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Effect of Soil Sodicity on the Growth, Ion Content and Yield of Wheat (*Triticum aestivum* L.)

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Abstract: The effect of soil sodicity on growth, ion content and yield of Sarsabz, Marvi and Kiran wheat varieties was investigated in a pot experiment at the Department of Soil Science, Sindh Agriculture University, Tando Jam. Soil was artificially alkalinized to varying levels of ESP ranging from 4 to 25. The results of this study revealed that the effects of soil sodicity increased with increase in ESP levels of the soil. The adverse effects of sodicity on seedling emergence, plant height and yield were associated with high Na^+, low K^+ and K^+/Na^+ ratio analyzed in the flag leaf sap. There were differences among 3 wheat varieties in terms of the performance in sodic environment. Variety Marvi was observed to be more tolerant to soil sodicity from emergence to maturity. The improved growth and yield of this variety were associated with lower leaf Na^+ and higher K^+ and K^+/Na^+ ratio than Sarsabz and Kiran. These results indicated that the cause of low wheat yield in sodic soils may be due to poor soil structure caused by high exchangeable Na^+ and high soil pH. The results of this study support the selection of Marvi for its use in future breeding program to screen out new local genotypes that can tolerate poor soil structure as well as high sodium stress.

Key words: ESP, sodicity, wheat yield

INTRODUCTION

The presence of high exchangeable Na^+ on clay complexes disperses the clay colloids and hence the adverse physical conditions become the major problem in sodic soils[1-3]. Sodic soils also show high pH values usually up to 10.5 resulting from the high HCO^-_3 concentration of the irrigation water or groundwater entering the soil and from the hydrolysis of the Na^+ rich clays[1]. Organic matter in the sodic soils is highly dispersed and is distributed over the surface of the particles, giving a dark color; hence the term "black alkali" was formerly used for sodic soils. Heavy textured sodic soils become more sticky and plastic when wet and hard when dry, leading to cultivation problems. Hydraulic conductivity of sodic soils is decreased, hence irrigation water moves more slowly through the soil leading to waterlogging on the soil surface. If the soil surface becomes more saturated during irrigation, air entry is restricted and anaerobic (water-logged) condition may develop, causing de-nitrification and the production of plant toxins. In anaerobic conditions plants are also more sensitive to salt damage, direct toxicities of Na^+ and ionic imbalance. There are several crop species[4] that are able to thrive very successfully on salt-affected soils. Several crop species including wheat tolerant to saline soils have been identified, but the effects of sodicity are different than salinity[5], hence the varieties tolerant to salinity may not be tolerant to sodicity.

The present investigation was undertaken to study the effect of exchangeable sodium percentage on seedling emergence, growth, yield and the absorption of Na^+ and K^+ by 3 bread wheat varieties.

MATERIALS AND METHODS

In order to screen out sodicity tolerant wheat varieties the effect of different ESP levels on seedling emergence, growth, ion uptake and yield of 3 bread wheat varieties was investigated. The experiment was performed in a wire-house of the Department of Soil Science, Sindh Agriculture University, Tandojam.

Sodic soil was prepared following the method of Bains and Fireman[6]. The soil (plough layer) collected from the cultivated field of the Latif Experimental Farm, of Sindh Agriculture University, Tandojam, was air dried, passed through 1/8 inch garden sieve. To prepare sodic soil treatments with low, medium and high ESP levels, the soil was divided into 3 lots and half soil of each lot was spread on polyethylene sheet as a thin layer (1-2 cm).

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In order to generate ESP 10, 15, 20 and 25, the half soil of lot 1, 2 and 3 was sprayed with 0.25, 0.5, 0.75 and 1 M $NaHCO_3$ solutions, respectively with the help of knapsack sprayer. A few minutes later the remaining half soil of each lot was uniformly spread over the first treated soil layer and was sprayed with the same volume and concentration of salt solutions. To reduce evaporation and to give maximum incubation time, the treated soils were covered with other polyethylene sheets. The sheet covers were then removed 3 days later. On the 4th day the soil of each lot was then mixed, raked with hands and was allowed to air-dry. The air-dried soil of each treatment including control was placed in 5 kg plastic pots with drainage holes in bottom. Soil filled pots were placed on wooden benches of the wire-house and arranged in a Randomized Complete Block Design.

Soil samples were collected from each pot before sowing. Soil samples were analyzed for soil texture, organic matter, $CaCO_3$, P (Olsen P), N%, pH, EC ($dS\ m^{-1}$) and cations (Na^+, Ca^{2+} and Mg^{2+}) using appropriate methods of analysis published in USSL[7] and Rowell[1]. SAR and ESP were also calculated following the methods of Rowell[1].

Seeds of 3 bread wheat varieties viz., Sarsabz, Marvi and Kiran were sown in the 5 kg plastic pots down into the soil at 4 cm row-to-row and plant-to-plant distance. Seedling emergence was recorded at 5, 10 and 20 days after sowing (DAS). At 20 DAS seedlings were thinned to a single plant at each position. The pots were watered regularly to reduce losses by evapo transpiration. To provide adequate nutrition a compound fertilizer (Engro NPK) containing 10 N: 22 P_2O_5: 10 K_2O was applied to each pot. When they became fully expanded the flag leaves of 3 plants per variety were sampled from each treatment. They were placed in Eppendorf tubes and stored at -10°C. Leaf sap was later extracted and analyzed for Na^+ and K^+ by flamephotometer using the method of Gorham *et al.*[8]. The plants were harvested at maturity by cutting at soil level. The plants that have previously been sampled for chemical analysis were not included in the yield data. The ears of harvested plants were separated from the straw and dried at 82°C for 48 h. The grains from each pot were threshed, cleaned, counted and weighed. These grains were used to calculate grain yield.

RESULTS AND DISCUSSION

Soil characteristics: The chemical properties of the original soil showed pH, ECe, SAR and ESP values typical of that an agricultural soil of Sindh (Table 1). However, when the same soil was treated with different proportions of $NaHCO_3$, it showed an increase in pH with markedly higher values of ESP and SAR. The ECe ($dS\ m^{-1}$) of treated soil was also increased but to a smaller extent. Higher values of pH, SAR and ESP in sodic soil treatments indicate 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[1]. The dark color shown by the sodicity treated soil indicates the dissolution, dispersion and upward movement of humus colloids. Other workers[6,9-12] have also prepared sodic soils by using the same salt ($NaHCO_3$) and reported similar types of changes in soil properties.

Seedling emergence and growth: It is evident from the results, that the seedling emergence (%) was lower in all the sodic soil treatments than in the control. The seedling emergence (%) recorded 5, 10 and 20 DAS decreased significantly ($P<0.05$) by increasing ESP (Table 2). The effect of varieties was also significant ($P<0.05$) at 5, 10 and 20 DAS. Among 3 wheat varieties, Marvi showed better emergence. However, the interaction of sodicity x variety was non-significant, generally the emergence (%) of Marvi variety was higher in all sodic soil treatments than in the control. The decrease and delay in seedling emergence under sodic soil treatments was possibly due to the lower availability of water, poor physical conditions of soil and direct effect of excess sodium on germinating seeds[2,13,14].

Plant height recorded at maturity was significantly ($P<0.05$) decreased by increasing sodicity (Table 3). Plants grown in all sodicity treated soils were significantly shorter than in the control. In all treatments the plants of Marvi were significantly ($P<0.05$) taller than Sarsabz and Kiran varieties. The effect of interaction of sodicity x varieties for plant height was significant ($P<0.05$). Compared to the other 2 varieties, the plants of Marvi were significantly taller in sodic soil treatments than in the control.

The decreasing effects of sodicity on plant height confirm the adverse physical (poor soil structure, impeded drainage and water-logging conditions) as well as chemical effects (high pH, low nutrient availability, excess Na^+ ion in the soil solution) of sodic soil on plant growth. Similar adverse effects of sodic soils on wheat plants have also been observed by other workers[3,12].

Difference between varieties for plant height was possibly genetical[8]. It is also evident from the previous studies[3,12] that different species and varieties of wheat respond differently to sodic soils.

Na^+, K^+ and K^+/Na^+ ratio determined in the flag leaf sap: Effects of soil sodicity on Na^+, K^+ and K^+/Na^+ ratio determined in the flag leaf sap of three (Sarsabz, Kiran and

Table 1: Soil characteristics and salt concentrations used to prepare soils of different ESP levels

Treatments	$NaHCO_3$ added	pH (1:5)	EC (dS m^{-1})	SAR	ESP (Desired)	ESP (Obtained)
T_1 (Control)	No salt	7.0	2.5	6	----	4.1
T_2	0.25 M	7.3	2.8	16	10	12.1
T_3	0.50 M	7.5	3.0	28	15	18.3
T_4	0.75 M	8.4	3.1	48	20	22.7
T_5	1.00 M	8.8	3.2	67	25	27.9
Organic matter	= 0.95%	Textural class	=Sandy clay loam		$CaCO_3$ =5.2%	
P (Olsen P)	= 11.0 (mg kg^{-1})	N	= 0.0475 (%)			

Table 2: Effects of different ESP levels on the seedling emergence (%) of 3 wheat varieties, recorded 5, 10 and 20 days after sowing (DAS)

	Varieties			
ESP	Sarsabz	Marvi	Kiran	Means
05 days after sowing				
Control	50.58	48.11	30.84	43.17
10	16.03	20.97	14.81	17.27
15	4.93	14.80	6.17	8.63
20	2.46	4.70	3.70	3.62
25	1.23	0.00	0.00	0.41
Means	15.05	17.51	11.10	
10 days after sowing				
Control	67.88	85.16	67.87	76.63
10	28.36	46.68	32.06	35.70
15	17.04	44.42	21.03	27.50
20	15.96	16.06	14.80	15.60
25	4.94	0.00	0.00	1.64
Means	26.83	38.46	27.15	
20 days after sowing				
Control	72.83	88.88	77.77	76.83
10	33.31	62.93	35.78	44.00
15	18.50	56.78	19.74	31.67
20	18.50	25.97	18.51	20.99
25	6.10	0.00	0.00	2.06
Means	29.86	46.91	30.36	

	Sodicity treatments		Variety		Sodicity*Variety	
	SED	LSD	SED	LSD	SED	LSD
05 DAS	3.824	6.214***	2.960	4.813***	6.625	NS
10 DAS	6.214	12.690***	4.813	9.829*	10.764	NS
20 DAS	6.538	13.352***	1.307	2.670**	11.325	NS

Table 3: Effects of different ESP levels on the plant height and grain and straw yield of 3 wheat varieties

	Varieties			
ESP	Sarsabz	Marvi	Kiran	Means
Plant height (cm)				
Control	73.33	78.00	72.33	74.55
10	53.33	68.00	61.66	64.00
15	53.00	57.00	50.66	53.77
20	---	---	---	---
25	---	---	---	---
Means	63.11	67.66	61.55	
Grain yield (mg plant^1)				
Control	413.33	430.00	493.33	445.56
10	393.33	420.00	340.00	384.44
15	233.33	316.67	286.67	278.89
20	---	---	---	---
25	---	---	---	---
Means	260.00	291.67	280.00	
Straw yield (mg plant^1)				
Control	1127.00	1093.00	1010.00	1073.30
10	743.00	917.00	603.00	754.40
15	400.00	707.00	467.00	524.40
20	---	---	---	---
25	---	---	---	---
Means	567.50	676.67	520.00	

	Sodicity treatments		Variety		Sodicity*Variety	
	SED	LSD	SED	LSD	SED	LSD
Height	0.985	2.033***	0.763	1.575***	1.706	3.521***
Grain Yield	58.022	119.759	44.944	NS	100.49	NS
Straw Yield	86.766	179.086***	67.209	NS	150.28	NS

Marvi) wheat varieties is shown in Table 4. The data regarding Na^+, K^+ and K^+/Na^+ ratio in the flag leaf sap of three wheat varieties reveals that the increasing sodicity of soil significantly (P<0.05) increased the concentration of Na^+
and significantly deceased the concentration of K^+. Due to higher Na^+ and low K^+, K^+/Na ratio remained lower in leaf sap. The effect of varieties for Na^+ and K^+ was highly significant (P< 0.05) but for K^+/Na^+ ratio it was non-significant (P > 0.05). However, the variety Marvi showed lower Na^+ and higher K^+ and K^+/Na^+ ratio compared to the other two (Sarsabz and Kiran) varieties. The interaction of sodicity x variety was non-significant (P>0.05) for Na^+ and K^+/Na^+ ratio but it was highly significant (P<0.05) for K^+.

The concentration of K^+ was significantly (P<0.05) higher in the leaf sap of Marvi than Sarsabz and Kiran grown in the sodic soil treatments than in the control soil. The increased Na^+, decreased K^+ and lower K^+/Na^+ ratio in the flag leaf sap was possibly be due to the higher exchangeable sodium percentage (ESP 10 and 15) and nutrient imbalance caused by high pH. The difference between varieties for ion content was possibly due to several factors including genetic make up. Similar factors have also been explained by Mustafa *et al.*[14]; Singh and Totawat[15]; Chippa and Lal[16]; Rajpar[4]; Wright and Rajpar[3]; Akhtar *et al.*[17]; Rajpar *et al.*[12].

Grain and straw yield: The effects of soil sodicity on the grain yield of three wheat varieties (Table 3) shows that with the increase in sodicity grain yield plant^{-1} decreased significantly (P<0.05). Overall in all treatments the difference between varieties was non-significant. However, variety Marvi showed non-significantly higher yield than Sarsabz and Kiran varieties. The interaction of varieties x sodicity was also non-significant (P>0.05). However, variety Marvi produced slightly higher yield in sodic soil treatments than Sarsabz and Kiran. This

Table 4: Effects of different ESP levels on the Na^+, K^+ and K^+/Na^+ ratio analyzed in the flag leaf sap of 3 wheat varieties

	Varieties			
ESP	Sarsabz	Marvi	Kiran	Means
Na^+ (mol m^{-3})				
Control	18.33	10.50	18.67	15.83
10	83.00	60.26	89.99	77.75
15	254.00	130.00	170.33	185.00
20	---	---	---	---
25	---	---	---	---
Means	118.67	66.99	93.00	
K^+ (mol m^{-3})				
Control	205.33	205.33	218.33	209.67
10	82.46	143.33	87.33	104.38
15	53.33	82.64	46.09	60.67
20	---	---	---	---
25	---	---	---	---
Means	113.71	143.77	117.25	
K^+Na^+				
Control	13.01	22.94	13.48	16.48
10	1.00	2.42	1.02	1.48
15	0.20	0.63	0.27	0.38
20	---	---	---	---
25	---	---	---	---
Means	4.75	8.67	4.93	

	Sodicity treatments		Variety		Sodicity* Variety	
	SED	LSD	SED	LSD	SED	LSD
Na^+	18.648	39.181***	14.445	30.349***	32.30	NS
K^+	4.760	10.002***	3.687	7.748***	8.24	17.32***
K^+/Na^+	1.997	4.196***	1.547	NS	3.45	NS

------ = Plants not survived

indicates equal effect of sodicity on grain yield of all varieties.

Variety Marvi produced more grain yield than Sarsabz and Kiran, which indicates that the Marvi variety was slightly more tolerant than Sarsabz and Kirin. The decrease in grain yield under sodic conditions was possibly due to adverse soil physical (poor soil structure, water-logging, impeded drainage etc.) and chemical (high pH, low nutrient solubility and uptake of excess Na^+) conditions. The results are in agreement with those of Sharma[18]; Gill *et al.* [19]; Khan *et al.* [20]; Rajpar and Sial[5]. Increasing soil sodicity significantly ($P<0.05$) decreased (Table 3) the straw yield of wheat. However, Marvi produced slightly more straw yield than Sarsabz and Kiran. Similarly the interaction of sodicity x variety was non-significant. The ($P>0.05$) interaction indicated more or less the same response of all 3 varieties under sodic conditions.

The decrease in straw yield by increasing sodicity was associated with shorter plants, (Table 3), higher uptake of toxic ions such as Na^+ and lower uptake of K^+ (Table 4). Similar findings have also been reported by other researchers including Chippa and Lal[21]; Gorham *et al.*[8] and Rajpar *et al.*[12].

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