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Improvement of degraded physical properties of a saline-sodic soil by reclamation with kallar grass (*Leptochloa fusca*)

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Key words: available water, bulk density, hydraulic conductivity, *Leptochloa fusca*, saline-sodic soil, porosity, structural stability

Abstract

A field experiment was conducted to evaluate the effectiveness of growing salt tolerant plants to improve the physical characteristics of a saline-sodic soil. Kallar grass [*Leptochloa fusca* (L.) Kunth], a species tolerant to salinity, sodicity and alkalinity, was irrigated for five years with poor quality ground water (EC = 0.14 S m^{-1}, SAR_{adj} = 19.3, RSC = 9.7 meq L^{-1}). The soil physical properties of plant available water, saturated hydraulic conductivity, structural stability, bulk density and porosity were determined at the end of each year. The growth of kallar grass for three years significantly improved the physical properties of the soil and these were maintained with further growth of grass up to five years. Kallar grass significantly increased plant available water with time ($r = 0.97^{**}$). The available water was highly correlated ($r = 0.92^{**}$) with increases in soil organic matter content, porosity ($r = 0.99^{**}$) and other physical properties. Soil hydraulic conductivity increased substantially with time from 0.035 to 55.6 mm d^{-1} in the topsoil (0–20 cm) in five years and was significantly correlated with porosity, water retention, structural stability and organic matter content of soil. The soil structural stability index improved significantly from 32 to 151 with kallar grass and showed greater increases in the surface soil than at depth. The cropping of kallar grass resulted in a linear increase of soil organic matter content ($r = 0.92^{**}$) which improved porosity and other soil physical properties. ($r \leq 0.82^{*}$). This study confirmed that kallar grass is effective for rehabilitation and restoration of soil fertility in saline-sodic areas on a sustainable basis.

Introduction

Salinisation of soils and ground water is a serious land degradation problem in arid and semi-arid areas and is increasing steadily in many parts of the world including Pakistan. Saline soils cover about 380–995 M ha of the Earth's land surface (Tanji, 1990; Szabolcs, 1994; IAEA, 1995) and of these, 62% are saline-sodic or sodic. The estimates of salt-affected area in Pakistan vary widely because of the different classification criteria and survey methods used by various agencies (Sandhu and Qureshi, 1986; Ghassemi et al., 1995). However, about 6.3 M ha are believed to be affected by salinity, and the ground water in most of these saline areas is brackish and thus unfit for irrigation (Qureshi and Barrett-Lennard, 1998). A soil salinity survey (Water and Power Development Authority, 1985) has indicated that 38% of soil profiles studied were salt-affected; of these, 24% were saline-sodic, 11% saline and 3% non-saline-sodic.

Accumulation of excess sodium (Na^+) in soil causes numerous adverse phenomena, such as changes in exchangeable and soil solution ions and soil pH, destabilization of soil structure, deterioration of soil hydraulic properties, increased susceptibility to crusting and specific ion effects on plants (Shainberg and Levy, 1992; Qadir and Schubert, 2002). Saline-sodic

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*FAX No: +92-41-654213. E-mail: jakhterniab@yahoo.com; niabmail@niab.org.pk soils slake, disperse and swell under specific conditions when wet with rain or irrigation water; this decreases water and air movement, plant-available water, root penetration, seedling growth and plant establishment and increases runoff, ponding, waterlogging, erosion and impedes seed bed preparation (Sumner, 1993; Rengasamy and Sumner, 1998; Oster et al., 1999).

The threats of losing agricultural land to salinity are now well understood, and a great deal of effort is being made to combat the problem of soil and water salinity. Despite all these efforts, the area under salt-affected soils is increasing (Szabolcs, 1986; IAEA, 1995). While reclamation of vast areas of saline land seems difficult because of economic and climatic constraints, use of salt tolerant plants has been recommended as a useful alternate approach for increased productivity (Malik et al., 1986; Sandhu and Qureshi, 1986; Qureshi and Barrett-Lennard, 1998). Sandhu and Malik (1975) proposed a simple plant succession technique for reclamation of calcareous saline-sodic soils. In this approach, a salt tolerant species, *Leptochloa fusca* (L.) Kunth, locally known as 'kallar grass', is introduced as a primary coloniser of salt-affected land. This improves the soil conditions by reducing soil salinity, sodicity and pH in the root zone, thus facilitating the growth of other species in the succession (Mahmood et al., 1989; 1994).

The importance of biological methods for utilization or vegetative bioremediation of salt-affected soil is now well recognized all over the world (Qadir and Oster, 2002). Many studies have indicated improvements in soil structure by growing forages (Perfect et al., 1990; Caron et al., 1992; Haynes and Francis, 1993). As the length and biomass of the root system develops, improved soil water retention (Darwish et al., 1995) and decreased soil bulk density (Acharya and Abrol, 1978) have been observed. Quirk and Schofield (1955) demonstrated that soil permeability could be maintained even at high exchangeable sodium percentages (ESP) provided the electrolyte concentration of the percolating water remains above a threshold electrolyte concentration (TEC). In a recent review, Quirk (2001) discussed the dependence of TEC and turbidity concentration (TUC) on the sodium adsorption ratio and electrolyte concentration of soil solution and demonstrated that dispersion and loss of soil microstructure occurs when the electrolyte concentration is about one quarter of TEC and the flocculation concentration is almost 8 times the TUC. Robbins (1986a) reported a decrease in permeability in uncropped compared to cropped soils and indicated that calcareous sodic soil can be efficiently reclaimed by selecting suitable crops and amendments with appropriate water application rates and timing. A considerable increase in hydraulic conductivity of a strongly alkaline soil was reported by Gupta et al. (1989) by growing rice. Ilyas et al. (1995) observed that in general, the hydraulic conductivity was adversely affected by poor quality water in the soils of the Indus plain. Many studies (Oster et al., 1999; Bouwer, 2000; Gupta and Abrol, 2000; Qadir and Schubert, 2002) have indicated that the use of poor quality waters and salt-affected areas for crop production will increase in order to meet the food requirements of increasing population. Therefore, the problem of saline-sodic soils may be aggravated in future due to improper water management.

The growth of kallar grass improves the soil physical conditions and accelerates leaching of salts. However, systematic studies (e.g., Mahmood et al., 1989; 1994), describing successive changes in soil properties of saline land after kallar grass planting are scanty in the literature. Sustainability of growing plants on saline-sodic soils with saline water irrigation has not been thoroughly investigated. The question of how long term use of saline irrigation water will affect (i.e., deteriorate or ameliorate) the properties of soils degraded by salinity still remains unanswered. Studies were, therefore, conducted to monitor changes in chemical, physical and mineralogical properties of a saline-sodic soil profile in fields undergoing reclamation using kallar grass cultivation and irrigated with brackish water. Soil salinity, sodicity and pH decreased significantly in top soil in cropped fields as result of leaching of salts to lower depths (Akhter et al., 2003). The present paper reports on the changes in physical properties: water retention (θ_m), available water (AW), bulk density, porosity, structural stability and saturated hydraulic conductivity (K_s) at different depths in a saline-sodic soil over a 5-year period after planting kallar grass.

Materials and methods

The field experiment was carried out at the Biosaline Research Station (BSRS) of the Nuclear Institute for Agriculture and Biology, Faisalabad situated near the village of Dera Chahl, 30 km from Lahore, Pakistan. The station is at 74°7′ E; 31°6′ N and the average annual rainfall is about 500 mm. A two-factor factorial experiment was laid out in a randomized complete block design (RCBD) with three replicates. Eighteen plots of 30 m × 30 m having similar soil salinity and texture were established after a preliminary survey using a four-electrode electrical conductivity probe.

Kallar grass was planted on 15 plots while 3 plots were preserved as unplanted controls (T0). Initially three plots were also kept as irrigated controls. However, we abandoned these unplanted irrigated controls as the irrigation water did not penetrate the soil. These soils cannot be leached simply by water because of their extremely low permeability (Akhter et al., 1988; Mahmood et al., 1994). Flood irrigations of about 75 mm were applied when soil moisture content had fallen to about 50% of the water available (AW) at field capacity as indicated by neutron moisture meter readings. Irrigation water ($EC = 0.14\ S\ m^{-1}$) was applied at the rate of 1720 ± 56 mm per year and the mean annual rainfall during the 5-year study period was 497 mm (ranging from 475 to 520 mm with standard deviation of 19) most of which ($\geq 80\%$) occurred in the monsoon season (July–September). Kallar grass, a perennial species was grown continuously for five years and 3–4 harvests were taken each year. The harvested grass was removed from the field and used to feed livestock. Three plots were randomly selected at the end of the growing season (during November) for soil sampling and to measure the soil physical properties *in situ*. The growing of grass was continued for 5 years and sampling was carried out at the end of each year (T1–T5). Soil samples were collected from depths of 0–20 cm (D1), 40–60 cm (D2) and 80–100 cm (D3). These samples were analysed for chemical properties (see Akhter et al., 2003). The control uncropped plots were maintained without any operations except occasional weeding.

Soil samples for determination of texture, moisture retention and aggregate stability were collected before the start of the experiment and at the end of each year (T1–T5). These were obtained with a shovel and packed in tin boxes. Samples were air dried in a glass house and bigger aggregates were broken gently by hand. Roots were carefully removed and aggregates of different sizes were separated by sieving. These were separately packed in air tight boxes. Soil texture was determined by sedimentation (Day, 1965). The water retained by soil at different matric suctions was measured with a ceramic plate extractor (Soil Moisture Equipment Co. Santa Barbara, California, USA). The soil was added to cylindrical plastic holders, placed in the extractor, saturated with distilled water and equilibrated for a week at air pressures of 0.01, 0.03, 0.5 and 1.5 M Pa. The soil water content was determined gravimetrically and plant available water (AW) was calculated as the difference between the water contents at 0.03 M Pa (FC) and at 1.5 M Pa (PWP), where FC and PWP refer to field capacity and permanent wilting point, respectively. Organic carbon was determined by a modified Walkley-Black method (Nelson and Sommers, 1982) and organic matter was estimated by multiplying the organic carbon content by 1.72.

Soil bulk density was determined *in situ* by bulk density sampler (Blake, 1976) at the end of each growth year. The total soil porosity was determined from the soil bulk density (Vomocil, 1976) using the relation: $S_t = 100(1 - \rho_b/\rho_p)$, where ρ_b and ρ_p are soil bulk density and particle density, respectively. Particle density of soil samples was determined at the end of each growth year by pycnometer method (Blake and Hartage, 1986). The saturated hydraulic conductivity (K_s) of soil was determined using a Guelph permeameter (Model 2800KL, Soil Moisture Equipment Corp., USA) *in situ* (Reynolds and Elrick, 1985). The aggregate stability was determined by turbidimetric method (Akhter et al., 1994) modified from Pojasok and Kay (1989) and Molope et al. (1985) using natural dry aggregates of 0.1 g and 1–2 mm size. Initial turbidity (T_i) without any energy input and final turbidity (T_f) after dispersing the aggregates with ultrasonic probe were recorded in a fixed volume of irrigation water until it attained a constant value with turbidimeter (HACH Turbidimeter, Model 2100N). The turbidity values extrapolated to zero time were used to determine the stability index. The stability index (SI) was calculated using the relation: $SI = (T_f - T_b)/(T_i - T_b)$. T_b refers to turbidity of water used to measure stability index.

The data were subjected to analysis of variance (ANOVA). The F-test was used to identify treatment main effects and interactions followed by the least significant differences (LSD) test at 0.05 probability (*P*) level (Steel and Torrie, 1980). Data were also subjected to simple linear regression analyses. The regression coefficient (slope) and correlation coefficient (r) were verified at $P \leq 0.05$ and 0.01 levels. The standard error of estimate (SEE) was also calculated.

Table 1. Some characteristics of uncropped soil and irrigation water (IW) used. (SCL=sandy clay loam)

Parameter	Soil depth			IW
	D_1(0–20cm)	D_2(40–60cm)	D_3(80–100cm)	
Sand (%)	55	52	57	–
Silt (%)	23	25	25	–
Clay (%)	22	23	18	–
Texture	SCL	SCL	SCL	
Electrical conductivity (S m^{-1})	2.20	2.22	1.25	0.14
pH	10.4	10.5	10.4	7.6
Organic matter (g kg^{-1})	3.3	1.9	1.8	–
$CaCO_3$ (%)	0.6	0.7	0.9	–
Sodium adsorption ratio	184	185	115	7.8
Sodium adsorption ratio (adjusted)	–	–	–	19.3
Residual sodium carbonate	–	–	–	9.7
Na^+ (meq L^{-1})	226	207	128	10.4
Ca^{2+} (meq L^{-1})	2.0	2.0	1.9	2.1
Mg^{2+} (meq L^{-1})	1.0	0.5	0.6	1.5
K^+ (meq L^{-1})	0.4	0.2	0.2	0.2
Cl^- (meq L^{-1})	72.5	62.1	40.7	0.7
SO_4^{-2} (meq L^{-1})	39.4	22.2	13.5	0.4
HCO_3^- (meq L^{-1})	36.0	36.2	27.5	12.8

Results

The soil is sandy clay loam (very fine sandy loam, Alluvial, Typic Torriorthents, USDA) to a depth of one metre. The native soil was calcareous ($CaCO_3$ = 0.7%) and highly saline-sodic with low average organic matter content (2.3 g kg^{-1}). Pumped brackish underground irrigation water (EC = 0.14 S m^{-1}, $SAR_{adj.}$ = 19.3; residual sodium carbonate = 9.7 meq L^{-1}) categorized as brackish C3S2 (USDA, 1954) was used to grow kallar grass and the quality of this water did not change significantly over the life of the experiment. However, the salinity of irrigation water was lower than the salinity of soil under investigation. The Some selected soil properties and chemical composition of irrigation water are presented in Table 1. There were significant reductions in salinity, sodicity and pH (EC = 0.24 S m^{-1}, SAR = 29, pH = 8.9), and an increase in organic matter content (8.2 g kg^{-1}) after growth of kallar grass for 5 years. The details of chemical changes after specific times of kallar grass growth are presented elsewhere (Akhter et al., 2003). The changes in selected physical properties are described below.

Water retention (θ_m) and available water (AW)

The cropping of kallar grass for different periods (T1 to T5) significantly increased soil water contents (θ_m, kg kg^{-1}) measured at different suctions from 0.01 to 1.5 M Pa (Table 2) particularly after 5 years. At all suctions tested, θ_m generally increased as the growing time of kallar grass increased, with high r values ranging from 0.80 to 0.98** and with low standard errors of estimate (SEE = 0.006–0.010). The amount of plant available water (AW) also increased significantly after growing kallar grass for 5 years (Tables 3 and 4). Kallar grass growth progressively increased AW by about 38% over 5 years.

The data further revealed that amount of AW of all treatments (T1 to T5) increased statistically over the control (T0) but, in general, there were no significant differences between values of AW for successive years. However, the soil AW was directly and significantly ($P \leq 0.01$) related to the growing time (Table 3). The predicted AW was in the range of 0.17 to 0.218 kg kg^{-1}. The regression equation predicted that about 95% of the variations in the amount of AW are due to growing kallar grass for different periods.

Table 2. Influence of growing Kallar grass for different time periods on soil water retention (θ_m, kg kg^{-1}) measured at various matric suctions and on available water. Values for different depths are means of three determinations.

Growth year (T)	Soil depth			
	D_1 (0–20 cm)	D_2 (40–60 cm)	D_3 (80–100 cm)	Mean
		0.01M Pa		
0	0.247	0.240	0.246	0.244
1	0.287	0.274	0.277	0.279
2	0.271	0.267	0.251	0.263
3	0.279	0.272	0.273	0.275
4	0.287	0.268	0.278	0.278
5	0.300	0.288	0.285	0.291
r	*0.80*	*0.77*	*0.74*	*0.80*
		0.03M Pa		
0	0.208	0.211	0.207	0.208
1	0.234	0.232	0.243	0.232
2	0.247	0.249	0.243	0.246
3	0.261	0.260	0.258	0.260
4	0.270	0.268	0.278	0.278
5	0.280	0.274	0.289	0.281
r	*0.98*	*0.97*	*0.97*	*0.98*
		0.5M Pa		
0	0.080	0.081	0.072	0.078
1	0.085	0.071	0.087	0.081
2	0.080	0.083	0.080	0.081
3	0.088	0.090	0.082	0.087
4	0.087	0.084	0.082	0.084
5	0.089	0.092	0.089	0.090
r	*0.79*	*0.73*	*0.65*	*0.91*
		1.5M Pa		
0	0.053	0.060	0.054	0.055
1	0.059	0.059	0.060	0.059
2	0.063	0.066	0.059	0.063
3	0.066	0.069	0.061	0.065
4	0.069	0.060	0.077	0.063
5	0.071	0.066	0.062	0.071
r	*0.98*	*0.46*	*0.64*	*0.93*

Saturated hydraulic conductivity (K_s)

The saturated hydraulic conductivity (K_s) of the topsoil (0–20 cm) increased substantially with time under kallar grass (Figure 1). The maximum K_s value of 55.6 mm d^{-1} was obtained in T5 and the minimum value of only 0.035 mm d^{-1} was found in the uncropped plot. This increase was highly significant at $P \leq 0.01$ with $r = 0.99^{**}$ (Table 4). The predicted values of K_s increased from 2 to 52 mm d^{-1} due to improvement of the soil through enhancements of structural stability index and porosity after growing kallar grass for 5 years (Tables 3 and 4).

Bulk density

The soil bulk density decreased significantly in all cropped plots. Generally, growing kallar grass for 5 years produced progressive reduction of bulk density from an average value of 1.68 to 1.53 Mg m^{-3}. The soil bulk density also differed with depth (Table 3). There were clear differences in the bulk density of

Table 3. Influence of growing Kallar grass for different time periods on available water content, soil structural stability index, bulk density and organic matter. Values for different depths are means of three determinations.

Growth year (T)	Soil depth			
	D_1 (0–20 cm)	D_2 (40–60 cm)	D_3 (80–100 cm)	Mean
		Available Water		
0	0.155	0.151	0.153	0.153
1	0.175	0.173	0.170	0.173
2	0.184	0.183	0.183	0.183
3	0.195	0.191	0.199	0.195
4	0.216	0.199	0.211	0.212
5	0.214	0.203	0.212	0.210
		Structural Stability Index		
0	32	19	33	28
1	58	36	34	43
2	67	65	71	68
3	68	51	55	58
4	119	67	77	88
5	151	47	91	97
		Bulk density (Mg m^{-3})		
0	1.62	1.73	1.68	1.68
1	1.61	1.72	1.60	1.64
2	1.58	1.65	1.59	1.61
3	1.55	1.59	1.56	1.56
4	1.54	1.53	1.55	1.54
5	1.53	1.53	1.54	1.53
		Porosity (%)		
0	38.9	34.6	36.5	36.7
1	39.1	35.3	39.7	38.0
2	40.4	37.7	40.0	39.4
3	41.5	40.1	41.3	41.0
4	42.3	41.5	41.9	41.9
5	42.8	42.2	42.4	42.2

Table 4. Relationship between soil physical properties (Y) and Kallar grass growing time (T). $n = 6 \times 3 = 18$.

Variable	Regression equation	SEE	r
θ_m (at 0.01 M Pa)	Y=0.254 + 0.007T	0.010	0.80
θ_m (at 0.03 M Pa)	Y=0.214 + 0.015T	0.006	0.98**
0.05 M Pa	Y=0.078 + 0.02T	0.003	0.91*
1.5 M Pa	Y=0.056 + 0.003T	0.002	0.93**
Available Water	Y=0.158 + 0.012T	0.006	0.97**
Bulk density	Y=1.672 − 0.031T	0.013	0.98**
Porosity	Y=36.952 − 1.166T	0.448	0.983**
Stability index	Y=29.876 + 13.363T	0.434	0.96**
Saturated hydraulic conductivity	Y=2.07T2.007	0.521	0.99**

SEE – standard error of estimate; r – correlation coefficient ** Significant at 0.01 level

Table 5. Correlation coefficients among soil properties

Bulk density	Porosity	Stability index	Saturated hydraulic conductivity	Organic matter	
Available Water	−0.99**	0.99**	0.94**	0.96**	0.92**
Bulk Density		−0.99**	−0.96**	−0.81*	−0.92**
Porosity -			0.93*	0.98**	0.92*
Stability Index				0.95**	0.91*
Saturated hydraulic conductivity					0.97**

*,** Significant at 0.05 and 0.01 levels, respectively.

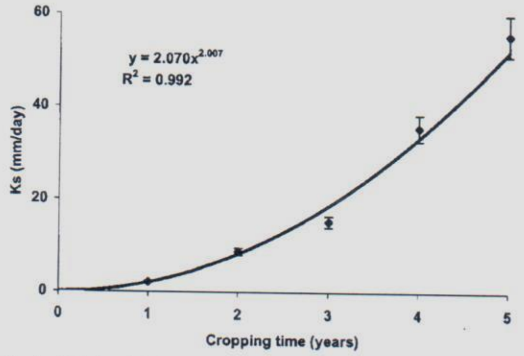

Fig. 1. Relationship between cropping time of Kallar grass and hydraulic conductivity (K_s) of top soil (0–20 cm). The values shown are means ± SD of nine determinations.

surface soil (0–20 cm) for all time periods compared to that at depth.

Porosity

The porosity increased significantly in all cropped plots. Growing kallar grass for 5 years increased porosity from an average value of 36.7 to 42.2%. The porosity was variable along the soil profile (Table 3). The increase was highly significant at $P \leq 0.01$ with r = 0.983** (Table 4).

Structural stability

The structural stability of the soil (measured as stability index, SI) increased significantly ($P \leq 0.01$) over 5 years. The maximum increase in SI over the control was observed in the topsoil after growing kallar grass for 5 years. The stability index increased progressively over time (r = 0.96**, Table 4).

Relationships between soil physical properties

Correlation analysis was carried out to verify the relationships amongst the different physical properties of the saline-sodic soil under study. High correlations existed between these parameters (Table 5). The available water (AW) was positively correlated with most other physical characteristics, viz. structural stability (SI), hydraulic conductivity (K_s) and porosity. Significant correlations were also recorded between porosity and SI, K_s and organic matter content . The hydraulic conductivity (K_s) was strongly correlated with all other physical properties ($r \leq 0.95$**)

Discussion

The growth of kallar grass increased the amount of water retained by soil. The effect was more pronounced near the surface (Table 2) due to more root activity in the topsoil and its effect in improving soil porosity, organic matter and other soil properties much more dramatically than at depth. The increases in soil water retention resulted in increased plant available water (AW) with cropping. Cassel and Nielsen (1986) suggested that AW, the water retained by soil between field capacity and permanent wilting point, may be more useful than water retention itself for measuring relative differences within and amongst soils. The results of the present study showed that AW increased significantly with cropping of kallar grass. AW showed a high positive relationship with soil organic matter content (Table 5). Morachan et al. (1972) reported that water retention of 2 mm sieved soil samples increased with increasing organic carbon content at suctions between 10 and 1500 k Pa. Organic matter (OM) increases water holding capacity and enhances AW (Bauer and Black, 1992; Darwish et al., 1995). The AW showed strong correlations with bulk density, porosity, structural stability and hydraulic conductivity; properties which may have influenced AW indirectly. Akhter et al. (1988) and Carter (1984) observed increases in saturation percentages of soil under cropping. Querejeta et al. (2000) showed that addition of organic matter and mechanical terracing with sub-soiling enhanced the water storage of the soil profile due to improvement in soil structure and permeability. The results of present study verified that cropping practices produce measurable changes in the physical properties such as plant available water and that these changes depend on the growing period of kallar grass.

The hydraulic conductivity (K_s) of soil increased with kallar grass growth and was positively correlated with porosity and negatively correlated with bulk density (Table 5). Olsen (1960) found strong increase in permeability with increase in soil porosity, while Gumbs and Warkentin (1972) recorded marked decreases in permeability with small increases in bulk density (1.10 to 1.25 Mg m^{-3}). Robbins (1986b) reported that a calcareous sodic soil maintained its hydraulic conductivity under cropping but that it decreased in uncropped soil. A considerable increase in hydraulic conductivity was reported by Gupta et al. (1989) by growing rice in a strongly alkaline soil. Meek et al. (1990) observed higher infiltration rates with long term growth of alfalfa compared to cotton. The beneficial effects of growing kallar grass and other plant species in improving the soil physical conditions of highly saline-sodic soils are well documented (e.g., Gupta et al., 1989; Meek et al., 1990). Results of our study clearly showed that growth of kallar grass improved hydraulic conductivity of the soil as a result of interactive processes such as increase in soil porosity, improved structural stability, organic matter and leaching of salts to lower depths (Akhter et al., 2003).

There was a reduction in soil bulk density and a corresponding increase in soil porosity by growing kallar grass as a management practice on a highly saline-sodic soil (Table 3). The grass has an extensive root system penetrating up to 1 m (Malik et al., 1986) and the proliferation of roots is probably the major factor responsible for the increased soil porosity. Miyazaki (1996) observed changes in soil bulk density by natural processes such as shrinkage with drying, consolidation with drainage and swelling with infiltration and reported that the greater the bulk density of a soil (or alternately the less the soil porosity), the smaller the saturated hydraulic conductivity. Meek et al. (1992) reported that an increase in bulk density from 1.7 to 1.89 Mg m^{-3} under cropping reduced the infiltration rate by a factor of four and increased penetration resistance by a factor of three. Douglas and McKeys (1978) found a linear relationship between $\log(K_s)$ and total porosity of the soil. The effectiveness of the biological method for improving soil physical properties such as soil bulk density is well documented (Glauser et al., 1988; Costa et al., 1991).

Soil structural stability, determined as stability index (SI), increased significantly at a fairly uniform rate during kallar grass cropping and top soil showed a greater increase in SI values than those at depth (Table 3). The interactive effect of increasing organic matter with root growth and a significant reduction in soil salinity, sodicity and alkalinity with enhanced leaching (Akhter et al., 2003) caused substantial increases in soil stability with cropping of kallar grass. Other studies (Haynes and Francis, 1993; Chenu et al., 2000) have reported increases in aggregate stability by growing a variety of economical crops in different soil types.

Bruce et al. (1992) found a positive linear relationship between soil carbon and increase in stable aggregates under cropping. Growing forages, Haynes and Francis (1993) and Perfect et al. (1990) found that soil structure improved considerably with increasing root biomass and root length density. Caron et al. (1992) also reported large increases in soil aggregate stability by growing bromegrass for 3 years. In other studies it was found that cropping practice significantly influenced the structural stability, particularly water stable aggregation (Tisdal and Oades, 1980; Ried and Goss, 1981).

It may have been that some of these beneficial changes observed in this experiment were wrought by the irrigation water itself which was less saline and less sodic than the soil. However, it was not possible to leach the unplanted soil as its permeability was so low that a true control treatment was not available. This may mean that, to some degree, the growth of the Kallar grass served to punctuate a rather impermeable matrix with useful biopores which then allowed the leaching process to begin in earnest so that soil remediation could begin. The foregoing may be summarized by noting that the effectiveness of the 'biological' approach, i.e., growing kallar grass (*Leptochloa fusca*) for improvement of degraded saline-sodic soil has been clearly demonstrated by the results of this present field study. The continuous cropping of kallar grass produced improvement in the physical properties of a deteriorated soil within a period of three years. The soil maintained these improved characteristics with further growth of grass and confirmed the sustainability of the biological approach of reclaiming salt-affected soils. Growing kallar grass as a management practice on a highly saline-sodic soil has the potential to restore fertility to a degraded soil.

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