USE OF BRACKISH-WATER FOR AGRICULTURE: GROWTH OF SALT-TOLERANT PLANTS AND THEIR EFFECTS ON SOIL-PROPERTIES

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ABSTRACT

A five-years field study was conducted, on a saline sodic soil, to evaluate the effectiveness of biological approach for improvement of salt-affected wasteland, in terms of soil physical, chemical and mineralogical characteristics. Kallar grass (Leptochloa fusca (L) Kunth), being tolerant to salinity, sodicity and alkalinity, was grown for five years, irrigated with saline under-ground water. The cropping of kallar grass improved appreciably the physical (Available water, hydraulic permeability, structural stability, bulk density and porosity), chemical (Salinity, pH, Sodium adsorption ratio and organic matter) and mineralogical properties of soil within a period of three years. The soil maintained the improved characteristics, with further growth of grass, upto five years. The study confirmed that salt-affected soils can be improved effectively through biological means, and that growing salt-tolerant plants is a suitable approach. Kallar grass showed a tremendous potential to improve most of the physical, chemical and mineralogical properties, without any adverse effects of saline water on soil-properties.

INTRODUCTION

Salinity of soils and ground-water is a serious soil-degradation problem, which is growing steadily in many parts of the world, including Pakistan. It is a multi-dimensional problem in several countries and has wide macro and micro socio-economic implications. It occurs mainly, but not exclusively, in arid and semi-arid regions, low-lying areas and river valleys. Food-production in many parts of the world, particularly in arid and semi-arid regions, is severely affected due to decrease in area under cultivation, increase in area under salinization and decrease in overall productivity of good and fertile soils, as a result of improper irrigation and water-management practices (IAEA, 1995).

Soil salinity is wide-spread in all the countries where climate is arid to semi-arid and average rainfall is less than the evapo-transpiration. Salt-affected soils cover about 10 % of the total dry land-surface of the earth (Szabolcs, 1986). These salt-affected areas are distributed throughout the world and, unfortunately, no continent is free of salt-affected soils. There are large variations in the extent, type of salinity and geo-morphological characteristics of salt-affected soils from one region to the other. Since these salt-affected soils occur in various forms, both in large areas and in small isolated locations on most of the earth's surface, the knowledge of their extent is understandably incomplete. Based on reliable data, the extent of existing salt-affected soils on our globe is presented in Table-1 (Szabolcs, 1986).

Pakistan is located between longitude 61° and 76°E and latitude of 24° and 37°N. In major part of Pakistan the climate is semi-arid to arid because the average annual precipitation is 250 mm and ranges from 100-760mm. It is estimated that 66.7 % of the area of Pakistan receives rainfall less than 254 mm, 24.2 % between 254-508 mm and 5.4 % between 508-762 mm, and only 3.7 % more than 762 mm. The potential evapotranspiration exceeds precipitation by a factor of 8, which leads to unfavourable distribution of salts and their accumulation in the root-zone. Some of the areas are very hot, with an average summer temperature of 39°C and maximum upto 53°C. The winter is fairly cool, with an average temperature of 20°C and minimum down to –2 °C.

The estimates of salt-affected area in Pakistan vary between 2.2-7.9 million hectares (Muhammad, 1978; Akbar et al., 1977; Chaudhry et al., 1978; Szabolcs, 1979). Ahmad and Dharejo (1980) and WAPDA (1985) reported that salt-affected areas range from 4.0-5.7 million hectares. Detmann (1982) estimated that 40,000 hectares of land were being lost, due to salinity and water-logging

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Table-1. Salt-Affected Soils On Continents And Sub-Continents *(Szabolcs, 1986).*

Continents/subcontinents	x 10^6 ha
North America	15.775
Mexico and Central America	1.965
South America	129.163
Africa	80.608
South Asia	87.608
North and Central Asia	211.686
South east Asia	19.983
Australia	357.33
Europe	50.804
Total	**954.922**

every year in Pakistan. Scholz (1982) also described the alarming situation in Pakistan, due to loss of 4 to 5 hectares of land to salinity per hour. According to a report by (MINFAL, 1999), the salinized area consists of 6.2 million hectares of arable land in Pakistan (Table-2).

The Indus basin is one of the largest alluvial plains in the world, formed by the river Indus with its five large tributaries. The Indus basin is potentially capable of providing vast amount of food and fiber for human consumption. However, the immense agricultural potential of these plains remains nowhere near realization due to numerous factors, such as poor management, lack of inputs and research, etc.

Rapidly increasing salinity and water-logging in vast areas of cultivated land is threatening the entire future of this food bowl. The worst affected areas are located in the middle of DOABA (areas between two rivers). Under irrigated agriculture, salinity and sodicity occur in patches and area under-surface soil-salinity is 6.2 Mha, out of which 9.7, 19.9, 38.6 and 31.8 % area is very slightly, moderately, severely, and very severely, saline, respectively (Table-2). Out of four Provinces, Punjab is severely affected by salinity (43.2 %), followed by Sindh (34.2), Baluchistan (21.8 %), and NWFP (0.8 %). The irrigated plains of Indus-basin possess an extensive ground-water aquifer under 16.2 million hectares (Mha). Out of this 5.2 Mha contain water with less than 1000 mg L^{-1} of total soluble salts (TSS), about 2.5 Mha have ground water of moderate salinity (TSS = 1000 to 3000 mg L^{-1}) and 8.5 M ha possess water of high salinity (TSS more than 3000 mg L^{-1}). The ground water table is severely affected by monsoon rains (Tables-3).

Table-2: Province-Wise Summary --- Extent Of Saline/Sodic Soils In Pakistan *(Area in 000 ha).*

Province	Slightly Saline	Moderately Saline	Severely Saline	Very Severely Saline	Total
Punjab	472.4	804.8	738.3	652.0	**2667.5**
%	(17.7)	(30.2)	(27.7)	(24.4)	**(43.2)**
Sindh	118.1	324.7	1173.1	493.7	**2109.6**
%	(5.6)	(15.4)	(55.6)	(23.4)	**(34.2)**
NWFP	5.2	25.7	8.7	8.9	**48.5**
%	(10.7)	(52.9)	(18.0)	(18.4)	**(0.8)**
Baluchistan	3.0	74.6	464.7	805.6	**1347.9**
(%)	(0.2)	(5.5)	(34.5)	(59.8)	**(21.8)**
Total	**598.7**	**1229.8**	**2384.8**	**1960.2**	**6173.5**
%	**(9.7)**	**(19.9)**	**(38.6)**	**(31.8)**	**(100.0)**

Source: Agricultural statistics of Pakistan, 1999-00.

Table-3: Water-Table Levels In Pakistan Before/After Monsoon (Area in Million Hectares).

Province	Surveyed Area	Before Monsoon			After Monsoon		
		0-1.5 m	1.5-3m	>3 m	0-1.5m	1.5-3m	>3 m
NWFP	0.563	0.057 (10%)	0.113 (20%)	0.393 (70%)	0.065 (12%)	0.138 (25%)	0.36 (64%)
PUNJAB	9.971	0.539 (5%)	2.280 (23%)	7.132 (72%)	1.179 (12%)	2.806 (28%)	5.986 (60%)
SIND	5.739	0.397 (8%)	3.760 (71%)	1.118 (21%)	3.438 (60%)	1.256 (22%)	1.045 (18%)
BALUCHISTAN	0.397	0.041 (10%)	0.198 (49%)	0.162 (41%)	0.093 (24%)	0.065 (16%)	0.239 (60%)
TOTAL	**16.67**	**1.034 (6%)**	**6.351 (39%)**	**8.805 (55%)**	**4.775 (29%)**	**4.265 (26%)**	**7.63 (46%)**

Source: SCARP Monitoring Organization (1989), Planning Division, WAPDA.

The water-table remains within 1.5 m in 6 % of the area before monsoon and increases to 29 % of the total area after monsoon season (Table-3).

Different countries have adopted different strategies to deal with the problem. In Pakistan, various departments and agencies have suggested and applied various remedial measures to solve the salinity and water-logging problem. So far, Water and Power Development Authority (WAPDA) has completed 44 Salinity Control and Reclamation Projects (SCARPs), covering an area of about 5.17 Mha. Additonally, 14 SCARPs, covering an area of about 2.9 Mha, are under construction (ICID, 1991).

In SCARPs, Hydrological and / or Engineering approach of drainage-leaching combination is being applied. The approach involves the elimination of water-logging and salinity, by lowering the ground water table and using the pumped water to support the existing canal-water supplies and leaching the surface-salts. The story of achievements and failures of WAPDA, using hydrological approach, is controversial and complex. According to WAPDA, the salt-affected area was reduced by 17%, as interpreted from aerial photographic surveys in 1953 and 1979 (WAPDA, 1985). However, field investigations in SCARP 1, carried out by Central Monitoring Organization of WAPDA and Soil Survey of Pakistan, indicated that various targets were hardly touched (Atta-ur-Rehman 1976; Qureshi et.al., 1978).

The hydrological approach is essential to achieve good drainage in the irrigated areas, but it is highly energy-intensive and creates problems of disposal and/ or utilization of pumped saline ground-water. Most of the national efforts for controlling the salinity have been commonly based on the engineering-based concepts of drainage. These efforts may be suitable in areas where fresh water is available. Therefore, research is imperative to evolve proper strategy for arid and semi-arid salt-affected lands, where the source of irrigation is only ground-water.

A final solution of the salinity problem requires leaching of salts with good-quality water, coupled with efficient drainage-system. Proper disposal sites, suitable drainage-channels, sufficient gradient for gravity-flow and good-quality water are prerequisites for engineering approach to be applied. However, In Pakistan, engineering approach is difficult to implement because, of non-availability of good quality water and absence of drainage network in the affected areas. The drained water seeps into the surrounding areas if drained through unlined drainage-channels. The approach may be easier near coastal areas, where gradient for gravity-flow is available but scarcity of good-quality water and unavailability of huge funds required render the approach difficult to practice.

Table-4: Salt Tolerant Limits (Root Zone Salinity Causing 50% Yield Reduction) Of Different Plants *(From Silver Jubilee Of Niab).*

Species	EC(dSm-1)	Species	EC (dSm-1)	Species	EC (dSm-1)
Grasses		Beta vulgaris	19	Cassia sturtii	15.8
Leptochloa fusca	22.0-14.6	Lotus carniculatus	16.7	Acacia saligna	15.7
Sporobolus arabicus	21.7	Trifolium alexandrinum	15.8	Acacia bivenosa	13.7
Cynodon dactylon	21.0-13.2	Sesbania aculeate	13	Leucanena leucocephala	12.4
Hordeum vulgare	19.5-10.0	Hasawi rushad	12.5	Acacia kempeana	11
Sorghum vulgare	16.7-15.0	Medicago sativa	13.2-12.2	Acacia aneura	9.5
Panicum antidotale	16	Sesbania rostrata	12	Acacia cunnighamii	9.4
Echinochloa crusgalli	15.9	Macroptilium atropurpureum	12	Acacia holosericea	9
Polypogon monspeliensis	13.7	Trifolium rsupinatum	11.6	Acacia adsurgens	4.3
Avena sativa	11.8-9.1	TREES		Acacia validineriva	1.7
Lolium multiflorum	11.2	Acacia sclerosperma	38.7	VEGETABLES	
Echinochloa colonum	11.2	Acacia ampliceps	35.7	Aster tripolium	31.7
Desmostachya bipinnata	9	Prosopis juliflora	35.3	Brassica napus	19.5
Panicum maximum	9.0-8.5	Prosopis chilensis	29.4	Trigonella faenum-graecum	19.2
Sorghum halepense	7	Casuarina obesa	29.2	Spinacea oleracea	14.8
SHRUBS		Acacia victoriae	28.2	Medicago falcate	13.4
Suaeda fruticosa	48	Acacia cambagei	27.7	Brassica carinata	12.5
Kochia indica	38	Eucalyptus striaticalyx	26.2	Brassica juncea	12.4-8.44
Atriplex nummularia	38	Acacia salicina	24.5	Lactuca sativa	9.9
Atriplex amnicola	33	Casuarina glauca	24.4	Brassica campestris	9.8
Atriplex lentiformis	23	Prosopis tamarogo	22.7	Eruca sativa	9.4
Atriplex undulata	22.5	Acacia calcicola	19.9	Coreandrum sativum	5.7
Atriplex crassifolia	22.5	Acacia coriacea	18.2		
Sesbania Formosa	21.4	Cassia nemophila	16.8		

The ground-water in most of the salt-affected areas is saline and that is the basic factor, which limits the agricultural production. The saline water is not suitable for agricultural or fruit crops, but it can be used for growing salt-tolerant plants. Plants have acquired vast genetic variability during their evolution over millions of years. They have adapted to so many kinds of habitats and grow on mountains, plains, marshes, cold and hot climates and even in sea. Growing salt-tolerant plants (trees, shrubs, bushes and grasses) provide biomass, which can be used directly as fodder or fuel-wood, or converted to value-added products, such as biogas, compost and alcohol, etc., and the process is termed as 'Biological Approach' (Malik et al., 1986). The data presented in Figure-1 summarize the entire biological approach and various options available to the farmers. This approach considers saline soils and brackish water as a useable resource, rather than liabilities.

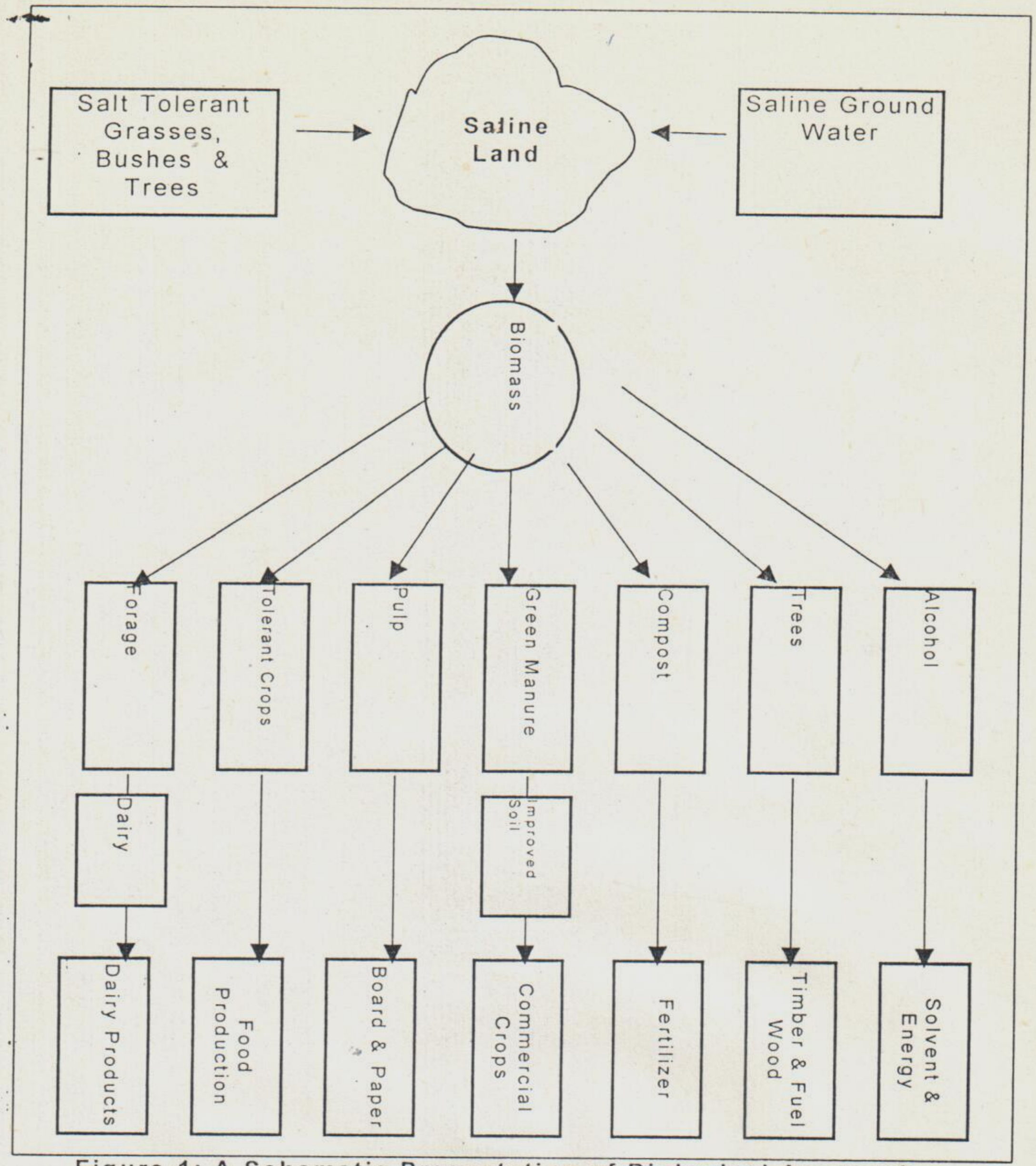

Figure-1: A Schematic Presentation of Biological Approach.

Many crops and other species are being studied for their salt-tolerance and water-use efficiency the world over. In Pakistan, over 100 plant-species belonging to different genera have been screened for the limits of their salt-tolerance. Table-4 gives a list of plant-species, with the limits of their salt- tolerance, screened at NIAB. Among these Kallar grass has been the most economical and useful plant to grow on salt-affected soils (Malik et al. 1986) of Pakistan. The biological approach for utilization of saline lands and water is not the ultimate answer for tackling the salinity problem, but it does provide an inexpensive alternative to the highly expensive leaching and drainage approach for reclamation of salt-affected soils.

In Pakistan, good-quality water is not available in sufficient quantity for irrigation and leaching of salts down to lower layers. In areas with shallow water table, salts accumulate on the soil-surface, due to capillary phenomenon. Many of these areas have saline ground-water that cannot be used to irrigate economic crops. In the developing countries, no serious attention has been given to the proper use of

Table-5: Some Physical And Chemical Properties Of Uncropped Soil And Irrigation Water Used. *(Values Are Means of 3 Replicates)*

(a) Physical Property	Soil Depth				
	Unit	D1	D2	D3	
Sand	gKg^{-1}	550	520	570	
Silt	gKg^{-1}	230	250	250	
Clay	gKg^{-1}	220	230	180	
Textural Class	Sandy clay loam				
	$KgKg^{-1}$	0.155	0.151	0.153	
Available Water Bulk density	Mgm^{-3}	1.62	1.73	1.68	
Porosity	%	38.9	34.6	36.5	
Stability index		31.9	18.6	32.6	
Hydraulic permeability	mmd^{-1}	0.35	0.25	0.44	
(b) Chemical Properties			Soil		IW
EC_e	dSm^{-1}	22	22.2	12.5	1.4
pH		10.4	10.5	10.4	7.6
OM	gKg^{-1}	3.3	1.9	1.8	-
SAR		184.4	185.2	114.5	7.8
ESP		73	73.1	62.6	-
SAR_{adj}		-	-	-	19.3
RSC		-	-	-	9.7

D1=0-20 cm, D2=40-60 cm, D3= 80-100 cm, EC_e= Electrical conductivity
OM= Organic matter, SAR= Sodium adsorption ratio, adj= Adujusted
ESP= Exchangeable sodium percentage, RSC= Residual sodium carbonate
IW= Irrigation water used.

brackish ground-water and water flowing through the drainage channels. Presence of saline subsurface water poses a threat of salinization to fertile soils, but in Pakistan, due to lack of awareness, environmental degradation is not taken care of properly. Proper uses of brackish ground-water need to be explored; growing salt-tolerant plants on salt-affected soils is one such option available. This will increase the agricultural production, which is the backbone of economy in developing countries.

The purpose of this research was to study the physical, chemical and mineralogical changes in a highly saline-sodic soil under biological reclamation. The altering composition of soil-solution was used to explain the changes in selected properties of a highly salt-affected soil, in terms of effectiveness and sustainability of the approach over a period of 5 years.

MATERIALS AND METHODS

Five-year field-study was conducted at Biosaline Research Station (BSRS) of Nuclear Institute for Agriculture and Biology (Faisalabad), situated near village Dera Chahl, 30 Km from Lahore, Pakistan. The station is located at longitude 74°7 ′E and latitude 31°6 ′N. Average annual rainfall is about 500 mm. At BSRS, model plots have been established to demonstrate the Biological Approach for economic utilization of salt-affected soils, by growing salt- tolerant plants irrigated with brackish ground-water. This station is used as a model for sustainable development of salt-affected land, using different techniques.

A two-factors factorial experiment was laid out in a randomized complete block design (RCBD), with three replicates. Eighteen plots of 30 m x 30 m, having similar soil-salinity and texture, were established after a preliminary survey using four-electrode electrical-conductivity probe. Kallar grass was planted on 15 plots, while 3 plots were preserved as a control/fallow. Flood- irrigations of about 75mm were applied at about 50% of soil field capacity, as indicated by neutron-moisture readings. Complete record of irrigation-water applied and rainfall was maintained. Kallar grass, being perennial species, was continuously grown for five years and 5-7 cuttings were taken per year. Three plots were

Table-6: Mineralogical analysis of soil-clay fraction (%) at depth D1 (0-20 cm) as a function of growing kallar- grass.

Year (T)	Illite	RIS	Kaolinite	Chlorite
0	49±3	19±2.5	13±1.6	6±1.5
1	47±3	23±2.5	11±2.0	7±1.5
3	43±3	26±2.7	9±2.3	8±1.5
5	40±3	29±2.3	7±2.5	9±1.5
Mean	**44.8**	**24.5**	**10**	**7.5**
Year (T)	*H/G*	*Quartz*	*Feldspar*	*CEC*
0	4±1.2	4±1	2±1	33±1.5
1	5±1.4	4±1	3±1	32±1.2
3	6±2.0	4±1	4±1	30±1.9
5	7±1.7	4±1	4±1	29±1.8
Mean	**5.5**	**4**	**3.3**	**31**

CEC = Cation exchange capacity (meq/100 g)

H/G = Hematite/goethite

randomly selected at the end of each growing season (during November) for soil sampling and to measure the required soil physical properties in-situ. Samples for analysis of physical and chemical properties of soil were collected from pre-selected depths of 0-20cm (D1), 40-60 cm (D2) and 80-100 cm (D3). These samples were air-dried and ground to pass through 2 mm sieve. A saturated soil paste extract was obtained from sub-sample of each soil, using the method of US Salinity Laboratory Staff, 1954.

Soil-texture was determined by sedimentation technique, developed by Jennings et al. (1922) as described by Day (1965). The amount of water retained by the soil at different pressures was measured by ceramic-plate extractor (Soil Moisture Equipment CORP. USA). The amount of AW was calculated by the following formula:

AW(kgkg^{-1}) =Soil moisture at 0.03MPa(FC) - Soil moisture at 1.5MPa(PWP)

Soil bulk-density was determined in-situ by bulk-density samplers by Blake, (1976) at the end of every growth year. The field-saturated hydraulic permeability was determined, using Guelph permeameter (Model 2800KL, Soil Moisture Equipment CORP. USA) in-situ (Reynold and Elrick, 1985). The stability index (SI) was determined using dry aggregates of 0.1 g weight and 1-2 mm size (Akhter et al., 1994).

Electrical conductivity (EC_e) and pH of saturated paste extracts were determined for each sample by WTW conductivity meter LF-530 and Corning pH meter 130, respectively. Soil saturation extracts were analyzed for cations (Na, K, Ca and Mg). Sodium and K were determined with flame photometer (Model PFP7 Jenway) (U.S. Salinity Laboratory Staff, 1954) and Ca and Mg by titration with ethylene-diamine-tetra-acetate (EDTA). Total carbon and organic carbon were determined by a modified, Walkely-Black method (Nielson and Sommers, 1982). Inorganic carbon (Ci) was determined with modified volumetric calcimetric method, in which soil was treated with 4N HCl in the presence of $FeCl_2$ in a closed system and the volume of CO_2 released was determined. Organic matter was derived by multiplying the organic carbon with 1.72. Mineralogical analysis was carried out with X-ray diffraction (XRD); the patterns were recorded with a Philips PW1710 microprocessor- controlled diffractometer (Raven, 1990 and Self, 1988).

RESULTS AND DISCUSSION

The soil was highly saline sodic (EC_e 22.2 dSm^{-1}; pH 10.4; SAR; 184.5) and non-gypsiferous sandy clay loam soil (Table 5). The brackish water (EC_e 1.4 dSm^{-1}; SAR 9.6; RSC 9.8 meL^{-1}) was used as a main source of irrigation in reclaiming saline sodic soil. Some of the selected soil-properties of control/fallow soil and chemical composition of the irrigation water used to grow kallar grass are presented in Table-4. The results revealed that the successive cropping of kallar grass for five years, as major treatments used (T1, T2, T3, T4 and T5) had a pronounced effect in improving some physico-chemical and with To. The soil AW was found to be directly and significantly ($p \leq 0.01$) related to the

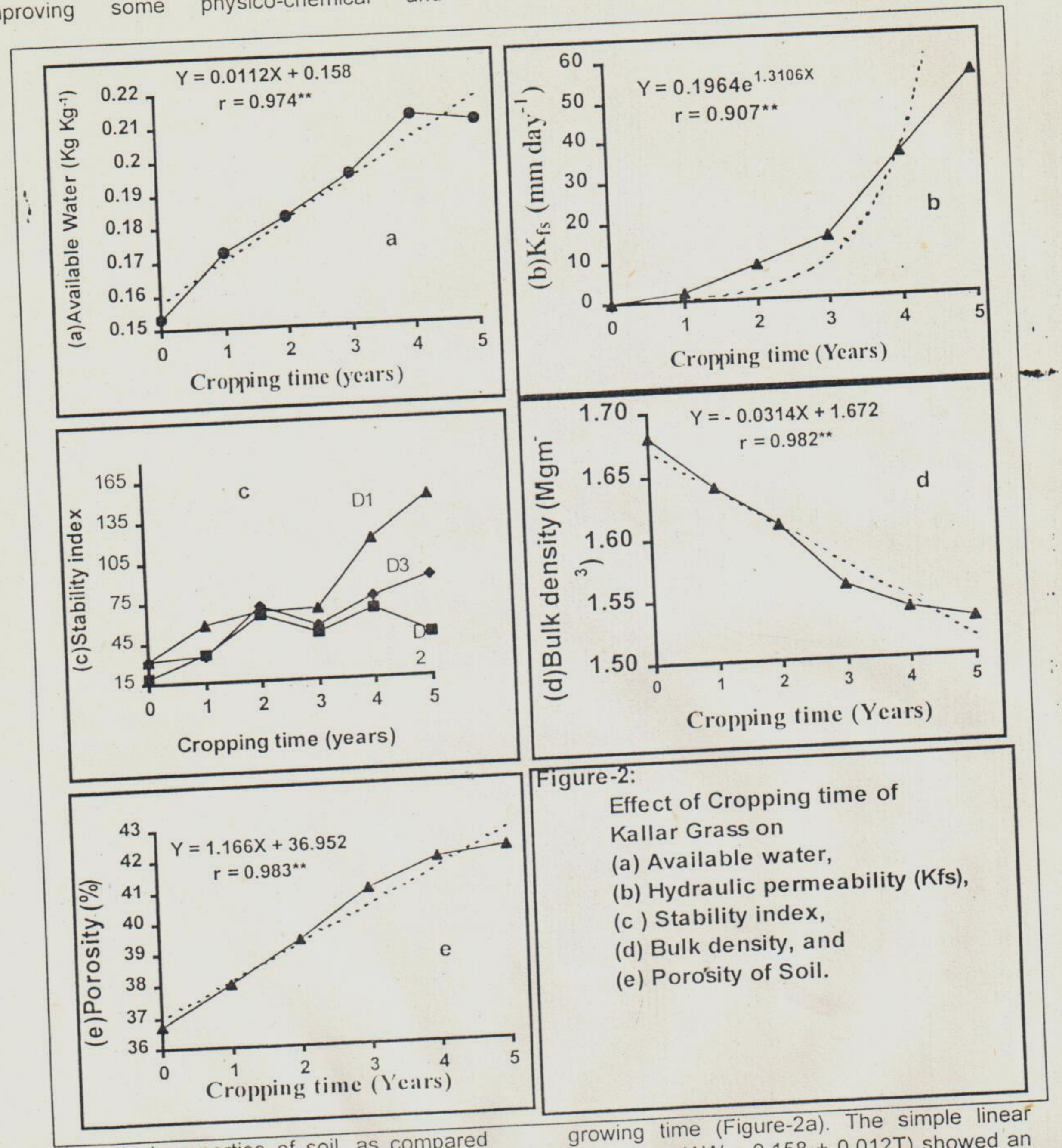

Figure-2:
Effect of Cropping time of Kallar Grass on
(a) Available water,
(b) Hydraulic permeability (Kfs),
(c) Stability index,
(d) Bulk density, and
(e) Porosity of Soil.

mineralogical properties of soil, as compared with uncropped practice system (To).

The amount of available water (AW) for plants increased (statistically) after growing kallar grass for 5 years. The cropping of kallar grass over all periods (1-5 year) highly increased the AW by 27.5%, as compared to uncropped soil. The maximum increase of 38.6% was found with the treatment T4 (after 4 years of cropping), followed by 37.3, 27.51, 19.6 and 13.1% after 5, 3, 2 and 1 year, as compared

growing time (Figure-2a). The simple linear regression ($AW = 0.158 + 0.012T$) showed an increase rate of 0.012 $KgKg^{-1}$, (i.e.1.2%) with highly significant r value of 0.974**(Figure-2a).

The saturated hydraulic permeability (K_{fs}) of the soil increased at the upper depth D1. The effect of cropping-system on the K_{fs} was highly significant. The maximum K_{fs} value of 55.6 mmd^{-1} was obtained in T5 and minimum value of 0.35 mmd^{-1} was found in To. The maximum increase of 159- fold after T5 was followed gradually by 6.1, 25.1, 43.8 and 101.6 times with T1, T2, T3 and T4, as compared with K_{fs} of uncropped plot. The hydraulic permeability increased in an approximately exponential manner with the growing period of kallar grass (Figure-2b). The rate of increase of K_{fs} 0.982 mmd^{-1} was highly significant at $p \leq 0.01$ level, with an excellent correlation coefficient (r = 0.969**) with high R^2=0.940 value.

The soil-stability index (SI) in this study largely increased over all growing seasons (5 years) by 154% of control treatment. The maximum increase in SI of 247 % was observed after 5 years of cultivation, followed by 216, 110, 144 and 54 % over control after 4, 3, 2, and 1 year, respectively. The regression analysis indicated that SI increased linearly and significantly (SI = 29.87 + 13.37T) with increase in growing-time (Figure-2c), with a high regression coefficient (b) and high r (0.957**), R^2 (0.915). The SI values increased at constant rate of 13.36 for each year of agronomical practices tested.

The soil bulk-density (BD) significantly decreased in all cropping treatments (Ts) used, as compared to BD, of To. The application of biological approach for 5 years showed a linear reduction in BD with high r value (0.982**), R^2 value of 0.964. The 96.4% BD reduction shown by regression-model resulted due to increase of cropping period. The effect of growing-period of kallar grass on soil porosity was highly significant (Figure-2d): the maximum increase 15.0% in porosity of the soil occurred after 5 year followed by 14.2, 11.7, 7.4, and 3.5% at T4, T3, T2 and T1 over To, respectively. The soil porosity increased in a proportional pattern by increasing the growing period (Fig. 2e). The increasing rate of soil porosity (average of 1.166 $\%year^{-1}$) was highly significant with an excellent value of r=0.983** ($p \leq 0.01$).

The soil salinity (EC_e) significantly ($p \leq 0.05$) decreased after growing kallar-grass for five years. The cropping periods over all years significantly reduced the soil EC_e by 71.4 % over To. The maximum reduction of 87.3% was observed in T5, followed by 79.9, 83.6, 64.6 and 41.8 % reduction after 4, 3, 2 and 1 year in T4, T3, T2 and T1, respectively, as compared with To. The regression analysis showed that EC_e exponentially ($\ln EC_e = 2.783 - 0.408T$) decreased with growing time of kallar grass (Figure-3a), with highly significant regression coefficient (b) and high correlation coefficient (r =0.958** at $p \leq 0.01$) and coefficient of determination (R^2=0.918). The EC_e decreased at a constant rate of 0.408 unit (dSm^{-1}) per year of growing kallar grass. The 91.7% of EC_e reduction resulted because of increase of cropping time.

Soil pH statistically decreased in all treatments tested by cropping kallar- grass, as compared to soil pH of uncropped plots. The maximum decrease of 14.4 % in pH of soil was observed after 5 years, compared with To. The cultivation of kallar grass had a significant linear effect (r = 0.854* at $p \leq 0.05$) on pH with a decrease rate of 0.229 unit for each year of growing kallar grass (Figure-3b). The soil pH differed significantly at different depths of the soil-profile. As a general pattern, the soil pH gradually increased with increase in soil depth. The highest reduction of 2.5% in soil pH was recorded in upper soil-depth D1, as compared with soil reaction at the deeper depth D2 (Figure-3b).

A considerable decrease in SAR of soil was recorded with all the cropping treatments. Overall, five year of cropping of kallar grass reduced SAR of soil significantly (67.8%) over the uncropped control soil. The SAR reduction was 32.5, 29.3, 39.9, 51.0 and 51.2% from T1 to T5, respectively, over the mean reduction of 5 year. The SAR apparently decreased in an exponential pattern ($\ln SAR=4.926-0.343T$) as the growing time was increased (Figure-3c). The reduction-rate of SAR 0.343 $meqL^{-1}year^{-1}$ was highly significant at $p \leq 0.01$ level with the best correlation coefficient (r=0.968**). The reduction of soil SAR was mainly due to the cropping system employed.

The effect of cropping practices on soil organic matter (OM) was highly significant ($p \leq 0.05$)). All treatments resulted in enhancement of OM in a progressive pattern (Figure-3d). The maximum OM value of 8.2 gkg^{-1} was found after 5 years and 2.0 gkg^{-1} was recorded in To. Maximum increase of 3.6 fold at 5 years, followed gently by 2.1, 2.9, 3.0 and 3.01 folds increase throughout 1-4 year. The soil OM significantly increased linearly (OM=3.452 + 1.026T) when growing periods were increased, with a good correlation-coefficient (r=0.911* at $p \leq 0.05$). Therefore, the growth of kallar grass caused 83.0% of the observed variability in soil OM content. The content of OM increased by a rate of 1.026 gkg^{-1} $year^{-1}$ because of growth of kallar grass compared with uncropped soil.

Characterization of clay fraction of uncropped soil under investigation revealed micacious-dominated mineralogy. The soil clay fraction contained a mixture of mica, illite, smectite, kaolinite, chlorite, with minor amounts of hematite/ goethite (H/G), quartz and traces of feldspar (Table-6). X-ray diffraction (XRD) confirmed that illite dominated, with an average of 44.8%, followed by randomly interstratified material mainly smectite (RIS), 24.5%, kaolinite, 10.0%, chlorite 7.5%, H/G 5.5%, quartz 4% and feldspar 3.25%. Data indicated that the soil belonged to micaceous class, with cropping period of five year (T1 to T5) reduced the illite content by 18.4%, followed by 12.25 and 4% after 3 and 1 year (T3 and T1) compared with uncropped soil (Table-6). The regression analysis indicated that illite decreased linearly (Illite=48.831 - 1.814T) with the increase in cropping time with high correlation coefficient (r= 0.998** at $p \leq 0.05$. The randomly interstratified (RIS) material, mainly smectite, generally increased with cropping kallar grass, compared to control soil (Table-6). An increase of 52.6% in RIS was noted after 5 years, followed by 36.8% with T3

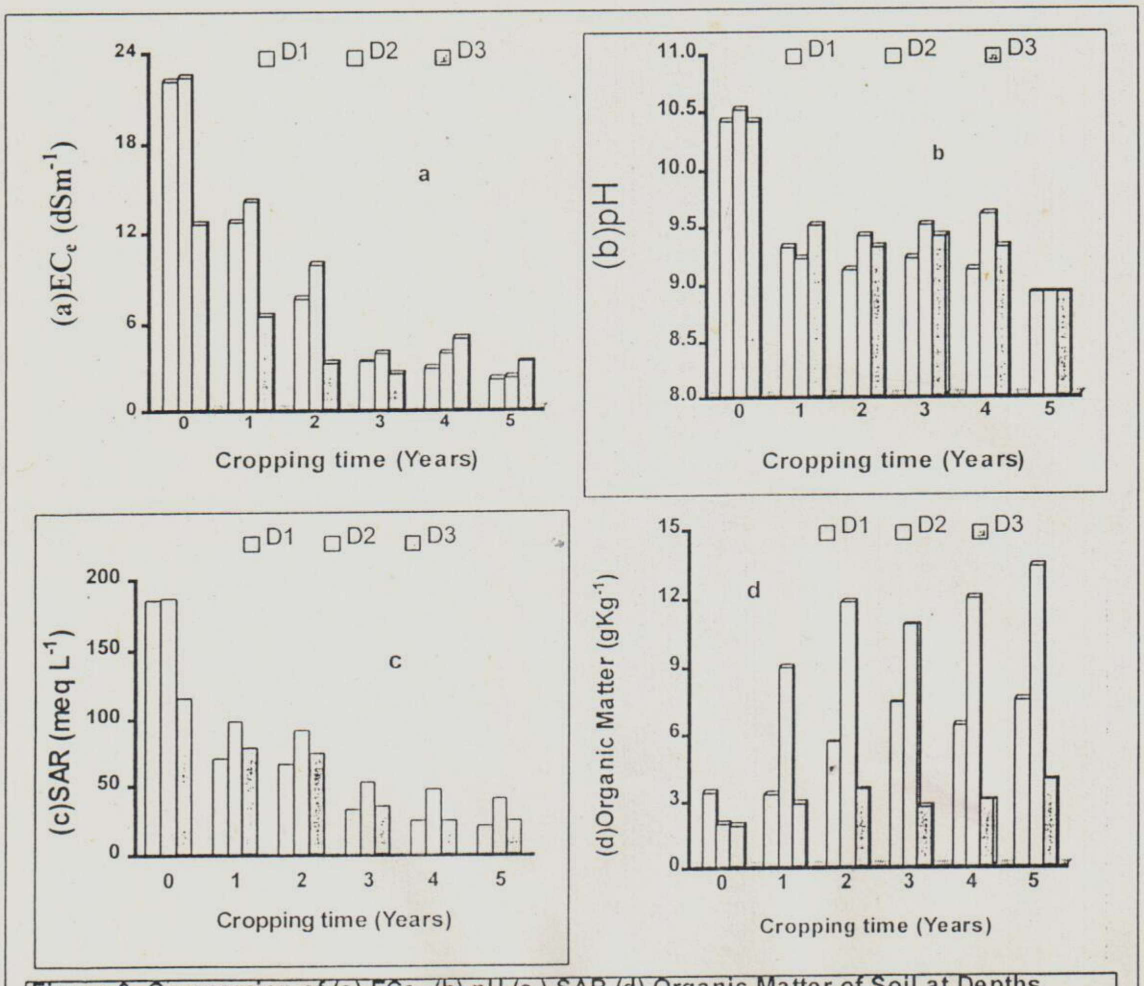

Figure-3: Comparsion of (a) ECe (b) pH (c) SAR (d) Organic Matter of Soil at Depths

D1 (0-20cm),
D2 (40-60cm) and
D3 (80-100cm) as a function of cropping time of kallar grass.

younger mineralogy and most likely with early stage of weathering in uncropped soil.

The illite content certainly decreased with cropping periods of growing kallar grass. The and 21.1 % with T1 over uncropped soil. The RIS increased in a linear fashion (RIS=20.017 - 1.880T) significantly at $p \leq 0.05$ with r = 0.977*.

Kaolinite, the third most important mineral in soil-clay fraction, was considerably reduced with cropping under the applied biological management system. Maximum reduction of 46.1% was recorded after 5 years of cropping, followed by 30.8 and 15.4% after 3 and 1 year, compared to To soil (Table-6). The cropping of kallar grass had a good linear and significant (r =0.989* at $p \leq 0.05$) effect on kaolinite, with decrease rate of 1.153 gKg-1 per year. Chlorite, commonly recognized as unstable mineral, increased with cropping period. Five years of cropping enhanced chlorite content by 1.5 times, followed by 1.33 and1.16 times after 3 and 1 year of cropping. The regression analysis confirmed that chlorite significantly increased in a linear manner with increase in growing seasons (Chlorite=6.203 + 0.560T), with significant regression- coefficient (b) and good correlation-coefficient (r = 0.989* at $p \leq 0.05$). The chlorite increased at constant rate of 0.560 gKg-1 per year of cropping period. The hematite/goethite (H/G) increased under kallar-grass growth, compared with uncropped fallow soil. The H/G of soil clay fraction increased by 75, 50, and 25% after 5, 3 and 1 year of cropping period, respectively (Table 6), compared to To soil. Regression analysis showed a linear relationship between H/G and cropping time with good correlation coefficient of (r = 0.989* at $p \leq 0.05$). Quartz in soil- clay fraction maintained its original composition of 4% with cropping period of growing kallar grass (Table-6). The feldspar increased by 50% and 100%, after 1 and 3 years, respectively, and no further change was noted after 5 years of cropping, compared to uncropped soil.

CONCLUSIONS

The results confirmed that cropping of kallar-grass on a highly saline, sodic soil, irrigated with brackish water improved appreciably the soil physical (AW, Kfs, SI, BD and P), chemical (EC_e, pH, SAR and OM) and mineralogical properties, within a period of three years. Kallar grass maintained its growth without addition of any fertilizer for a long time. The proportion of clay-mineral component found in soil-clay fraction and significant evidences available confirmed that uncropped soils are highly unstable, very soft when wet and very hard when dry, due to greater amount of illite clay. The growth of kallar grass accelerated the rate of weathering, with transformation of mica to 2:1 expansible clay, and the soil attained an appreciable improvement in soil-aggregate stability, hydraulic permeability, available water, soil-porosity or bulk density, due to increase in organic matter and leaching of soluble ions from surface to lower depths.

The soil maintained the improved characteristics with further growth of grass upto five years. The results confirmed the sustainability of biological approach i.e. amelioration of saline lands by growing salt-tolerant plant species with brackish under-ground water.

REFERENCES

- Ahmed, R. and Dharego, M.S. 1980. Reclamation of salt-affected soils. Bull. Irrigation, Drainage and Flood Control Research Council of Pakistan, 10:46-59.
- Akbar, M., Shakoor, A. and Sajjad, M.S. 1977. Prospects of breeding for salt tolerance in rice. In: Muhammad, A., Askel, R. and Brostel, R.C.(Eds.), Genetic Diversity in plants. Plenum Press, New York, 291-299 pp.
- Akhter, J., Malik, K.A., Naqvi, M.H., Ahmad, S. and Murray, R. 1994. Aggregate stability of a saline sodic soil under irrigated kallar grass Faisalabad, Pakistan. Geol. Bull. Punjab Univ., 29:53-64.
- Atta-ur-rehman, C. 1976. Review of control of water-logging and salinity through SCARPs and need for long term planning. Bull. of Irrigation Drainage and Flood control Research Council of Pakistan, 6:30-47.
- Braunauer, S.P., Emmett, H. and Teller, E. 1938. Adsorption of gases in multimolecular layers. J. Am. Chem. Soc., 60:309-319.
- Chaudhry, M.B., Alim, M. and Rafiq, M. 1978. Nature and magnitude of saline and drainage problem in relation to agricultural development in Pakistan. Pak. J. For., 28:70-92.
- Day, P.R. 1965. Particle fractionation and particle size analysis. In: Black, C.A. (Ed.). Method of Soil Analysis, Part, 1, Physical and mineralogical properties, including statistics of measurement and sampling. Am. Soc. Agron., Madison, Wisconson, USA, 547-567 pp.

- Detmann, K. 1982. Signs of decay in Pakistan agriculture, loss of cultivated land and deterioration of social structure in irrigated areas of Punjab. In: MenSchuz, H. (Ed.), Problems of management of irrigated lands in areas of traditional and modren cultivation. Hamburg, 133-148.
- International Atomic Energy Agency (IAEA), 1995. Management strategies to utilize salt-affected soils. IAEA-TECDOC-814, Vienna.
- International Commission on Irrigation and Drainage (ICID), 1991. Irrigation and drainage developement in Pakistan. Asia year country report. Lahore, Pakistan.
- Jennings, D.S., Thomas, M.D. and Gardner, W. 1922. A new method of mechanical analysis of soils. Soil Sci., 14:485-499.
- Malik, K. A., Aslam, Z. and Naqvi, M. 1986. Kallar grass. A plant for saline land. Ghulam Ali Printers, Lahore, Pakistan, 93 pp.
- MINFAL (2000) Agricultural statistics of Pakistan (1999-00). Ministry of Food, Agriculture and Livestock. Goveronment of Pakistan, Islamabad, 302pp.
- Muhammad, S. 1978. Salt-affected soils of Pakistan. In: Proc. of Workshop/seminar on membrane biophysics and developement of salt tolerance in plants. March, 11-21. Univ. Agri. Faisalabad, Pakistan, 47-64 pp.
- Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Black, C.A. (Ed) Methods of soil analysis. Part 2. Chemical and microbiological properties, Second Ed. Agron. 9. ASA and SSSA. Madison. Wisconsin, USA, 539-579 pp.
- Quirk, J.P. 1955. Significance of surface areas calculated from water vapor sorption isotherms by use of B.E.T. equation. Soil Sci., 80:423-430.
- Qureshi, R.H., Sandhu, G.R. and Bhatti, H.M. 1978. Comments on the National strategy for control of water-logging and salinity in Pakistan; PARC sponsored Workshop on water-logging and salinity, May 2-4, NIAB, Faisalabad, (Unpublished).
- Raven, M.D. (1990). Xplot-version 3-user manual, manipulation of powder X-ray diffraction data. CSIRO Division of Soils Tech. Mem. No. 24/1990. 26 pp.
- Reynolds, W.D. and Elrick, D.E. 1985. In-situ measurement of field-saturated hydraulic conductivity, sorptivity and alpha parameter. Soil Sci., 140:292-302.
- Scholz, F. 1982. Punjab In:Dierche weltraums Atlas textband. Braunschweig. 241-242 pp.
- Self, P.G. 1988. User manual, PC based system for the control of a Philips PW1710X-ray diffraction system. CSIRO Division of Soils Tech. Mem. No. 41/1988. 31 pp.
- Szabolcs, I. 1979. Review of Research on Salt-affected soils. Natural Resources Research XV, UNESCO, Paris, 137 pp.
- Szabolcs, I. 1986. Agronomical and ecological impact on soil and water salinity. In: Stewart, B.A. (Ed.), Advances of soil science volume 4. Springer-verlag, Newyork, 188-218 pp.
- U.S. Salinity Laboratory Staff. 1954. Saline and alkali soils. USDA, Agric. Hand book No. 60. U.S. Govt. Print. Office, Washington, DC.
- Water and Power development Authority (WAPDA), 1985. Position paper on water-logging and salinity. Planning and development Division, Govt. of Pakistan, 27 pp.