Pakistan Journal of Applied Sciences 2(6): 631-636, 2002

Effects of Soil Salinity and Sodicity with and Without Soil Conditioner (polyacrylamide) on the Seedling Emergence and Growth of Different Wheat Varieties

I. Rajpar and N.B. Sial
Department of Soil Science, Faculty of Crop Production
Sindh Agriculture University Tando Jam, Pakistan

Abstract: A pot experiment in a clay loam soil was conducted to investigate the effects of high soil sodicity with poor (ESP 50) and stable structure (ESP 50 + plolyacrylamide (PAM)) and high soil salinity (ECe 19 dS/m) on seedling emergence and growth of eight (Kharchia-65, Anmol, NIAB-20, PAK-81, TW-161, Bakhtwar, KTDH-19 and SARC-1) wheat varieties. Seedling emergence, shoot height, shoot dry weight and root length were decreased by both salinity and sodicity. With the exception of seedling emergence, the effects of sodicity were greater than salinity. On the basis of shoot dry weight as an indicator some varieties (PAK-81, Bakhtwar, KTDH-19 and Anmol) were susceptible to both stresses and showed large decreases. In some varieties (SARC-1, TW-161, NIAB-20 and Kharchia-65) the effects of sodicity were greater than salinity, where as in others this trend was reversed. Addition of soil conditioner (PAM) in presence of high ESP increased water stable aggregates % which resulted in increase in seedling emergence, shoot height and shoot dry weight. All varieties except Bakhtwar, KTDH-19 and SARC-1 showed positive response to improved soil structure. However, the response was greater in some varieties (TW161, PAK-81 and Kharchia-65) than (Anoml and NIAB-20) others.

Key Words: Polymer, Salinity, Sodicity, Soil Structure, Wheat

Introduction

It is considered by many workers (Mustafa *et al.*, 1956; Barzegar *et al.*, 1997) that poor soil structure and sodium toxicity are the main adverse physico-chemical features of sodic soils. These limit seedling emergence, plant growth and increase the concentration of toxic ions in plants. The damage caused by sodicity depends on soil properties such as, organic matter, type and content of clay, extent of pH and ESP (Singh and Abrol, 1984; Rowell, 1994; Boem and Lavado, 1995).

The effects of sodicity on wheat depend not only on soil characteristics, but also on plant characteristics (Boem and Lavado, 1995). Several workers (Mehotra and Dass, 1973; Gorham, *et al.*, 1997) have shown that, among other factors, varietal differences and growth stage can influence the tolerance of wheat to sodicity.

Much of the experimental information published on the effects of sodicity on emergence and growth of wheat relates to the effects of high ESP. Little research has been conducted to identify the separate effects of ESP and poor soil physical properties. Also, there have been no clear reports whether varieties tolerant of sodic conditions are tolerant of poor structure or excessive sodium or both. The reason for this is that the investigators did not pay sufficient attention to the separation of physical and chemical effects of sodic soil. Separation of adverse physical effects from chemical effects is difficult. Treating soils with polymers (soil conditioners) is one possible means of accomplishing this separation (Allison, 1956)

The main purpose of this experiment was to separate out the physical and chemical effects of sodicity (high ESP) on emergence and early growth of different wheat varieties. The second purpose of this experiment was to determine if the effects of PAM varied between varieties. Cultivars that perform well in sodic soil conditions may or may not perform well under saline soil conditions. To investigate this the varieties were also grown in a saline soil treatment. Soil salinity is not due only to increase in Na^+ and Cl^- ions but there may be higher concentrations of other ions (Ca^{2+}, SO_4^{2-} and Mg^{2+} etc). Thus in this study a mixture of 3 different salts (NaCl, $CaCl_2.H_2O$ and $MgCl_2$) was added to prepare a saline soil.

Materials and Methods

Preparation of Saline and Sodic Soils: The experiment was conducted in a clay loam soil with 3.8 %C, and 0.28% N collected from a cultivated field on the research area of Henfaes Agricultural Research Station, Bangor, UK. To prepare a saline soil treatment with an ECe of approximately 18 (dSm^{-1}) a mixture of salts consisted of 1.24g NaCl, 1.55g $CaCl_2$ and 1g of $MgCl_2$ kg^{-1} of air dry soil was added (Rowell, 1994) to the original soil. To generate an ESP of approximately 50, the soil (clay loam) was treated with 1M $NaHCO_3$ following the method of Bains and Fireman (1964). To stabilize the structure of sodic soil in the presence of high exchangeable sodium, artificially alkalinized sodic soil was treated by spraying with anionic polyacrylamide (Soiltex L1, Allied Collieds Limited, Yorkshire, England UK) soil conditioner at the rate of 0.2kg/100 kg of soil. The experiment was performed in a well ventilated glasshouse without supplementary heating or lighting.

Seed Sowing, Irrigation and Fertilizer Application: There were two pots (52 cm x 23 cm surface x16 cm deep) of each soil treatment. Seeds of eight wheat (*Triticum aestivum* L.) varieties (Kharchia-65, Anmol, NIAB-20, Pak-81, TW-161, Bakhtwar, KTDH-19 and

SARC-1) were sown in the pots. There were 8 rows (replicates) per pot. Each row contained 8 varieties in a separate random order. Single seeds of each variety were placed in each position with 3 cm row to row and 4 cm seed to seed distance. Irrigation water was applied to each pot, whenever needed, in amounts sufficient to keep the soil moisture at a point close to the water holding capacity of the soil. To apply sufficient plant nutrients, a compound fertilizer containing 14%N, 4.4%P and 22% K (Phostrogen Ltd, Deeside Industrial Park, Flintshire CH5 2NS) was applied at the rate of 0.5g/l of soil.

Recording of Seedling Emergence and Final Harvest: All emerged seedlings were counted in one pot ten and twenty Days After Sowing (DAS). In the other pot all germinated plants were harvested at 10 DAS by uprooting carefully. After measuring shoot height (cm) and root length (cm), plants were washed with tap water and oven dried at 82 °C for 48 hours and their dry weight (mg/plant) was recorded.

Soil Analyses: Before sowing and after harvesting of seedlings, soil samples were collected. Electrical conductivity (EC_e), Na^+, K^+, Ca^{2+} and Mg^{2+} were determined in the saturation extract using the methods given by Rhoades (1982). Soil pH was determined using 1:2.5 soil:water extract, soil texture was analysed using the Bouyoucos hydrometer method, total N and total C % were analysed by a total element automated CHN analyser (Leco CHN-2000). Sodium adsorption ratio (SAR) and ESP were calculated from the values of soluble Na^+, Ca^{2+} and Mg^{2+} (Rowell, 1994). The % of Water Stable Aggregates (WSA) was determined by wet sieving method of Angers and Mehuys, (1993).

Statistical Analyses: The seedling emergence percentages data recorded 20 DAS were analysed by transforming in to arcsine values. Due to uneven numbers of plants emerged, five plants of each variety per treatment were selected at random for determination of shoot height, root length and shoot dry weight. Preliminary analyses of the data showed that there were differences between varieties within each treatment. To test for variety x treatment interactions the data for control, saline, sodic and sodic plus PAM treatments were pooled and an analysis of variance was performed using the procedure for analysis of a series of experiments, recommended by Cochran and Cox (1957). S. E. D and L. S. D. values were calculated. Significance levels are shown in the tables by *, * *, and * * * for 5, 1and 0.1% probability levels, respectively. The non-significant differences are denoted by N. S.

Results and Discussion

Soil Characteristics:. The chemical properties (Table 1) of the original soil before sowing and after harvesting of the seedlings showed a low values of pH, ECe, SAR, and ESP with 1.5% of total carbon and 0.14 % total N. However, when the same soil was treated with 1M $NaHCO_3$, it showed an increase in pH together with markedly higher values of ESP and SAR. The ECe (dSm^{-1}) of treated soil was slightly increased. The effect of PAM on pH, ESP and SAR was very slight. After harvesting of the seedlings there was no distinct change in pH, SAR and ESP compared to before sowing, however ECe was markedly increased.

As sodicity increased the percentage of Water Stable Aggregates (WSA%) decreased. Treatment of sodic soil with PAM resulted in a large increase in the %WSA, so that the value obtained was similar to that of the control. Following the addition of the salt mixture, there was a marked change in the chemical properties of soil. The value of ECe was typical of that highly saline soil, but the pH value was lower compared to that of the control and sodic soil treatments. Although the SAR and ESP of the saline soil were higher than in the control. At the time of harvest the saline soil showed a decrease in pH and ECe, but an increase in SAR and ESP.

Effects on Seedling Emergence: Seedling emergence % was significantly ($p<0.005$) lower in the salt-affected soil treatments than the control. The effect of salinity was significantly greater than that of sodicity (Fig.1 & Table 2). However, there was a greater delay in emergence in the sodic soil, than in the saline soil treatment. Salinity decreased emergence %. Treating the sodic soil with PAM resulted in a small but significant ($p<0.005$) increase in seedling emergence %. Differences between varieties were also evident (Fig. 2 & Table 2). Variety Anmol had significantly lower seedling emergence than other varieties at both stages. Although, the interaction of soil treatments x varieties was not statistically significant ($p>0.005$), the results (Table 2) suggested that the effects of salt treatments on different varieties were different. Kharchia-65 and SARC-1 showed higher seedling emergence % than other cultivars in all treatments. Sodic soil treated with PAM resulted (Table 2) in a significant increase in emergence % of TW-161, Anmol and NIAB-20.

Effects on Seedling Growth: Seedlings in salt- affected soil treatments were significantly ($p<0.005$) shorter than in the control (Table 3). The effect of sodicity on shoot height was significantly ($p<0.005$) greater than that of salinity. Treatment of sodic soil with PAM resulted in a small but significant ($p>0.005$) increase in plant height. There were also small but significant ($p<0.005$) differences in shoot height between varieties. The interaction of soil treatments x varieties was also significant. Differences in height between varieties were greater under saline and sodic conditions, than in the control and sodic soil + PAM treatment. In some varieties (Bakhtwar, KTDH-19, SARC-1 and NIAB20) the effect of sodicity on plant height was greater than the effect of salinity, but in others (Anmol, PAK-81 and Kharchia-65) the effects of both salinity and sodicity were more or less similar. Treatment of sodic soil with PAM resulted in a small but significant recovery of shoot height in some varieties (TW-161, Anmol and PAK-81).

Shoot dry weight of seedlings in salt treated soils was significantly ($p<0.005$) lower than in the control. Similarly as it was in shoot height, the effect of sodicity was significantly ($p<0.005$) greater than that of salinity. The interaction of soil treatments x varieties was also significant ($p<0.005$). NIAB-20 and SARC-1 had high shoot dry weight/plant in both saline and sodic conditions. Varieties with low shoot dry weight under saline conditions (Anmol and PAK-81) also had low shoot

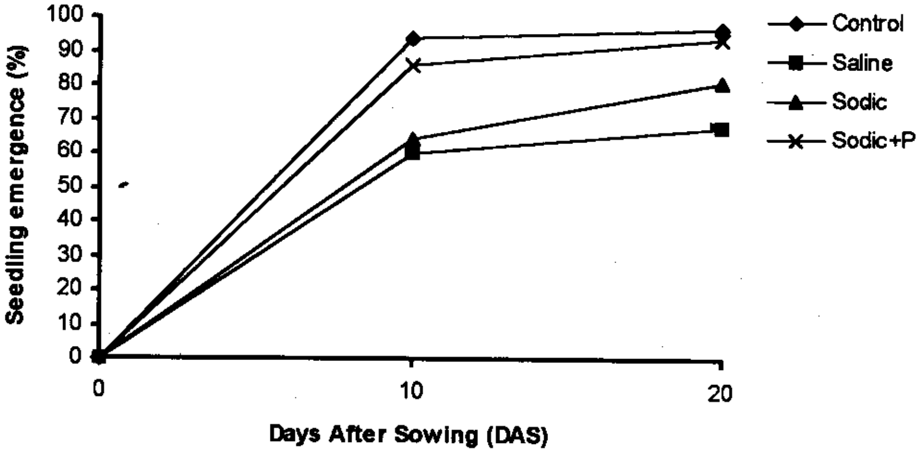

Fig.1. Effect of salt-affected soil treatments, on seedling emergence of wheat recorded at 10 and 20 DAS. Values are the means of 8 wheat varieties

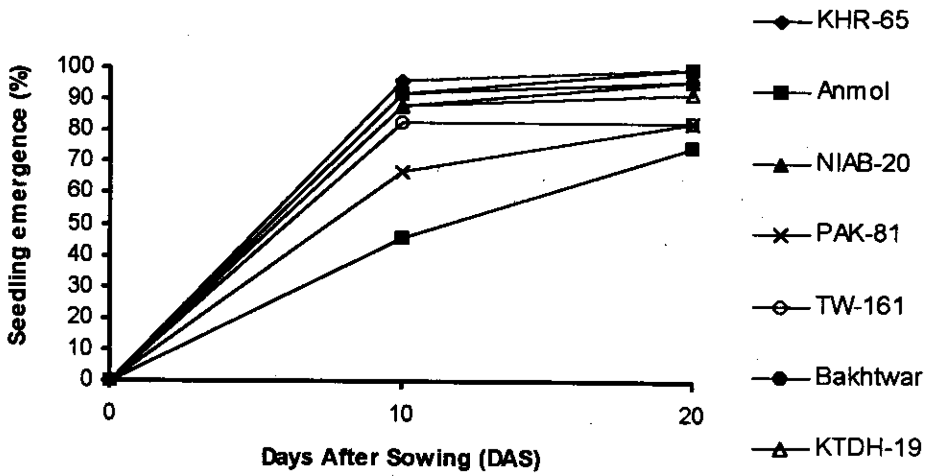

Fig.2. Effect of varieties on seedling emergence, recorded a 20 DAS. Values are the means of 4 soil treatments

Table 1: pH, ECe, SAR, ESP and WSA%, of the Soil Before Sowing and after Harvest

Treatment		pH (H_2O)	ECe (dS/m)	SAR	ESP
Before sowing	(Salt added)				
Control	Nil	6.5	1.6	1.0	0.1
Sodic	1M ($NaHCO_3$)	9.2	3.0	62.5	48.0
Sodic + PAM	1M ($NaHCO_3$)	8.8	3.5	57.4	45.9
Saline	($NaCl$, $CaCl_2$ and $MgCl_2$)	5.9	19.2	3.4	3.7
After harvest					
	WSA (%)				
Control	71	6.5	3.6	1.3	0.0
Sodic	38	8.8	8.3	64.1	48.6
Sodic + PAM	73	8.5	6.7	58.2	46.6
Saline	not measured	5.0	18.6	10.6	12.7

Table 2: Effects of Salinity, Sodicity and Sodicity + PAM on Seedling Emergence % of Different Wheat Varieties Recorded at 20 DAS. Fig. In Paranthesis Show the Values of Arcsine Transformed Data

Soil treatments Variety	Control	Saline	Sodic	Sodic +PAM	Mean
Khar-65	100 (1.57)	100 (1.57)	100 (1.57)	100 (1.57)	100.0 (1.57)
Anmol	75 (1.17)	38 (0.58)	50 (0.78)	100 (1.57)	65.6 (1.03)
Niab-20	100 (1.57)	50 (0.78)	88 (1.37)	100 (1.57)	84.4 (1.32)
PAK-81	100 (1.57)	75 (1.17)	75 (1.17)	75 (1.17)	81.3 (1.28)
TW-161	100 (1.57)	63 (0.98)	50 (0.78)	100 (1.57)	78.1 (1.23)
Bakhtwar	100 (1.57)	63 (0.98)	100 (1.57)	88 (1.37)	87.5 (1.37)
KTDH-19	100 (1.57)	63 (0.98)	88 (1.37)	88 (1.37)	84.4 (1.32)
SARC-1	100 (1.57)	100 (1.57)	100 (1.57)	100 (1.57)	100.0 (1.57)
Mean	96.8 (1.52)	68.8 (1.08)	81.2 (1.27)	93.7 (1.47)	

S. E. D. and L. S. D. for transformed data

Soil treatments		Variety		Soil trt:*Variety	
S. E. D	L. S. D	S. E. D	L. S. D	S. E. D	L. S. D
0.088	0.176* * *	0.126	0.25* * *	0.251	N. S

Table 3: Effects of Salinity, Sodicity and Sodicity +PAM on Shoot Height, Shoot Dry Weight and Root Length of Different Wheat Varieties, Harvested at 10 DAS

Variety	Control	Soil treatments Saline	Sodic	Sodic +PAM	Means
		Shoot height (cm)			
Khar-65	16	9	7	6	9.2
Anmol	16	3	3	5	6.5
Niab-20	13	8	5	6	8.1
PAK-81	17	5	3	5	7.4
TW-161	17	4	1	6	6.9
Bakhtwar	14	9	5	6	8.7
KTDH-19	14	9	5	5	8.6
SARC-1	13	11	5	6	8.8
Means	15.2	7.2	4.1	5.5	
		Shoot dry wt /plant (mg)			
Khar-65	26	15	7	13	15.4
Anmol	21	4	8	10	10.9
Niab-20	21	17	10	11	15.1
PAK-81	24	2	4	11	10.1
TW-161	26	9	3	11	12.3
Bakhtwar	25	11	12	9	13.9
KTDH-19	32	11	13	12	17.1
SARC-1	24	20	12	9	16.4
Means	24.7	11.2	8.8	10.7	
		Root length (cm)			
Khar-65	7	6	1	1	7.2
Anmol	7	4	1	1	7.0
Niab-20	8	6	1	1	7.8
PAK-81	7	2	1	1	7.4
TW-161	11	3	0	1	11.0
Bakhtwar	10	5	1	1	10.4
KTDH-19	10	4	1	1	9.6
SARC-1	8	5	1	1	8.0
Means	8.5	4.4	0.8	1.0	

	Soil treatment		Variety		treatment*Variety	
	S. E. D	L. S. D	S. E. D	L. S. D	S. E. D	L. S. D
Height	0.4	0.7* * *	0.5	1.1* * *	1.1	2.1* * *
Dry weight	1.0	1.9* * *	1.4	2.8* * *	2.8	5.6* * *
Root length	0.3	0.6* * *	0.4	N. S	0.9	1.7* * *

dry weight under sodic conditions. The treatment of sodic soil with PAM also resulted in a significant ($p<0.005$) increase in shoot dry weight of some varieties (Kharchia-65, PAK-81 and TW-161).

Root length of seedlings was also significantly ($p>0.005$) shorter in salt-affected soil treatments than in the control. The effect of sodicity was significant and more severe than the effect of salinity. The difference between varieties for root length was non significant($p<0.005$). But the interaction of soil treatments x varieties was significant. In the saline soil treatment PAK-81 and TW-161 had a shorter root system than other varieties. In the sodic soil treatments seedlings of all varieties had very short root systems and PAM had no positive or negative effect on root length.

Soil Characteristics: The addition of the salt mixture (NaCl, $CaCl_2$ and $MgCl_2$) resulted in a higher EC_e (dSm^{-1}) in the saline treatment, confirming the presence of higher concentrations of soluble salts (Table 1). Although SAR and ESP were slightly increased, the values observed were still within the range of values typical of saline (non- sodic) soils (USSL, 1954; Qureshi and Lennard, 1998). Conversely in the sodic treatment, following the application of $NaHCO_3$ salt, low ECe and higher values of pH, SAR and ESP were observed, indicating the adsorption of Na^+ and replacement of other cations from the colloidal complexes and release of HCO_3^- ions responsible for increasing the soil pH (Rowell, 1994). The low % WSA in the sodic treatment suggested the dispersion of clay and humus colloids (Barzegar *et al.*, 1997). The dark colour shown by the sodic soil, indicated the dissolution, dispersion and upward movement of humus colloids. Other workers (Pearson and Bernstein, 1958; Bains and Fireman, 1965; Sharma, 1991; Chaudhary, 1996) by using the same salt ($NaHCO_3$), reported similar types of changes in soil properties.

It is noticeable that PAM increased soil aggregation (WSA%) by 92 % compared to the aggregation shown by sodic soil treatment without PAM. The increase in soil aggregation by PAM suggested the preservation of existing aggregates (Cook and Nelson, 1986). Increase in soil aggregation and flocculation by adding polymers in sodic soils has also been reported by other workers including Saleh and Letey (1990). In general soil chemical properties remained unchanged between sowing and harvest. This was probably due to the short duration of the experiment. However, in the saline treatment there was a marked increase in SAR and ESP. This was possibly due to the adsorption of Na^+ from the applied NaCl salt and precipitation of soluble Ca^{2+} as $CaCO_3$. Formation of sodic soil from saline and saline-sodic soils has been reported by other workers (Qureshi and Lennard, 1998). Using the classification of salt-affected soils presented by USSL (1954) and Qureshi and Lennard (1998), these soils can be classified as strongly saline and strongly sodic. The properties of these soils can be compared with the properties of excavated profiles of salt-affected soils in India (Singh *et al.*, 1989) and Pakistan (Rajpar & Sial, 1997).

Seedling Emergence: The effects of salinity on emergence (Averaged overall varieties) were greater than the effects of sodicity. Salinity decreased the seedling emergence at 10 and 20 DAS by 37 and 29 % respectively. The decreases in emergence % caused by sodicity at 10 and 20 DAS were 32 and 17% respectively. Salinity and sodicity both decreased and delayed emergence. Chabra *et al.*, (1979) also reported that due to the lower availability of water and possibly the direct effect of excess sodium on germinating seeds, high sodicity delays the emergence of crop seeds. Moustafa *et al.*, (1966) also concluded that the final germination % of wheat seeds was higher in sodic soil (32-61.8 ESP) than in saline soil with total soluble salts of 1.23-2.4 %. Averaged over all varieties, treatment of sodic soil with PAM increased seedling emergence % by 15 % compared to the sodic soil treatment without PAM, so that the values observed were similar to those in the untreated control. The increase in seedling emergence % was probably due to increase in soil aggregation. Carr and Greenland (1975) have also presented the similar results.

Seedling Growth: Salinity and sodicity decreased shoot height by 53 and 73 %, shoot dry weight by 55 and 64 % and root length by 48 and 91 % respectively. This indicates that in this experiment, under these conditions, the effects of sodicity on growth were greater than the effects of salinity. However, such comparisons must be treated with caution, as the effects observed in such studies depend on the stress levels imposed. Although both salinity and sodicity were high (Qureshi and Lennard, 1998), had different stress levels been tested, different results might have been obtained. The decreases in growth of plants observed in saline soils may have occurred as a result of toxic effects induced by excessive amounts of soluble salts, or an imbalance of nutrients (Gorham, 1994). The decrease in growth and dry matter production in the sodic soil condition may be due to changes in soil physical properties, nutritional disorders related to high pH and impaired metabolism. The greater adverse effects of sodicity than salinity on root growth may be either due to greater accumulation of toxic ions, decreased adsorption of some essential nutrients, low permeability to air and water, or the dispersed colloidal structure of sodic soils (Toky and Srinavasu, 1995). A larger effect of high exchangeable Na^+ than Ca^{2+} and Mg^{2+} on barley root growth has also been reported by Ratner, (1935). Other authors including Abrol and Bhumbula (1979) and Baykal (1979) have also confirmed that the early seedling stages of wheat are more sensitive to salinity and sodicity than later stages. In the sodic soil treatment most of the seedlings emerged and they grew to a certain height and then gradually turned yellow and withered. Similar types of seedling response have also been observed by Moustafa *et al.*, (1966). Pearson and Bernstein (1958) also reported the necrosis and eventual death of barley and wheat seedlings in sodic soils with ESP values in the range of 36 to 60. As seen from the Table 3, the treatment of sodic soil with PAM resulted in small increases in shoot height and shoot dry weight. However, the values observed were still markedly lower than those of the control treatment. Despite this small response to PAM, visual observations suggested that plants in the sodic soil treatment had effectively stopped growing, whereas those in the sodic + PAM treatment were still growing, and showed little evidence of chlorosis.

Varietal Response: The analyses of variance performed on the data showed that there were differences between varieties in the effects of salt treatments on seedling growth but not on seedling emergence. Differences in response of seedling emergence between varieties should be treated with caution as the Variety x salt-treatment interaction was non significant. The effects of salinity on shoot height and shoot dry weight were greater in 3 varieties (Anmol, PAK-81 and TW-161) than others. The results of this experiment provided no evidence to suggest that varieties that are tolerant of salinity are also tolerant of sodicity. Using shoot dry weight per plant at 20 DAS as an indicator, some

varieties (PAK-81, Bakhtwar, KTDH-19 and Anmol) were susceptible to both stresses and showed large decreases. In some varieties (SARC-1 TW-161, NIAB-20 and Kharchia-65) the effects of sodicity were greater than salinity, whereas in others this trend was reversed. This may be a consequence of the high stress levels using in the experiment. Other workers have shown that some varieties that are tolerant to salinity are also tolerant to sodicity eg. Kharchia-65 (Joshi *et al*., 1982; Chippa and Lal., 1995). All varieties except Bakhtwar, KTDH-19 and SARC-1 showed a positive response to PAM (a lower % decrease in shoot dry weight per plant).
However the response to PAM was greater in some varieties (TW-161, PAK-81 and Kharchia-65) than others (Anmol and NIAB-20). Anmol, PAK-81 and TW-161 showed poorer performance than the other varieties tested and that places these in the category of salt sensitive. The difference between varieties resulted from saline and sodic soil treatments can be due to genetic variability. Varietal variability in several crops, including barley (Chaudhary *et al*., 1996) and wheat (Joshi *et al*., 1980; Chippa and Lal, 1991; Khan *et al*., 1992) has also been observed under saline and sodic conditions.

References

Allison, L.E., 1952. Effect of Synthetic Polyelectrolytes on the structure of saline and alkali soils. Soil Sci. 73: 443-454.

Angers, D.A. and G.R. Mehuys, 1993. Aggregate stability to Water. In soil Sampling and Methods of Analysis, Can. Soc. of Soil Sci. (M.R. Carter, Eds.), pp. 651-655. Lewis Publishers, Boca Raton, Florida.

Bains, S.S. and M. Fireman, 1964. Effect of Exchangeable Sodium Percentage on the Growth and Absorption of Essential Nutrients and Sodium by Five Crop Plants. Agron. J. 56: 432-435.

Barzegar, A.R., P.N. Nelson; J.M. Oades, and P. Rengasamy, 1997. Organic Matter, Sodicity, and Clay Type: Influence on soil Aggregation. Soil Sci. Soc. Am. J. 61: 1131-1137.

Boem, G. and R.S. Lavado, 1996. The Effects of Soil Sodicity on Emergence, Growth, Development and Yield of Oilseed Rape (*Brassica napus*). J. Agric. Sci. Camb. 126: 169-173

Carr, C.E. and D.J. Greenland, 1975. Potential Application of Polyvinyl Acetate and Polyvinyl Alcohol in the Structural Improvement of Sodic Soils. Soil Sci. Soc. Am. J. 7: 47-63.

Chabra, R.; S.B. Singh, and I.P. Abrol, 1979. Effect of Exchangeable Sodium on the Growth, Yield and Chemical Composition of Sunflower (*Helianthus annus* L.). Soil Sci. 127: 242-247.

Chippa, B.R. and P. Lal, 1991. Effect of Soil Sodicity on Yield, Yield Attributes and Nutrient Uptake by Different Varieties of Wheat. Current Agric. 15: 29-33.

Chippa, B.R. and P. Lal, 1995. Na/K ratios as the basis of Salt Tolerance in Wheat. Aust. J. Agric. Res. 46: 535-539.

Choudhary, O.P.; A.S. Joson, and M.S. Bajwa, 1996. Rooting and Yield Relationships in Different Barley Cultivars Grown under Increasing Soil Sodicity Stress Conditions. Crop Impr.. 23: 1-11.

Cochran, W.G. and G.M. Cox, 1957. Analysis of the Results of a Series of Experiments. In Experimental Designs (2nd Eds) pp. 545-565. Chapman & Hall Ltd, London.

Cook, D.F. and S.D. Nelson, 1986. Effect of Polyacrylamide on Seedling Emergence in Crust-forming Soils. Soil Sci. 141: 328-333.

Gorham, J., 1992. Salt Tolerance of Plants. Science Progress Oxford. 76: 273-285.

Gorham, J., 1994. Salt Tolerance in the Triticeae: K/Na Discrimination in Some Perennial Wheatgrasses and their Amphiploids with Wheat. J. Experi. Bot. 45: 441-447.

Gorham, J.; J. Bridges; J. Dubscovsky; J. Dvorak; P.A. Hollington; M-C. Luo, and J.A. Khan, 1997. Genetic Analysis and Physiology of Trait for Enhanced K/Na Discrimination in Wheat. New Phytolo. 137: 109-116.

Joshi, Y.C.; D.R. Snehi; A. Qadar, and A.R. Bal. 1982. Salt tolerance in Diploid, Tetraploid and Hexaploid Wheat. Ind. J. Plant Physio. 4: 421-422.

Joshi, Y.C.; A. Qadar, and R.S. Rana, 1979. Differential Sodium and Potassium Accumulation Related to Sodicity Tolerance in Wheat. Ind. J. Plant Physio. 22: 226-230.

Khan, M.Y.; A. Rauf; I. Makhdoom; A. Altaf, and M.S. Sultan, 1992. Effects of Saline-Sodic Soils on Mineral Composition of Eight Wheats Under Field Conditions. Sarhad J. Agric. 8: 477-487.

Mehotra, C.L.; and S.K. Dass, 1973. Influence of Exchangeable Sodium on the Chemical Composition of Important Crops at Different Stages of Growth. J. Indi. Soc. Soil Sci. 21: 355-365.

Moustafa, A.H. I.; A.I. Shahbassy; E.M. Gohar; A. Naim; A.A. Rahman, and M.E. Elshal, 1966. Growth and Cationic Accumulation by wheat and Barley Plants as Influenced by Various Levels of Exchangeable Sodium. The Agric. Res. Rev. 44: 1-17.

Pearson, G.A.; and L. Bernstein, 1958. Influence of Exchangeable Sodium on Yield and Chemical Composition of plants: II wheat, Barley, Oats, Rice, Tall Fescue and Tall Wheatgrass. Soil Sci. 86: 254-261.

Qureshi, R.H. and E.G. Barret-Lennard, 1998. Saline Agri.for Irrigated land in Pakistan. A Handbook. ACIAR, Canb. Aust..

Rajpar, I.A. and Sial N.B., 1997. Relationship between salts of soil profile and underground water. *PJAEVS*. 13, 19-23.

Rhodes, J.D., 1982. Saturation extracts. In soil sampling and Methods of Analysis, Canad. Soc. Soil Sci. (M.R. Carter, Eds.), pp. 162-163. Lewis Publishers, Boca Raton, Florida.

Rowell, D.L., 1994. Soil Science Methods & Applications. Addison Wesley Longman Ltd, Edinburgh Gate, Harlow, Essex, CM2 0JE, England.

Saleh, M.A. and J. Letey, 1990. Physical Properties of Sodium-treated Soil as Affected by two Polymers. Soil Sci. Soc. Am. J. 54: 501-504.

Sharma, S.K., 1991. Effect of Exchangeable Sodium on Growth, Yield and Ionic Relations in Wheat Genotypes Differing in Sodicity Resistance. Indi. J. Plant Physio. 34: 349-356.

Singh, K.N., 1989. Gene Effects on Some Quantitative Characters in Wheat under salt Stress Conditions. Ann. Agric. Res. 10: 1-4.

Singh, S.B. and I.P. Abrol, 1985. Effect of Soil Sodicity on the Growth, Yield and Chemical Composition of Groundnut (Archis hypogaea Linn.). Plant & Soil 84: 123-127.

Toky, O.P. and V. Srinivasu, 1995. Response of Sodium Bicarbonate Sodicity on Survival, Seedling Growth and Plant Nutrients of four Multipurpose Arid Trees. Ann. of Arid Zone 34: 115-120.

USSL, 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Dept. Agri. Hand. book. 60.Washington. D.C., U.S.A.