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Effect of Soil Salinity on Growth of Millet in Lysimeter Experiment

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Abstract: *Phytoremediation of soils of different salinity levels have been investigated in this study using salt tolerant forage crop. Soil was salinized with 5 levels of NaCl (0, 50, 100,150, 200 mmol L^{-1}) in 100 cm height and 50 cm diameter lysimeters . Millet (Pennisetum glaucum L.) was planted as a reclaiming crop for saline soil.*

Results showed that relative yield (the ratio between saline treatment and non-saline treatment) obtained from 200 mmol L^{-1} treatment was 74, 77 and 75% for shoot, grain and total biomass weight, respectively which considered acceptable from economic aspect. General trend showed that using SALINITY model capture the essential features of leaching saline soil. However, it was concluded that SALINTY model did not take phytoremediation into consideration which led to higher predicted ECe values comparing with the measured values. Modeling salt and water during phytoremediation is needed to submit new criteria of saline soil reclamation.

Key words: *millet, modeling, lysimeter*

I. Introduction

Saline agriculture is defined as the cultivation of tolerant crops using saline soil and/ or saline water for irrigation. This kind of agriculture had been considered in many countries in arid and semiarid region. There are indications both historical and recent that saline agriculture is a viable alternative to conventional agriculture.

The main impediment to more widespread acceptance and use of saline agriculture is the possible degradation of soil and water resources.

Studies have shown that restoration of salt affected could be done by using phytoremediation. As a definition, phytoremediation is a non-destructive in situ remediation technique that used plants to clean up contaminated soil, water or air (Willey,2006). The findings of Begdullayeva et al. (2007) indicate the potentiality of using salt tolerance crops for phytomelioration of marginal lands in Karakalpakstan.

The success of phytoremediation of saline soils requires a greater understanding of the processes fostering phytoremediation, the potential of plant species to withstand ambient salinity and salinity levels in soil and water, and also of the uses and markets for the agricultural products produced. Strategic research on such aspects would further elucidate the role of phytoremediation in the restoration of saline soils for sustainable agriculture and conservation of environmental quality. Qadir and Oster (2002) demonstrated that amelioration through phytoremediation was achievable in much less time than initially anticipated. Such findings were based on the use of appropriate plant species and irrigation and soil management practices that assisted in higher rates of soil amelioration phytoremediation of salt affected soils is achieved by the following : i- use of plants to remove contaminants, such as salt, plants that are tolerant to salinity can yield above ground biomass that accumulates salt and can be removed from the site through harvesting (Chang 2007).ii- the ability of plant roots to increase the dissolution rate of calcite, thereby resulting in enhanced levels of Ca^{+2} in soil solution to effectively replace Na on the cation exchange Complex (Ahmed et al. 2003; Qadir et al. 2007). Crop tolerance to salinity is of high importance due to the extent and the constant increase in salt-affected areas in arid and semi-arid regions. Millet (Pennistum glaucum L.), generally consideredas fairly tolerant to salinity, could be an alternative crop option for salt affected areas. Millet is a suitable crop to grow while leaching is occurring. Moreover, millet is a quick-growing summer forages or grain crop. Ground watertables are generally at their lowest during summer, and the vegetative cover provided by the millet crop prevents capillary rise of groundwater which could lead to further salinization.The millet tolerates soil salinity (ECe) up to 6 dS m^{-1} (6000 µScm^{-1} or 3840 ppm) without a significant decrease in dry matter production. At an ECe of 9 dS m^{-1}, its production is expected to decrease by about 25% (Evans, 2006). Large genotypic variation was reported to exist in millet for salinity response (Ashraf and McNeilly 1987, 1992; Dua 1989). The availability of high levels of tolerance offers a scope to integrate this tolerant crop into appropriate management programs to improve the productivity of the saline soils. It is found that millet crop accumulate 224 kg ha^{-1} of salt by 8 t ha^{-1} yield (Gritsenko and Gritsenko, 1999). Millet seems to be sensitive at germination stage in ECe of 16 dS m^{-1} and beyond but this sensitivity is to some extent compensated by the tillering capability (Dua 1989). However, it seems that salinity response estimated at germination stage does not correlate well with plant performance at later stages (Munns and James 2003).

Transient soil-based models such as SALINITY generally use numerical solutions of water and solute movement. The model based on complete mixing equation and numerical integration by modified trapezoidal method of the mixing plate (Al-Gilani 1999). However, the presence of crop roots in the soil is treated as a simple sink term and plant growth dynamics is generally not considered. Transport through the root zone is modeled as a series of events or processes within a finite collection of discrete depth intervals. These sequential events or processes include infiltration of water; drainage to field capacity, plant water uptake resulting from transpiration, and/or evaporative losses from the soil surface Modeling studies considered useful in attempts to better understand and/or predict the movement of agricultural and other contaminants in the vadose zone, one example is the evaluation of remediation strategies for salt-affected soils (Suarez, 2001).

This study is conducted to assess the efficiency of phytoremediation modeling to predict soil salinity during growing season.

II. Methods

Experiment set up: - Lysimeter system consisting of 15 tanks with 100 cm height and 50 cm diameter .A wirehouse was settled for this purpose in the college of Agriculture – University of Baghdad. A layer of coarse sand and gravel, 10 cm thick, was covered by repacked soil collected from 0-15 cm soil layer –field in College of Agriculture - Abu Graib (Table 1). The non-saline silty clay loam textured soil was air dried for a week then passed through a 4-mm sieve. At the bottom of each tank a pipe serving as drainage outlet connected the tank with a conical flask to receive leachates. The set up was covered at a height of 3 m by a sheet of transparent plastic to protect the assembly against precipitation. Soil was salinized with NaCl (0, 50, 100, 150, 200 mmol L^{-1}). The NaCl was dissolved in distilled water and applied to each tank corresponding to the field capacity levels of the soil according to Tekalign et al., (1996). After planting barley at winter season, the second stage was planting another crop at summer season.

Table 1: Chemical and physical properties of soil from Abu-Graib – College of Agriculture fields, (0-15 cm depth) used in the lysimeter experiments

Parameter		
Partical size distribution		
Sand		
Silt	g kg^{-1}	172
Clay	g kg^{-1}	455
Organic matter	g kg^{-1}	373
pHe	g kg^{-1}	2.3
ECe	g kg^{-1}	7.7
Soluble Cations	dS m^{-1}	2.6
Na+		
Ca+²	mmol L^{-1}	11.4
Mg+²	mmol L^{-1}	8.5
K+	mmol L^{-1}	6.8
Cl^{-}	mmol L^{-1}	0.48
SO_4^{-2}	mmol L^{-1}	17.5
HCO_3^{-}	mmol L^{-1}	3.6
Total N	mmol L^{-1}	2.0
Available P	mg kg^{-1}	60.4
Available K	mg kg^{-1}	5.3
CEC	cmol$_c$ kg^{-1}	1.2
Bulk density	cmol$_c$ kg^{-1}	24.9
Field capacity	Mg m^{-3}	1.2
	cm\cm	0.27

Planting: - Each tank was planted with millet (Pennisetum glaucum L.). A complete randomized block design with three replicates was used. The tested treatments are 5 levels of soil salinity which mentioned above. Plant nutrients N, P and K were added according to plant utilization:- 100 kg N ha^{-1} as urea ,50 kg P ha^{-1} as mono calcium phosphate and 50 kg K as potassium sulfate. After 12 days of germination, 20 plants left in each tank.

Irrigation: - Plants were irrigated with fresh (tap) water. Based on ET monthly estimation by modified Penman equation (FAO, 1977). ET values were: 292 and 258 mm for July and August, respectively. Leaching requirement (LR) is estimated by the equation:

$$LR = \frac{ECiw}{5ECt - ECiw}$$

Where ECiw is the EC of the irrigation water and ECt is the soil EC that should not be exceeded in order to minimize yield loss. After determining LR by this equation, the LR estimated by this equation = 0.18 knowing that: ECiw= 0.75 dSm^{-1}(Table1) and to minimize yield loss ECt = 1 dS m^{-1}. For each month, the total amount of water required (WR) by the crop was estimated by knowing the crop's evapotranspiration (ET):

Table 2: Chemical composition of water used for irrigating millet crop (summer season).

Source	Na+	Ca+2	Mg+2	K+	Cl⁻	SO_4^{-2}	HCO_3^-	EC $dS\ m^{-1}$	pH	SAR
	$mmol_c\ L^{-1}$									
Tap water	**2.92**	**2.06**	**1.54**	**0.02**	**3.76**	**0.45**	**2.01**	**0.75**	**7.23**	**2.18**

$$WR = ET/(1 - LR)$$

WR values estimated from the equation above = 356 and 314 mm for July and August, respectively.Leachates (drainage water) were collected and their volumes are recorded with their specific dates of collecting and analysing their ionic composition. Net salt\ ionic removal through leachates (Q_i) was calculated for each month through growth period with help of the formula (Ahmad et al., 2003):

$$Q_i = \Sigma (C_{ij} - C_{1s}) V_j$$

Where C_{ij} is salt \ionic concentration in the leachate and C_{1s} is that in the leaching solution (applied water) at a given volume V_j.

Soil samples also were collected and analyzed. Soil and water and plant analysis were carried out according to Ryan et al. (2003).

III. Results

Soil salinity criteria

The data of soil ECe pre and post cultivation of millet crop (Figure 1) showed general reduction in soil salinity occurred in all levels of NaCl and soil depths after cultivation. Lowest ECe values were obtained at 0-30 cm and ranged between 2.4 -14.9 and 1.8-9 dSm^{-1}pre-and post-cultivation, respectively. Highest values were obtained at 60-90 cm and ranged between 3.1-16.2 and 2.8-10 dSm^{-1}pre-and post-cultivation, respectively. It was observed that cropping reduced the soil salinity to a considerable level in all the treatments. However, highest reduction after cultivation was recorded at the level of 200 mmol L^{-1}NaCl of 40, 40, 38% for the three depths: 0-30, 30-60, 60-90 cm, respectively. Sodium and chloride ions are major contributors to soil salinity thus they were measured pre and post cultivation (Figure 2). General trend reduction was noticed which agreed with ECe data. Lowest values of sodium were recorded at 0-30 cm and ranged between 14-105.93 and 7.62 - 83.97mmol L^{-1}pre and post –cultivation, respectively. While Cl^- ranged between 16.8- 117.9 and 7-80 mmol L^{-1}, respectively. Highest values were obtained

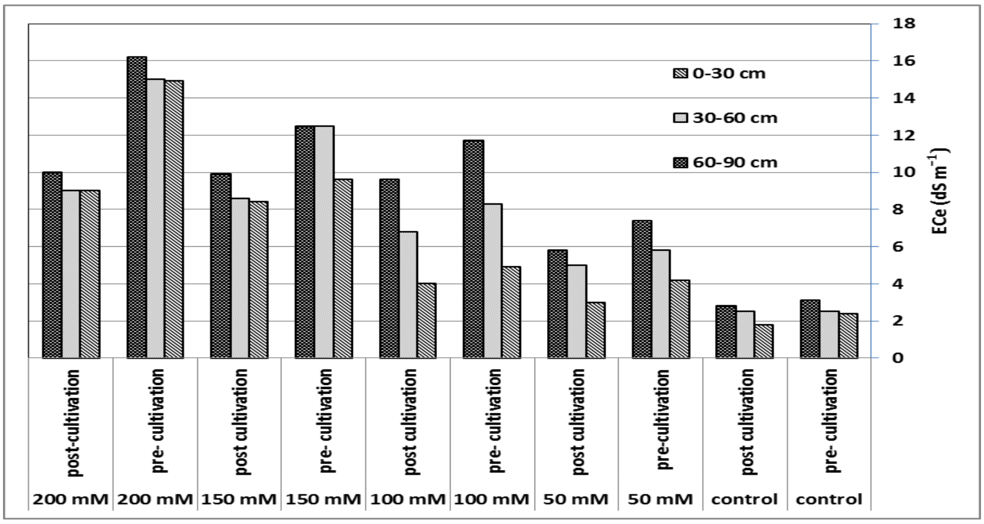

Fig. 1. Electrical conductivity (ECe) of soil pre and post millet cultivation

13.61- 116.4 and 12.95- 88.46 pre and post – cultivation, respectively. Major salinity ions: Na^+ and Cl^- behaved similarly as ECe. The similarity between ECe and both NaCl behavior in soil was noticed by many studies (Al-Zubaidi 1992 and Al-Hassani 1984).

Millet crop Performance at soil salinity treatments

In the current study the productivity of millet in response to salinity levels at summer season was assessed, based on the (stem + leaf) biomass, grain and total biomass produced under salinityas that of control (Table 3). Statistical analysis was done using least significant differences (LSD) to compare the mathematical averages. Large variation was found for the shoot biomass at different treatments. It was clear from the data that yield significantly ($p\leq 0.05$) reduced with increasing NaCl concentrations. Maximum shoot dry weight of 64.57g was obtained at control treatment while minimum dry weight of 28.58 g was obtained at 200 mmol L^{-1}.

Data presented in table 3 showed that maximum grain weight of 18.85 g was recorded for control treatment. Statistical analysis revealed that NaCl levels had significantly ($p\leq 0.05$) affected grain yield. Minimum grain yield of 6.76g was obtained at 200 mmol L^{-1}. Total above ground biomass weight indicated that maximum weight of 83.42 g was recorded for control treatment and significantly differed from minimum weight of 35.34 g which was recorded for 200 mmol L^{-1}. Before cultivation of millet, soil salinity of 150 and 200 mmol L^{-1} treatments was above threshold which is according to Evans (2006) equal to 6 dS m^{-1} for leading to yield loss as a response to elevated salinity. Although ECe for

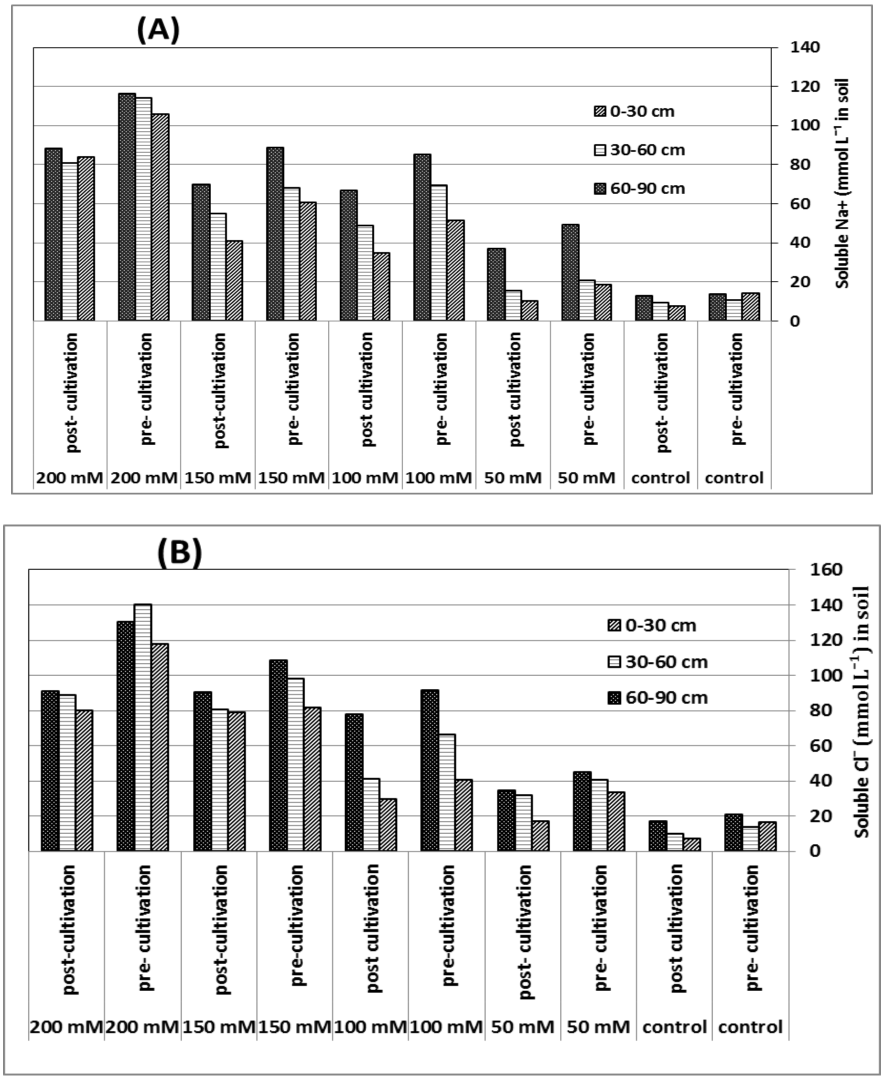

Fig. 2. Concentrations of Na^+ (A) and Cl^- (B) in soil pre and post millet cultivation

100 mmol $L^{-1}$was below threshold salinity, it gave significantly lower yield than control and 50 mmol L^{-1}.This could be attributed to the rise in temperature. Dalton et al. (1997) found that increase in root zone temperature caused significant increase (96%) in the threshold value of root zone salinity. However, the ratio

between saline treatment and non-saline treatment which defined as relative yield was 74, 77 and 75% for shoot, grain and total above ground biomass weight, respectively which considered acceptable from economic aspect according to Maas and Hoffman (1976). Relative yield for highest salinity level (200 mmol L^{-1}) was 44, 36 and 42% for shoot, grain and total above ground biomass weight, respectively.

Table 3: Dry weight of straw, grain and total above ground biomass of millet in soil treated with different NaCl levels – summer season.

NaCl (mmol L^{-1}) treatment	Dry weight (g)		
	Shoot (stem+leaf)	Grain	Total above ground biomass
Control	64.57	18.85	83.42
50	62.60	16.43	79.03
100	47.88	14.60	62.48
150	33.03	10.09	43.12
200	28.58	6.76	35.34
LSD 0.05	11.65	4.33	20.77

Ionic Concentration in millet crop fractions

Statistical analysis of the data indicated that increasing NaCl levels cause a significant ($p \leq 0.05$) increase in Na^+ concentration in shoot and grain (Table 4), maximum concentrations were obtained from 200 mmol L^{-1} of 28.32 and 4.11mg g^{-1}, while minimum value of 9.59 and 2.31 mg g^{-1} was recorded for control. Similar trend was observed in Cl^- concentration in shoot and grain, minimum value of 9.54 and 4.15mg g^{-1} was recorded for control while maximum value of 21.67and 5.26mg g^{-1}, respectively was obtained form 200 mmol L^{-1}. Increasing levels of NaCl caused insignificant decrease in K^+, $Ca^{+2}$and Mg^{+2} in shoot and grain. Sodium and chloride were the major cations that significantly accumulated in crop biomass as NaCl levels increased, unlike potassium which decreased with NaCl increasing. High concentration of both Na^+ and Cl^- ions in the root zone reduced the uptake of other essential ions like Ca, Mg and K.

Table 4: Concentration of elements in both straw and grain of millet crop at five NaCl levels in soil.

Concentration (mg g^{-1})		NaCl (mmol L^{-1})					LSD 0.05
		Control	50	100	150	200	
Shoot (stem+ Leaf)	Na+	9.59	10.68	17.99	20.56	28.32	8.14
	Cl^-	9.54	13.67	20.50	20.53	21.67	3. 55
	Ca^{+2}	3.66	3.34	3.41	3.27	3.23	NS
	Mg^{+2}	3.32	2.75	3.12	2.91	3.19	NS
	K+	27.86	27.62	26.82	25.45	25.99	NS
Grain	Na^+	2.31	2.57	3.08	3.85	4.11	0.45
	Cl^-	4.15	4.36	4.51	4.82	5.26	0.64
	Ca^{+2}	3.43	2.68	2.67	2.79	2.89	NS
	Mg^{+2}	2.87	2.75	2.43	2.79	2.78	NS
	K+	6.58	6.88	6.79	6.06	5.93	NS

Leaching of salts from cultivated soil

Table 5 showed the volumes of leachates that percolated through the root zone of millet crop. Leachates ranged between 3080-4350 cm^3 at July. Reduction in volumes occurred at August and ranged within 1200-2800 cm^3. Increasing of NaCl levels caused increasing of leachates volumes. Reclamation demands enough supplies of irrigation water in order to flush down desorbed sodium along with other salts. Leachates that percolate through the root zone increased with NaCl levels. The infiltration of applied water through the soil is the evidence of the improvement of soil physical conditions. The salinity levels in soil solution during phytoremediation maintain adequate soil structure and aggregate stability that facilitate water movement through the soil profile and enhance the amelioration process (Oster et al.,1999).

Table 5: Leachate volumes percolated through soil during growth season of millet crop at five NaCl levels in soil.

NaCl (mmol L^{-1}) treatment	Leachates volumes (cm^3)	
	July	August
Control	3080	1200
50	3440	1540
100	3700	1960
150	3840	2200
200	4350	2800

Leaching fraction (LF) defined as the fraction of irrigation more water than required to meet the evapotranspiration needs of the crop which pass through the root zone to leach excess soluble salts. Actual leaching fraction (LF) illustrated in Table 6. General reduction in LF values existed with decrease of NaCl levels. Limits of LF were between 0.070-0.099 at July and reduced to 0.031-0.072 at August. Calculating the salts removed by LF showed an increasing trend as the NaCl levels increased (Table 6). The results showed that LF increased as salinity increased. However LF was less than leaching requirements LR that was added with irrigation water (0.18). Despite that water requirement (WR) used in irrigation was relatively high, It is observed that LR is about 2.5- 2 and 6-2.2 fold more than LF at July and August, respectively and they were less than the preferential flow with bypass fraction found by van Hoorn et al. (1997). This indicated that significant portion of LR was used by crop as evapotranspiration due to the rising temperature at summer season. Since the amelioration of saline soils depends on the movement of water through the soil profile to remove excess salts from the root zone, it is important that leaching and drainage for salinity control should: i- minimize flow of water through the soil profile to reduce dissolution of soil minerals, and ii- reduce drainage volume which collected from the drainage (Qadir et al., 2006). As a result of these findings, highest amounts of Sodium and chloride ions were removed at 200 mmol $L^{-1}$of 287.13 and 283.85 $mmol_c$ at July and August respectively (Table 7).

Table 6. Leaching fraction (LF) obtained from the ratio between the amount of drainage water (leachate) and the amount of irrigation water (WR) during growth season of millet crop at five NaCl levels in soil.

NaCl (mmol L^{-1}) treatment	LF	
	July	August
Control	0.070	0.031
50	0.078	0.039
100	0.084	0.050
150	0.087	0.057
200	0.099	0.072

Table 7: Salts contents of leachates during growth season of millet crop at five NaCl levels in soil.

NaCl (mmol L^{-1}) treatment	Salts ($mmol_c$)	
	July	August
Control	93.94	33.45
50	94.67	91.63
100	220.15	124.46
150	195.64	201.30
200	287.13	283.85

Using of SALINITY in salinity modeling in the rootzone

A crop –based model for salinity management- SALINITY- was tested using data from the experiment for millet crop. SALINITY model simulation is shown in Fig. 3. General trend of ECe values increased with increasing of soil depth. Although the overall trend was similar in both measured and predicted values, it is observed that predicted values were higher than measured values for the different salinity treatment. This could be attributed to that SALINTY model did not take

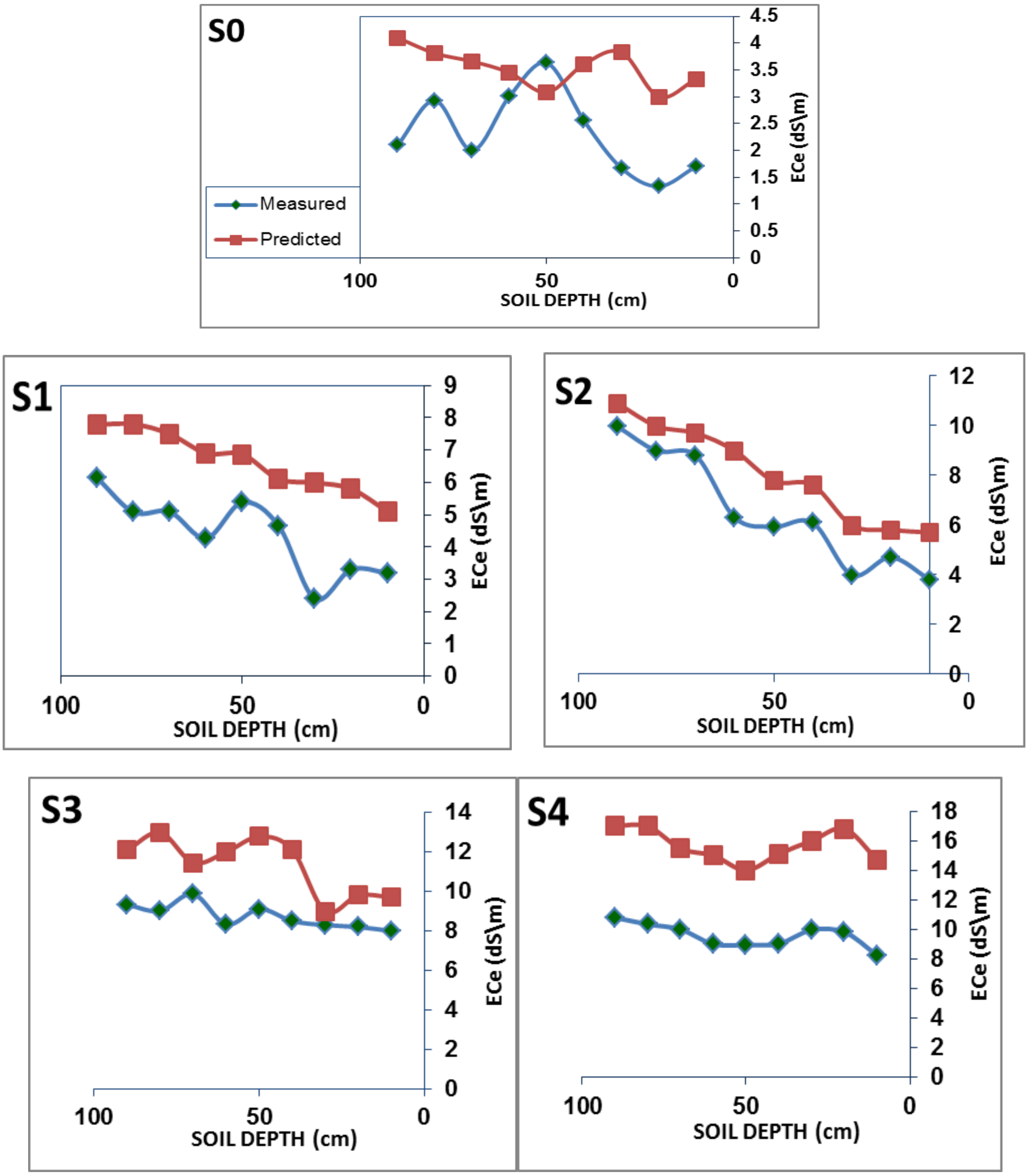

Fig. 3. Measured and simulated electrical conductivity of soil (ECe) after millet harvesting using SALINITY model for S1 (0 mM NaCl), S1(50 mM NaCl), S2(100 mM NaCl),S3 (150 mM NaCl) and S4 (200 mM).

Phytoremediation into consideration which led to higher predicted ECe values. These results indicate the need to extend SALINITY model with a routine, which takes into account the effects of phytoremediation.

IV. Discussion

Salt removal was increased as NaCl levels increased in soil. This could be attributed to leaching efficiency which enhanced in soil and led to remove salts through the rootzone. Millet is proved to be enhancing leaching of salts through its roots. Moreover, millet is a quick-growing summer forages or grain crop and the vegetative cover provided by the millet crop prevents capillary rise of which could lead to further salinization. Salt diffusion from micropores to macropores was accelerated by the high temperature at July and August, which led to be leached by irrigation water and continues downward movement at the end of the growing season. However, the results indicate substantial yield loss due to pre-cultivation salinity. To avoid such loss, Qadir et al (2006) recommended leaching before sewing. Another solution is to use multi-cuts for millet forages which showed very encouraging results and maximize the yield (Taha and Ismail 2008).

Accumulation of Na^+ salts by plants contributes to osmotic adjustment to increased external salinity. Krishnamurthy et al. (2007) stated that the millet salinity tolerance associated with increased K^+ and Na^+ content. Millet does not seem to be efficient excluder of Na^+ from the shoot. The mean of Na^+ concentration in the shoot was about three fold higher for 200 mmol L^{-1} than that observed under control. Many studies suggested that the harvest of aerial plant portion can contributed considerably to removal of salt (Zia, 2006).

V. Conclusion

Millet cropping in conjunction with leaching increases salt removal efficiency. Simulating salt removal during the amelioration process provides insight into understanding movement of salts in soils.

Modeling salt and water during phytoremediation is needed to submit new criteria of saline soil reclamation.

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