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PHYTOREMEDIATION OF SOIL SALINITY USING SALT HYPERACCUMULATOR PLANTS

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SUMMARY

Various salt hyperaccumulator plants collected from semi arid saline areas of North-West India - Haryana and Rajasthan like *Arundo donax, Atriplex nummularia, Atriplex lentiformis, Atriplex amnicola, Haloxylon recurvum, Heliotropium eichwaldi, Portulaca oleracea, Salsola baryosma, Suaeda fruticosa* and *Suaeda nudiflora* were found promising and shortlisted after extensive experimentation in the laboratory and screen house studies dealing with various salt hyperaccumulator characteristics like soil ECe and comparative total salt ion accumulation in the soil vis-à-vis above ground biomass. These were grown in salinity microplots using artificially saline soil of 8 and 16 dSm^{-1} of salinity. Various plant growth parameters like cumulative shoot length at the time of harvesting at vegetative stage, fresh / dry shoot biomass, ash content , total organic matter, total dissolved solids (TDS), phytoaccumulation of salt ions in above ground biomass, total salt ionic content left in the soil after harvesting, decrease in soil ECe per year, per cent remediation, salt accumulation in above ground biomass and deduced phytoremedaition of these potential salt hyperaccumulator plants were calculated. Our estimates showed that best salt hyperaccumulators were in the order of *Suaeda fruticosa, Suaeda nudiflora, Portulaca oleracea, Atriplex amnicola, Atriplex lentiformis* and *Haloxylon recurvum* which could phytoextract 32.72, 32.70, 29.04, 20.63, 20.58 and 18.11 kg salts ha^{-1} $year^{-1}$ at 8 dSm^{-1} and *Suaeda nudiflora, Portulaca oleracea, Suaeda fruticosa, Salsola baryosma, Haloxylon recurvum* and *Atriplex lentiformis* could accumulate 101.39,89.44,74.76,66.77,62.10 and 60.67 kg toxic salts ha^{-1} $year^{-1}$ in their above ground biomass at 16 dSm^{-1} of salinity, respectively. It is deduced that time taken for phytoremediation of soil salinity up to safe level of 2 dSm^{-1} was 1.66 to 2.37 years for 8 dSm^{-1} and it was 4.89 to 6 years for 16 dSm^{-1} of soil salinity

Key words: **Phytoremediation, salt hyperaccumulator, soil salinity**

INTRODUCTION

Phytoremediation is envisaged as a benign and cost effective plant based green technology that depends on the remarkable ability of some plants to extract and accumulate the toxic metals or ions in the above ground shoots of certain plants or remove or neutralize various other organic chemicals from soil or aqueous environment (Robinson *et al.* 1980, Salt *et al*. 1998, Yurtseven and Baran 2000, Parsad 2004). Phytoremediation technique is less costly, non-invasive and is an acceptable way to redress the removal of environmental contaminants (Schwitzguebel 2004). According to Salt *et al.* (1998), phytoextraction is a phytoremediation technique that exploits the unique ability of some plans to accumulate unusually high amount of chemicals/toxic metals including salt ions in their harvestable tissues. Although more emphasis is on

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phytoextraction which is one of the sub-sets of phytoremediation. However, there are few research studies with respect to phytoextraction of salts/ heavy metals (Zhao *et al.* 2004, Elizabeth 2005).

Increasing salinity of two important natural resources, i.e. underground water and soil is a major constraint afflicting crop production in arid and semi-arid regions especially in India (Garg and Gupta 1997). Salinity also affects primary productivity of our crops at the national and global level (Chinnusamy *et al.* 2005). The menace of ever expanding saline soils has been increasing although efforts have been undertaken from time to time to combat it through breeding for salt tolerance of crops, adopting various agronomic practices and also following different physiological, biochemical and biotechnological approaches (Sparks 1995, Burns *et al.* 1996), but with limited success. In recent years considerable diverse research efforts have been made in the use of plants to remove inorganic, organic and heavy metal contaminants from the soil (Kumar 1996, Chaney *et al.* 1997, Khan *et al.* 2000, Miyamoto *et al.* 2004, Suresh and Ravishanker 2004, Abbad *et al.* 2004). Accordingly, the present phytoremediation studies were undertaken with a view to develop a sustainable supplementary technology for desalinization of saline areas by the use of various salt hyperaccumulator plants using native flora so as to exactly quantify their soil salinity reclamation potential.

MATERIALS AND METHODS

The experiment was conducted in specially fabricated salinity microplots with transparent rain proof canopy at CCS Haryana Agricultural University farm area (Fig. 1). This setup had 20 microplots made up of leak proof reinforced concrete. Each microplot had the dimension, i.e. 1m length x 1m breadth x 1m depth. Each microplot was filled with bulk dune sand soil (Typic Torripsamments) weighing about 3000 kg. The soil was artificially salinized with two levels, i.e. 8 dSm^{-1} and 16 dSm^{-1} of Cl -dominated salinity (Fig. 2). This salinity was created by different salts like NaCl, $MgCl_2$, $MgSO_4$ and $CaCl_2$ using 1:1 Na:Ca+Mg ratio and 1:3 Ca:Mg ratio; where $Cl:SO_4$ ratio was 7:3 on milli equivalent basis (Fig. 3). This salinity is nearly akin to natural Cl -dominated salinity existing in this part of India. As the native nutrient status of the dune sand was almost nil, the salinity was superimposed on Arnon and Hoagland nutrient solution and poured in leak proof gravel based microplots (Fig. 3)on soil saturation percentage basis. Finally 25 seedlings/ saplings were grown of each of the 10 salt hyperaccumulator plants - *Arundo donax, Atriplex amnicola, Atriplex lentiformis, Atriplex nummularia, Haloxylon recurvum, Heliotropium eichwaldi,*

Fig. 1. The overview of salinity micro plots where the different salt hyper accumulator plants were grown

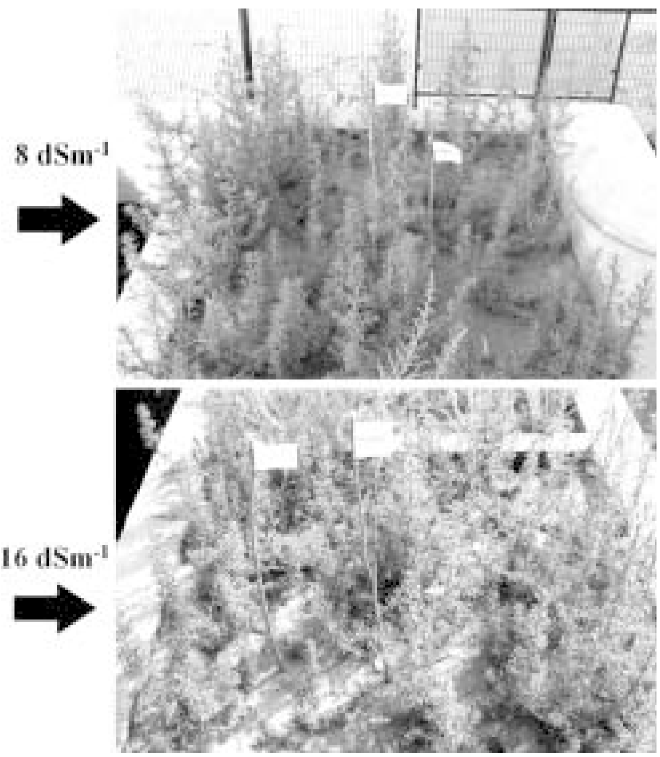

Fig. 2. *Suaeda nudiflora* growing at 8 and 16 dSm^{-1} salinity levels in microplots

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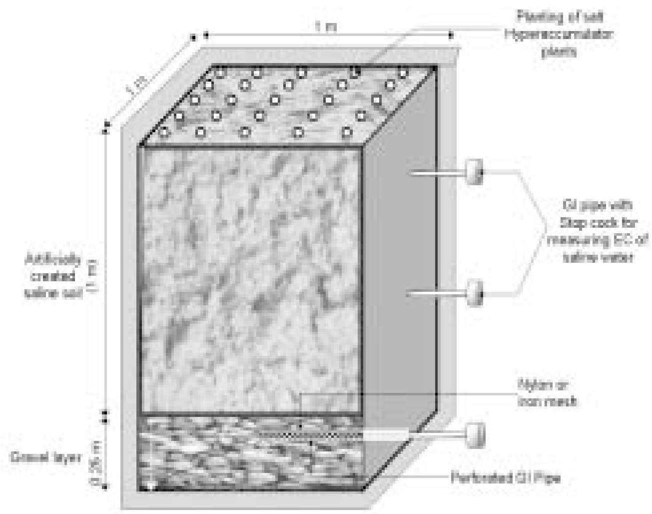

Fig. 3. A diagrammatic representation of a salinity micro-plot

Portulaca oleracea, Salsola baryosma, Suaeda fruticosa and *Suaeda nudiflora* in each of the 20 microplots with two completely randomized replications. Irrigation of plants whenever needed was done up to field capacity after measuring the moisture content in each salinity microplot. Half of the total water was poured from above and half through an outlet provided in each microplot a little above the base so that adequate salinity is maintained throughout the soil profile in the microplot. ECe of the soil in each microplot was monitored at regular intervals throughout the year.

This experiment was initiated in March, 2004 and the first harvesting was taken by cutting the whole shoot biomass little above the ground in the month of June. All these plants were capable of regeneration and so watering was continued and thus subsequent harvestings were done in October and again in February. Therefore, the data presented here is the mean of three harvestings of these salt hyperaccumulator plants from March 2004 to February 2005. The growth of these salt hyperaccumulator plants was quite subdued during winter season. Various growth parameters like cumulative shoot length at the time of harvesting (cm), fresh shoot biomass (g m^{-2}), total dissolved solids (g m^{-2}), phytoaccumulation of salt ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, $Cl^–$, $SO_4^{2–}$), total salt ionic content in soil left after harvesting of salt hyperaccumulator plants, decrease in soil ECe (dSm^{-1}) per year in a microplot, time taken for phytoremediation of soil salinity up to safe level of 2 dSm^{-1} salinity, per cent remediation, salt accumulation in above ground biomass (kg ha^{-1}), deduced phytoremediation of salt hyperaccumulator plants (kg of salts removed ha^{-1} $year^{-1}$) were done after pooling the results of three harvestings.

The contents of Na^+ and K^+ were determined by flame photometer. Ca^{2+} and Mg^{2+} were estimated by EDTA titration according to the method given in USDA, Handbook (1954). Chloride (Cl^-) was measured by the ion analyzer (Orion, USA) using chloride specific electrode and sulphate (SO_4^{2-}) was measured by turbidimetric method as suggested by Chesin and Yien (1950). Total dissolved solids (TDS) were determined by taking 1g dry weight of material of each plant in a conical flask and 100 ml of distilled water was added. The solution was boiled and filtered. The volume was made to 100 ml and TDS was recorded using a conductivity meter (Systronic-308). Ash content was measured by weighing the empty crucible and then added 1g of dry weight of material into the crucible. Heated the crucible with material in a muffle furnace at 550°C for 30 minutes. After cooling the crucible was weighed again to get the final weight. So ash content/g dry weight was equal to final weight – crucible weight. Electrical conductivity of soil saturation extract (ECe) was measured by using conductivity bridge and expressed as dS m^{-1} at 25°C.

RESULTS AND DISCUSSION

The cumulative mean shoot length (Table 1) was increased in all the salt hyperaccumulator plants with increase in salinity from 8-16 dSm^{-1}. The maximum enhancement was observed in *Atriplex* sp. It was followed by *Suaeda nudiflora, Heliotropium eishwaldi* and *Haloxylon recurvum*. However, least increase in height was observed in rest of the salt hyperaccumulator plants with increment in salinity. These results are in accord with the observations of Neales and Sharkey (1981) in *Disphyma australe* where an increase in growth, leaf number per plant and leaf fresh weight has been reported with the increment of salinity to a level of 200 mol m^{-3} NaCl. Ala *et al.* (1994) also found that plant growth, shoot volume and plant biomass was enhanced up to 10 dSm^{-1} but decreased at 20 dSm^{-1} of salinity.

Table 1. Effect of 8 and 16 dSm^{-1} of Cl -dominated salinity on cumulative shoot length, fresh/dry biomass, ash content and total organic matter in 10 salt hyperaccumulator plants grown in salinity microplots

Species	Cumulative shoot length at the time of harvetsing (cm)		Mean	Fresh shoot biomass (kg m^{-2})		Mean	Dry shoot biomass (kg m^{-2})		Mean	Ash content (g m^{-2})		Mean	Total organic matter (g m^{-2})		Mean
	8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}	
Arundo donax	71.49	73.29	**72.39**	5.50	6.30	**5.90**	1.73	2.00	**1.86**	182	215	**198.5**	1548	1785	**1666.5**
Atriplex amnicola	68.19	84.34	**76.26**	17.29	24.70	**21.00**	3.12	3.55	**3.34**	200	249	**224.5**	2920	3301	**3110.5**
Atriplex lentiformis	56.38	74.00	**65.19**	8.10	9.40	**8.75**	2.70	3.35	**3.03**	354	383	**368.5**	2346	2967	**2656.5**
Atriplex nummularia	72.58	103.13	**87.85**	15.40	9.40	**12.40**	2.55	2.00	**2.28**	377	372	**374.5**	2173	1628	**1900.5**
Haloxylon recurvum	32.16	37.69	**34.92**	9.84	19.37	**14.61**	1.93	4.06	**3.00**	316	330	**323**	1614	3730	**2672**
Heliotropium eichwaldi	64.58	72.41	**68.49**	33.11	26.60	**29.86**	4.51	3.40	**3.96**	484	472	**478**	4026	2928	**3477**
Portulaca oleracea	61.29	64.76	**63.02**	15.19	15.40	**15.30**	4.29	5.17	**4.74**	346	444	**395**	3944	4726	**4335**
Salsola baryosma	69.34	70.46	**69.90**	9.79	21.70	**15.74**	3.18	4.12	**3.65**	420	455	**437.5**	2760	3665	**3212.5**
Suaeda fruticosa	65.68	67.66	**66.67**	12.38	17.90	**15.14**	3.45	4.55	**4.00**	659	1073	**866**	2791	3477	**3134**
Suaeda nudiflora	84.00	93.58	**88.79**	14.90	18.40	**16.65**	4.21	5.88	**5.04**	771	808	**789.5**	3439	5072	**4255.5**
Mean	**64.57**	**74.13**	**69.35**	**13.11**	**16.92**	**15.31**	**3.17**	**3.25**	**3.21**	**410.9**	**480.1**	**445.5**	**2756.1**	**3327.9**	**3042**
CD at 5% level S= Species T= Treatment	*S = NS T = 6.038 &S x T= 8.368*			*S = 0.205, T = 0.415 &S x T= 2.200*			*S = 0.055, T = 0.100 &S x T= 0.300*			*S = 5.5, T = 6.5 &S x T= 8.4*			*S = 0.022, T = 0.049 &S x T= 0.070*		

Fresh and dry above ground shoot biomass increased with increase in salinity from 8-16 dSm-1 except in case of *Atriplex nummularia* and *Heliotropium eichwaldi* (Table 1). However, mean fresh shoot biomass was the highest in case of *Heliotropium eichwaldi* followed by *Atriplex amnicola*, *Suaeda nudiflora*, *Salsola baryosma*, *Portulaca oleracea* and *Suaeda fruticosa*. Likewise, the mean shoot dry biomass was highest in *Suaeda nudiflora*, *Portulaca oleracea* and *Suaeda fruticosa*. However, it was lowest in *Arundo donax*, *Atriplex nummularia* and *Haloxylon recurvum*. It may be observed that the magnitude of differences between fresh and dry weight was the highest in *Heliotropium eichwaldi*. Comparison between the means of fresh and dry weight results, reveals that *Arundo donax* registered the least shoot fresh and dry biomass and it was consistently on the higher side in case of *Suaeda nudiflora*. These results are in agreement with Cherian *et al*. (1999) who observed increase in growth, total fresh and dry mass in some halophytes with increase in salinity. Even, Cherian and Reddy (2000) reported similar behaviour in *Suaeda nudiflora*. Likewise, Khan *et al.* (2000 a, b, c) also observed increase in growth and dry mass with increasing salinity in *Atriplex griffithi*, *Suaeda fruticosa* and *Haloxylon recurvum* from 360-400 mol m^{-3} NaCl, but decreased at higher salinity. On the contrary, Rao *et al.* (1999) observed a decline in total plant biomass, root length and number of multiple shoots with increase in salinity from 25-35 to 45-55 dS m^{-1} in *Salvadora persica*.

Ash content: Ash content increased in most of the salt hyperaccumulators with enhancement of salinity from 8 to 16 dSm-1 except *Atriplex nummularia* and *Heliotropium eichwaldi* (Table 1). The mean ash content was in the order *Suaeda fruticosa* > S. *nudiflora* > *Heliotropium eichwaldi* > *Salsola baryosma* > *Portulaca oleracea* > *Atriplex nummularia* > *Atriplex lentiformis*. The least mean ash content was observed *in Arundo donax* followed by *Atriplex amnicola* and *Haloxylon recurvum*. The above results corroborate the findings of Joshi (1982) who advocated that ash content in *Salicornia brachiata* mainly consisted of Na^+ and Cl^- and it had direct correlation with increased salt accumulation. Likewise, considerable high ash content was found in *Suaeda nudiflora* and *Salicornia brachiata* as a result of excessive accumulation of salts. In the present study also this contention proved logical as both *Suaeda fruticosa* and *Suaeda nudiflora* registered highest ash content as well as phytoaccumulation of salt ions (Tables 1 and 2) at both 8 and 16 dS m^{-1} salinity levels. Similarly, Waisel and Ovadia (1972) also reported 34 to 43% ash in *Suaeda monoica*, while Chaudhari *et al.* (1964) found 41.2% ash in *Suaeda fruticosa* dry biomass. This was also found true for many species of *Salicornia* (Kabanov and Otegenov 1973, Gorham and Gorham 1975).

Total organic matter: The total organic matter was enhanced with increment of salinity from 8 to 16 dSm^{-1} in all the salt hyperaccumulator plants under investigation except *Atriplex nummularia* and *Heliotropium eichwaldi* (Table 1). The mean organic matter was the highest in *Portulaca oleracea* followed by *Suaeda nudiflora, Atriplex amnicola, Heliotropium eichwaldi, Salsola baryosma, Sueda fruticosa, Atriplex amnicola and Haloxylon recurvum*. The least mean organic matter was found in *Arundo donax* and *Atriplex nummularia*. These results go hand in hand with Kolchevskii *et al.* (1995) who studied 14 species of C_3 and C_4 plants and resolved that the ash content was higher under increasing soil salinity. Ala *et al.* (1994) showed that the ash content of plants increased with concomitant decrease in organic matter content under salinity in comparison to control in *Atriplex amnicola*. Exactly similar report was given by Miyamoto *et al.* (1996) who have reported higher ash content under salinity in *Atriplex nummularia, Distichlis palnaeri, Batis maritima* and *Suaeda esteroa*. The ash content of plants increased and the organic content of plants was significantly reduced with the increment of salinity in *Suaeda fruticosa, Atriplex griffithi* var. *Stocksii* (Khan *et al.* 2000 a,b,c) and in *Salicornia herbacea* (Shimizu *et al.* 2003) as well. Gonzalez *et al.* (2005) studied that the total solute concentration in plants increased with salinity and this was mainly due to increase in the amount of internal inorganic ions in a salt tolerant halophyte *Cynara cardunculus*.

Total dissolved solids (TDS): The data presented in Table 2 clearly depicted that total dissolved solids (representing organic as well as inorganic components of plant dry material) increased with enhancement of salinity from 8-16 dSm^{-1} in all the potential salt hyperaccumulator plants except *Heliotropium eichwaldi*. In fact, TDS varied in the order of *Suaeda fruticosa > S. nudiflora > Salsola baryosma > Portulaca oleracea > Atriplex lentiformis > Haloxylon recurvum > Atriplex nummularia >A. amnicola*. However, *Arundo donax* followed by *Heliotropium eichwaldi* possessed the lowest TDS amongst all the potential salt hyperaccumulator plants. These results are in conformity with Gonzalez *et al.* (2005) who have found that total solute concentration in plants increased with salinity and this was mainly due to increase in the amount of internal inorganic ions in a salt tolerant halophyte *Cynara cardunculus*. These results indirectly correlated to soil-water habitat characteristics of these plants, plant tissue water and osmotic potentials and total soluble salts in the soil and in the plant tissue (Rao and Agarwal 1964, 1966, Rao *et al.* 1966)

Phytoaccumulation of salt ions in above ground biomass of plants: The total phytoaccumulation of salt ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}) in the above ground biomass in salt hyperaccumulator plants was increased 2 to 3 folds at 16 dS m^{-1} in comparision to 8 dS m^{-1} of salinity level (Table 2). Interestingly, the magnitude of phytoacccumulation was observed in the order *Suaeda nudiflora > Suaeda fruticosa > Portulaca oleracea > Salsola baryosma > Atriplex lentiformis > Atriplex amnicola > Haloxylon recurvum*. The least accumulation was observed in *Atriplex nummularia* followed by *Arundo donax* and *Heliotropium eichwaldi*. These results are in consonance with Aslam *et al.* (1979) in *Diplachne fusca*, where an increase in Na^+ and decrease in K^+, Ca^{2+}, Mg^{2+} contents was observed with increasing salinity. Khan *et al.* (2000 a,b,c) in *Atriplex griffithi, Suaeda fruticosa* and *Haloxylon recurvum* showed similar results in the sense that the Na^+ and Cl^- contents in both shoots and roots was enhanced with increase in salinity, but Ca^{2+}, K^+ and Mg^{2+} content was declined with increasing salinity. Similar results were also reported by Mahmood *et al.* (1996) in *Suaeda fruticosa, Kochia indica, Atriplex crassifolia, Sporobolus arabicus, Cyanodon dactylon, Polypogon monspeliensis* and *Desmostachya bipinnata*. Maggio *et al.* (2000) revealed that most of Na^+ concentration was centered in the leaves of *Salvadora persica* under salinity and it was 40 fold greater than the non-salinized controls with significant reduction in leaf K^+ and Ca^{2+} concentrations.

Table 2. Effect of 8 and 16 dSm^{-1} of Cl -dominated salinity on total dissolved solids (TDS), phytoaccumulation of salt ions and decrease in soil ECe per year in 10 salt hyperaccumulator plants grown in salinity microplots

Species	Total dissolved solids (TDS) (g m^{-2} shoot biomass)		Mean	Phytoaccumulation of salt ions in above ground biomass of plants (g m^{-2})		Mean	Total salt ion content left in soil after harvesting of salt hyperaccumulator plants (g kg^{-1} soil)		Mean	Decrease in soil ECe per year (dSm^{-1}) in a microplot		Mean
	8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}	
Arundo donax	6.816	10.00	**8.408**	693.55	2181.58	**1437.57**	6.38	15.76	**11.07**	2.24	2.40	**2.32**
Atriplex amnicola	11.793	16.827	**14.310**	1275.92	3783.26	**2519.74**	6.23	15.16	**10.70**	2.35	2.44	**2.39**
Atriplex lentiformis	19.278	31.825	**25.551**	1372.12	4045.03	**2708.57**	6.48	15.53	**11.00**	2.64	2.52	**2.58**
Atriplex nummularia	19.150	16.060	**17.605**	881.74	1753.33	**1317.54**	6.48	15.65	**11.06**	2.73	2.65	**2.69**
Haloxylon recurvum	14.166	34.144	**24.155**	1207.70	4140.08	**2473.89**	5.37	15.57	**10.47**	3.13	2.31	**2.72**
Heliotropium eichwaldi	12.943	8.160	**10.551**	1119.73	3228.10	**2173.92**	6.52	15.87	**11.20**	2.23	2.31	**2.27**
Portulaca oleracea	24.152	35.776	**29.964**	1936.45	5963.21	**3949.84**	6.46	15.54	**11.00**	2.50	2.65	**2.57**
Salsola baryosma	52.566	29.375	**40.970**	1519.78	4451.53	**2985.66**	6.35	15.26	**10.81**	2.19	2.35	**2.27**
Suaeda fruticosa	30.577	83.392	**56.979**	2181.55	4984.03	**3976.42**	6.18	15.20	**10.69**	2.55	2.86	**2.70**
Suaeda nudiflora	26.902	60.975	**43.938**	2180.11	6759.72	**4469.92**	6.20	15.32	**10.76**	2.35	2.35	**2.35**
Mean	**21.834**	**32.653**	**27.243**	**1354.90**	**4128.99**	**5483.89**	**6.29**	**15.49**	**10.88**	**2.49**	**2.48**	**2.48**
CD at 5% leve S= Species T= Treatment	*S = 0.020, T = 0.039 & S x T= 0.058*			*S = 0.126, T = 0.174 & S x T= 0.210*			*S = 0.19, T = 0.32 & S x T= 0.52*			*S = 0.012 T = 0.014 & S x T= 0.026*		

Salt ion content left in soil after harvesting of salt hyper accumulator plants: Salts left in the soil after harvesting of salt hyperaccumulator plants decreased more by *Haloxylon recurvum, Sueda fruiticosa* and *Suaeda nudiflora* at 8 dSm^{-1} of salinity and by *Atriplex amnicola*, *Salsola baryosma*, *Suaeda fruticosa* and *Suaeda nudiflora* at 16 dSm^{-1} of salinity (Table 2). This indirectly proves that these salt hyperaccumulators must be quenching more salts from the soil. This was also apparent from the cumulative means of the two salinity levels as well. It was in the order of *Haloxylon recurvum> Suaeda fruticosa> Atriplex amnicola> Suaeda nudiflora>Salsola baryosma> Atriplex lentiformis*. These results are in confirmation with Villers *et al*. (1995) who observed that *Atriplex semibaccata* also had salt leaching characteristics from soil. Similarly *Atriplex lentiformis* was shown to improve soil properties like EC, pH and organic matter under saline conditions (Arya *et al.* 1996, 1998).

Efficacy of removal of salt ions by salt hyperaccumulator plants: Salt hyper accumulation by different plants also caused a concomitant decrease in ECe of the soil in a microplot / year (Table 3). At 8 dSm^{-1}, there was a significant reduction in the ECe of the soil in the order of *Haloxylon recurvum> Atriplex nummularia > Atriplex lentiformis > Suaeda fruticosa > Portulaca oleracea > Suaeda nudiflora=Atriplex amnicola*. The least decrease in soil ECe per year was found by *Salsola baryosma* followed by *Arundo donax* and *Heliotropium eichwaldi*. On the other hand at 16 dSm^{-1} of salinity the decrease in ECe per year was prominently more by *Suaeda fruticosa* followed by *Atriplex nummularia*, *Portulaca oleracia* and *Atriplex lentiformis*. The least decrease was accomplished with *Heliotropium eichwaldi, Haloxylon recurvum, Salsola baryosma* and *S. nudiflora*.

The time taken for phytoextraction of salts by these salt hyperaccumulators to bring down soil salinity up to the safe critical limit of 2 dSm^{-1} was computed. It was least (1.66 to 2.21 years) by plants like *Haloxylon recurvum, Atriplex nummularia, Atriplex lentiformis, Suaeda fruticosa, Portulaca oleracea, Suaeda*

Table 3. Effect of 8 and 16 dSm^{-1} of Cl - dominated salinity on time taken for phytoremediation of soil salinity, percent remediation and total deduced phytoremediation of 10 salt hyperaccumulator plants grown in salinity microplots

Species	Time taken calculated (years) for phytoremediation of soil salinity up to safe limit of 2 dSm^{-1}		Mean	Percent remediation per year		Mean	Total deduced phytoremediation of salt hyperaccumulator plants (kg ha^{-1} year^{-1})		Mean
	8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}		8dSm^{-1}	16dSm^{-1}	
Arundo donax	2.32	5.36	**3.84**	18.60	15.80	**17.20**	10.395	32.722	**21.55**
Atriplex amnicola	2.21	5.73	**3.97**	16.38	20.33	**18.35**	20.638	56.746	**38.69**
Atriplex lentiformis	1.96	5.55	**3.75**	18.76	20.53	**19.64**	20.580	60.675	**40.62**
Atriplex nummularia	1.90	5.28	**3.59**	20.08	22.39	**21.23**	13.225	26.299	**19.76**
Haloxylon recurvum	1.66	6.06	**3.86**	14.96	17.13	**16.04**	18.115	62.100	**40.10**
Heliotropium eichwaldi	2.33	6.06	**4.19**	13.60	13.78	**13.69**	16.795	48.420	**32.60**
Portulaca oleracea	2.08	5.28	**3.68**	14.72	18.56	**16.64**	29.046	89.446	**59.24**
Salsola baryosma	2.37	5.97	**4.17**	16.77	14.65	**15.71**	22.795	66.771	**44.78**
Suaeda fruticosa	2.03	4.89	**3.46**	15.28	13.26	**14.27**	32.722	74.760	**53.74**
Suaeda nudiflora	2.21	5.95	**4.08**	15.12	17.35	**16.23**	32.701	101.395	**67.04**
Mean	**2.10**	**5.61**	**3.86**	**14.41**	**17.54**	**16.90**	**21.701**	**61.933**	**41.81**
CD at 5% level S= Species T= Treatment	*S = 0.09, T = 0.08 & S x T= 0.13*			*S = 0.037, T = 0.082 & S x T= 0.117*			*S = 0.124, T = 0.136 & S x T= 0.238*		

nudiflora and Atriplex amnicola at 8 dS m^{-1} of salinity. On the other hand at 16 dS m^{-1} of salinity it was phytoremediated to a safe limit in 4.89 to 5.95 years by plants like *Suaeda fruticosa, Portulaca oleracea, Atriplex nummularia, Arundo donax, Atriplex lentiformis, Atriplex amnicola* and *Suaeda nudiflora.* Conversely, more number of years (6.06 years) were taken to remediate soil salinity by *Haloxylon recurvum* and *Heliotropium eichwaldi* (Table 3).

It is noteworthy that *Arundo donax* (Family-Poaceae) possessed low biomass, ash content, total organic matter, TDS, phytoaccumulation of salt ions and total deduced phytoremediation of soil salinity (Table 1,2,&3). *Heliotropium eichwaldi* (Family Boraginaceae) despite having high biomass on saline soils (Table 1), proved to be poor phytoremediators of salinity because of the low level of salt hyperaccumulation (Table 2 and 3) and high amount of water content as apparent from comparison of fresh/dry biomass (data not given). In contrast to this, plant species like *Portulaca oleracea* (Family Portulacaceae) having sub-terranean habit registered high salt hyperaccumulation per unit dry biomass (Table 1 and 2) and therefore proved to be equally effective in terms of per cent remediation and total deduced phytoremediation of soil salinity per year (Table 3). Furthermore, species like *Suaeda fruticosa, Suaeda nudiflora, Salsola baryosma, Haloxylon recurvum, Atriplex lentiformis* and *Atriplex amnicola* (Family- Chenopodiaceae) were not only best salt hyperaccumulators (Table 2 and 3), but also in general had high biomass (Table 1). These plant species have the primary potential of desalination of saline soil from 16 dS m^{-1} to 2 dS m^{-1} in 4.89 to 6.06 years.

Our aforementioned results are in conjunction with Arya *et al.* (1996, 1998) that *Atriplex lentiformis* improved soil properties like EC, pH and organic matter under saline conditions. Sen and Rajpurohit (1982) and Rajpurohit and Sen (1991) have observed that hair and salt bladders in *Atriplex halocarpa*, *Atriplex hortensis* and *Atriplex vesicaria* accumulate salt ions from the soil against the concentration gradient. Mahmood *et al.* (1996) and Khan *et al.* (2000 a, b, c) have also advocated the use of plants like *Suaeda fruticosa*, *Atriplex nummularia* and *Atriplex stocksii* for enhancing productivity of degraded saline wasteland by using these as pasture fodder plants. Even a field level study in saline lands of Pakistan showed that *Suaeda fruticosa* could remove 2646 kg ha^{-1} NaCl in a year (Chaudhary *et al.* 1964) . Likewise, *Suaeda nudiflora* has also been used as a substitute vegetable crop in some areas in India (Cherian and Reddy, 2000, 2003). In the same way *Salvadora persica* occurred in saline black soil which could be used for phytoreclamation in unfavorable land (Rao *et al.* 1999, Maggio *et al.*2000). Dahiya *et al.* (1993) advocated the use of rhodes grass (*Chloris gayana*), guinea grass (*Panicum maximum*), paragrass (*Bracharia mutica*), *Panicum leavifolium* and *Sesbania sesquens* (Dhaincha) for desalinization and detoxification of saline wastelands of Haryana. Various research workers used seven Moroccan provenances of *Atriplex halimus* for restoration and rehabilitation of saline degraded lands (Abbad *et al.* 2004). Kumar (1988, 1996) and Suman (2005) also used forage grasses like *Brachiaria mutica, Leptochloa fusca, Setaria sphacelata, Chloris gayana, Sorghum sudanensis, Panicum laevifolium, P. antidotale* and *P. maxima* and *Cyanodon maritimus* to ameliorate salt and alkaline-affected soils.

Conclusively, the total deduced phytoremediation or efficacy of removal of salt ions by these salt hyperaccumulator plants in terms of kg of salts removed ha^{-1} $year^{-1}$ was 32.72, 32.70, 29.04, 20.63, 20.58 and 18.11 by *Suaeda fruticosa, Suaeda nudiflora, Portulaca oleracea, Atriplex amnicola, Atriplex lentiformis* and *Haloxylon recurvum* at 8 dS m^{-1} of salinity, respectively. Whereas at 16 dS m^{-1} of salinity salt hyperaccumulator plants like *Suaeda nudiflora, Portulaca oleracea, Suaeda fruticosa, Salsola baryosma, Haloxylon recurvum* and *Atriplex lentiformis* could phytoextract 101.4, 89.5, 74.8, 66.8, 62.1 and 60.7 kg salts ha^{-1} $year^{-1}$, respectively. Efforts are on to extend these studies to field condition.

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