominent in maize hybrid YH relative to maize hybrid Agroman- 6619 and YH-1898.

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