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ORIGINAL ARTICLE

POTENTIALITY OF *SUAEDA MONOICA* FORSK. A SALT MARSH HALOPHYTE ON BIOACCUMULATION OF HEAVY METALS FROM TANNERY EFFLUENT

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ABSTRACT

This study evaluated the tolerance and bioaccumulation potential of *Suaeda monoica* on heavy metals from tannery effluent. A pot culture experiment was made to investigated the impact of tannery effluent and salt on physiology and bioaccumulation of heavy metals and salts from tannery effluent. From the results it is demonstrated that *Suaeda monoica* showed hyper tolerance to heavy metals and salts. It is estimated from the results, that from 1 kg dry weight of plant sample *Suaeda monoica* accumulated heavy metals such as Chromium - 40.89 mg/kg, Cadmium - 17.50 mg/kg, Copper - 29.2 mg/kg and Zinc - 60.20 mg/kg and NaCl - 194.83 mg/g from tannery effluent treated soil when compared to NaCl treated soil and control. The result of this study revealed that *Suaeda monoica* is a salt marsh halophyte which represents a valuable tool in the restoration of heavy metals from tannery effluent polluted soil.

Key words: Halophyte, Tannery effluent, *Suaeda monoica*, NaCl, Heavy metals, Bioaccumualtion.

1. INTRODUCTION

Tannery industry is common in many parts of the world and it pollutes groundwater and ecosystems. Leather tanning industries have cropped up in India over the past three decades. Nearly 2161 tanneries are located in India and spread across the states of Tamil Nadu, West Bengal, Maharashtra, Punjab, Karnataka, Andhra Pradesh, Bihar and Uttar Pradesh. At present more than 568 tanneries well established in Dindigul, Erode and Vellore districts of Tamil Nadu (Murali and Rajan, 2012). Tamil Nadu accounts for almost 70 per cent of country's tanning capacity, 6 per cent of the global leather requirements and is the largest exporter of leather in the country. The value added products constitute about 80 per cent of the local exports of the industry (Vision Tamil Nadu, 2011).

Contamination of agricultural soil by heavy metals has become a serious environmental concern due to their mostly negative impact on crop growth and ecosystems (Zhang *et al* 2013). Such toxic elements are considered to be soil and water pollutants due to their widespread occurrence, and their acute and chronic toxic effect on plants grown in such soils as well as on humans living in their surrounding (Yadav, 2010). All heavy metals can be toxic when present above threshold concentrations.

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Cleanup of heavy metal contaminated soils is ulmost necessary in order to minimize their impact on the ecosystems. This is a challenging job with respect to cost and technical complexity (Barcelo *et al* 1986). So far different physical, chemical and biological approaches have been employed for this purpose. The conventional remediation methods include *in situ* vitrification, soil incineration, excavation and landfill, soil washing, soil flushing, solidification, and stabilization of electro-kinetic systems (Wuana and Okieimen, 2011). Generally, the physical and chemical methods suffer from limitations like high cost, intensive labor, irreversible changes in soil properties and disturbance of native soil microflora. Chemical methods can also create secondary pollution problems.

Besides heavy metals salinity is also one of the rising problems causing tremendous yield losses in many regions of the world especially in arid and semiarid regions. To maximize crop productivity, these areas should be brought under utilization where there are options for removing salinity or using the salt-tolerant crops. Use of salt-tolerant crops does not remove the salt and hence halophytes that have capacity to accumulate and exclude the salt can be an effective way.

A more efficient performance of several basic biochemical tolerance mechanisms provides an advantage to halophytes with respect to several environmental factors including heavy metals. Therefore, halophytes have been suggested to be naturally better adapted to cope with environmental stresses, such as heavy metals compared to salt-sensitive crop plants commonly chosen for phytoremediation purposes, and thus offer a greater potential of phytoremediation research for decontamination of heavy metal polluted soils. Research findings suggest that halophytes are ideal candidates for phytoextraction, phytostabilization, or phytoexcretion of heavy metal polluted saline and non-saline soils, while recent findings encourage the use of salt-accumulating halophytes for soil desalination in arid and semiarid regions (Manousaki and Kalogerakis, 2011).

The objective of the present study is to utilizing salt accumulating halophyte *Suaeda monoica* Forsk. to assess the feasibility of heavy metal and salt bio accumulation for restoration of heavy metal and salt from tannery effluent as an alternative method to other leaching techniques.

2. MATERIALS AND METHODS

Selection of species

Fast growing salt marsh halophyte *Suaeda monoica* Forsk. was selected for bioaccumulation of heavy metals and salts. *Suaeda monoica* is a pure halophyte, similar to *Suaeda maritima* in appearance growing in hyper saline soils and its distribution is also limited.

Experimental site

The experimental site was located at Anichampalayam village, Villupuram District (11° 55' N and 79° 32' E) of Tamil Nadu, India. The field experiments were conducted from January 2012 – June 2012. The experimental area received an average annual rainfall of 135.6cm spread over the year. Temperature ranged from a summer maximum of 33.26 ºC to a winter 29.68 °C.

Collection of the tannery effluent

The effluent samples were collected from the tannery industry situated at Chrompett near Chennai in clean plastic cans and stored at 4^0C for the analysis. The effluent was directly collected from the outlet of the industry.

Plant collection

Suaeda monoica plants were collected from the Pichavaram mangrove forest located between Vellar and Coleroon estuaries (latitude $11^0$22' N- $11^0$30' and longitude $79^0$45' E- $79^0$52') in Cuddalore District of Tamil Nadu, South India.

Design of the experiment

Red soil and sand (3:1 ratio) free from pebbles and stones were filled in polythene bags. The seedlings with similar size were transplanted from the nursery bed and planted at the experimental field.

The experiment comprised of the following three sets of treatments with five replicates and average values are reported.

1. Control- Without any treatment.
2. Salt treatment- Halophytes were treated with optimal level of NaCl for 4 times with a gap of 12 days.
3. Effluent treatment- Halophytes were treated with 250 ml of 75% tannery effluent for 4 times with a gap of 12 days.

The experiment was conducted for a period of 6 months (January to June- 2012) and it took place in an open-air area with natural light, temperature and humidity, to keep the plants under conditions as similar as possible to those the field. With the use of a plastic cover, care was taken no to let the plants to rained on, in order to avoid having any secreted heavy metals and ions washed away. Plants were watered every 2-3 days, depending on the evaporative demand, with approximately 200 ml of tap water. Care was taken not to prevent leaching of heavy metals and ions/salts from the polythene bags. Physical and chemical characteristic of tannery effluent, soil and halophytes are determined before planting and harvesting. Plant samples are harvested for experimental purpose at an intervals of 25, 50, 75, 100 and 125 days.

Physico-Chemical characteristic of experimental site

Analysis of physico-chemical characteristics of the tannery effluent is shown in table 1. Physico-chemical characteristics of soil treated with salt and tannery effluent are given in the table 2.

Measurement of EC and pH of the soil sample

The soil samples from 0-30 cm depth were collected from the experimental field for soil analysis. Soil samples were also taken at 0 day and 30 days intervals up to 120 days from the individual plots. These soil samples were dried and powdered gently with wooden wallet and passed through 2 mm sieve. The sieved soil samples were then taken up for analysis. The EC and pH was estimated by using the method of Jackson (1973).

Measurement of EC, pH of the plant sample

Five gram of fresh plant samples were ground in mortar and pestle by using water (1:3) and then filtered through cheese cloth. This crude extract was used to determine the EC in Elico EC meter and pH was measured in Elico pH meter.

Measurement of Sodium and Chloride (soil and plants) and SAR

The mature and fully developed leaves were detached from the twigs and surface dust was washed with distilled water and blotted dry. The mid-ribs were removed and laminae were oven dried at 80 °C and ground well and used for acid digestion. Plant sodium content was estimated by following the method of Williams and Twine (1960). Plant chloride content was estimated by following the method of Krishnamoorthy and Bhagwat (1990). Soil sodium content was measured by the method of Stanford and English (1949). Soil chloride content was measured by the method of Jakson (1973). SAR for soil was determined by the method of Richards (1954).

Measurement of chromium, cadmium, copper and zinc

Chromium, cadmium, copper and zinc from soil and plants were measured by the following the method of Lindsay and Norvell (1978).

Bioaccumulation of heavy metals and salts

The quantity of heavy metals and salts removed from the soil is based on the formula.
Total accumulation of heavy metal / salt =
Total biomass × 1 gm biomass accumulated heavy metals / salts

Statistical analysis

The experimental data were processed statistically by adapting the technique of analysis the variance of Standard Deviation (Snedecor and Cochran, 1967).

4.RESULTS

EC and pH of soil and plant samples

The level of EC and pH of the soil and plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil are presented in the table 3. In the present study, EC was reduced from 5.25 to 2.19 dSm^{-1} in *Suaeda monoica* cultivated in tannery effluent treated soil when compared to salt treated soil (from 4.28 to 2.10 dSm^{-1}) after 125 days of cultivation and correspondingly EC was increased from 4.25 to 8.75 dSm^{-1} in tannery effluent treated soil when compared to salt treated soil (from 4.19 to 8.44 dSm^{-1}).

Table 1. Physico-chemical characteristics of Tannery effluent

S. No	Parameters	Raw Effluent	BIS LIMITS IS 2490-2009
1.	Colour	Brown	-
2.	Odour	Offensive	-
3.	Turbidity	Turbid	-
4.	pH	10.7	5.5-9.0
5.	Electrical Conductivity (dSm^{-1})	4.99	
6.	Total hardness	568.00	100
7.	Total dissolved solids (mg/l)	3432.00	2100
8.	Total suspended solids (mg/l)	1589.00	100
9.	Alkalinity	1350.00	NM
10.	Biological Oxygen Demand	699	30
11.	Sodium (meq/l)	89.20	NM
12.	Chloride (meq/l)	54.63	NM
13.	Potassium (meq/l)	8.72	NM
14.	Calcium (meq/l)	9.90	NM
15.	Magnesium (meq/l)	10.88	NM
16.	Chromium (mg/l)	142.40	2.0
17.	Cadmium (mg/l)	28.2	2.0
18.	Copper (mg/l)	78.96	NM
19.	Zinc (mg/l)	212.90	1.0

NM- Not mentioned

In the present study from table 3, it was also noticed that pH was gradually declined in tannery effluent and salt treated soil. The pH was reduced from 8.3 to 7.10 (-14.4% reduction) in tannery effluent treated soil when compared to salt treated soil 7.7 to 6.85 (-11.03% reduction). Similar to plant EC, the pH of the plant sample was also increased from 6.80 to 9.40 (38.20%) in tannery effluent treated soil when compared to salt treated plants after 125 days of cultivation.

Table 3: EC and pH of the soil and plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S.No	Parameters	Salt treated soil	Tannery effluent treated soil
1.	pH	7.7	8.3
2.	Electrical Conductivity (dSm^{-1})	4.48	5.25
3.	Sodium (meq/l)	45.88	48.00
4.	Potassium (meq/l)	6.82	7.16
5.	Chloride (meq/l)	39.00	43.00
6.	Calcium (meq/l)	7.94	8.17
7.	Magnesium (meq/l)	8.13	8.88
8.	Chromium (mg kg^{-1})	4.80	82.00
9.	Cadmium (mg kg^{-1})	5.00	23.88
10.	Copper (mg kg^{-1})	18.19	54.90
11.	Zinc (mg kg^{-1})	26.00	55.00

Sodium, chloride in soil and SAR

The data on the bioaccumulation of sodium and chloride content of the soil sample and SAR content given are in table 4. Simultaneous reduction in plant sample was noticed up to 125 days of cultivation period and however maximum reduction in sodium and chloride content in soil was observed between 75-100 days. The highest reduction in sodium (-71.8%) and chloride (-53.4%) was noticed in tannery effluent treated soil when compared salt treated soil in sodium (-53.4%) and in chloride (-41.2%). SAR content was reduced from 16.44 to 7.70 meq/lit (-53.04% reduction) in *Suaeda monoica* cultivated in tannery effluent treated soil and from 16.18 to 7.80 meq/lit (-51.55% reduction) in salt treated soil.

Sodium and Chloride in plant samples

Table 5, shows the accumulation of sodium content in leaf, stem and root of *Suaeda monoica* cultivated in tannery effluent and salt treated soil. Leaves accumulated highest sodium content (350.2%) which is followed by stem (250.96%) and root (112%) when compared to salt treated soil (Leaf 304.96%, stem 220% and root 101% respectively) after 125 days of cultivation. Maximum accumulation was noticed from 75-100 days development.
Results of the study also indicated that chloride content was increased in *Suaeda monoica* cultivated in tannery effluent and salt treated soil and results are presented in table 6. Similar to sodium the maximum chloride accumulation was observed in *Suaeda monoica* cultivated in tannery effluent treated soil (Leaf 265.1%, stem 213.6% and root 120.8% respectively) when compared to salt treated soil (Leaf 230%, stem 190% and root 110% respectively).

Chromium, cadmium, copper and zinc content of soil and plant samples

Chromium, cadmium, copper and zinc content present in soil were gradually declined in tannery effluent and salt treated soil after 125 days of cultivation (Table. 7). Simultaneous increase in plant sample was noticed up to 125 days of cultivation period and maximum reduction in soil was

Table 3: EC and pH of the soil and plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S. No	Days	Soil EC (dSm^{-1})		Plant EC (dSm^{-1})		Soil pH		Plant pH	
		Salt	Effluent	Salt	Effluent	Salt	Effluent	Salt	Effluent
1.	0	4.28±0.21	5.25±0.26	4.19±0.20	4.25±0.21	7.70±0.38	8.30±0.41	6.57±0.32	6.80±0.34
2.	25	4.13±0.20	4.87±0.24	4.49±0.22	4.65±0.23	7.65±0.38	8.19±0.40	6.75±0.33	7.00±0.35
3.	50	3.92±0.19	4.42±0.22	5.28±0.26	5.44±0.27	7.44±0.37	7.99±0.39	7.14±0.35	7.41±0.37
4.	75	3.30±0.16	3.53±0.17	6.47±0.32	6.66±0.33	7.12±0.35	7.65±0.38	7.58±0.37	7.96±0.39
5.	100	2.18±0.10	2.30±0.11	8.14±0.40	8.37±0.41	6.88±0.34	7.14±0.35	8.72±0.43	9.24±0.46
6.	125	2.10±0.10	2.19±0.10	8.44±0.42	8.75±0.43	6.85±0.34	7.10±0.35	8.90±0.44	9.40±0.47

Table 4: Sodium and chloride content of soil and SAR content of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S. No	Days	Soil sodium (meq/lit)		Soil chloride (meq/lit)		Soil SAR (meq/lit)	
		Salt	Effluent	Salt	Effluent	Salt	Effluent
1.	0	45.8±2.29	48.0±2.40	39.0±1.95	43.0±2.15	16.1±0.80	16.4±0.82
2.	25	44.7±2.23	45.4±2.27	37.8±1.89	39.7±1.98	16.0±0.80	16.1±0.80
3.	50	40.4±2.02	40.6±2.03	35.9±1.79	35.3±1.76	15.1±0.75	15.2±0.76
4.	75	32.1±1.60	30.4±1.52	33.4±1.67	27.9±1.39	12.5±0.62	12.0±0.64
5.	100	20.1±1.00	14.3±0.71	26.8±1.34	18.1±0.90	8.4±0.42	6.0±0.31
6.	125	18.0±0.90	13.5±0.67	22.9±1.14	17.7±0.88	7.8±0.39	7.7±0.40

Table 5: Sodium content of the plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S. No	Days	Plant sodium (meq/lit)					
		Salt			Effluent		
		Leaf	Stem	Root	Leaf	Stem	Root
1	0	14.10±0.70	12.40±0.62	11.00±0.55	14.10±0.70	12.40±0.62	11.00±0.55
2	25	18.33±0.91	14.88±0.74	11.99±0.59	19.03±0.95	15.50±0.77	12.15±0.60
3	50	25.94±1.29	18.60±0.93	13.42±0.67	26.79±1.33	19.22±0.96	13.75±0.68
4	75	38.07±1.90	24.42±1.22	16.94±0.84	40.04±2.00	25.66±1.28	17.05±0.85
5	100	54.20±2.71	36.82±1.84	21.34±1.06	59.92±2.99	39.68±1.98	21.61±1.09
6	125	57.10±2.85	39.68±1.98	22.11±1.10	63.49±3.17	43.52±2.17	23.22±1.16

Table 6: Chloride content of the plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S. No	Days	Plant chloride (meq/lit)					
		Salt			Effluent		
		Leaf	Stem	Root	Leaf	Stem	Root
1	0	10.28±0.51	6.91±0.34	4.18±0.20	10.28±0.51	6.91±0.34	4.18±0.20
2	25	12.43±0.62	8.15±0.40	4.59±0.22	12.85±0.64	8.36±0.41	4.68±0.23
3	50	16.03±0.80	10.29±0.51	5.51±0.27	16.85±0.84	10.71±0.53	5.64±0.28
4	75	22.30±1.11	14.51±0.72	6.89±0.34	23.60±1.18	15.20±0.76	6.98±0.34
5	100	32.17±1.60	19.34±0.96	8.27±0.41	34.12±1.70	20.17±1.00	8.65±0.43
6	125	33.93±1.69	20.03±1.00	8.77±0.43	37.54±1.87	21.67±1.08	9.23±0.46

observed between 75-100 days of development period. The highest reduction in chromium (-43.9%), cadmium (-49.3%), copper (-48.9%) and zinc (-42.9%) was observed in tannery effluent treated soil when compared to salt treated soil [chromium(-40.6%), cadmium (-34.0%), copper (-42.2%) and zinc (-31.1%) respectively].

The results on chromium, cadmium, copper and zinc content in plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil are presented in table 8. Similar to sodium and chloride *Suaeda monoica* accumulated chromium (892.4%), cadmium (980.2%), copper (734.2%) and zinc (508%) after 125 days of cultivation in tannery effluent treated soil when compared to salt treated soil [chromium (3.88%), cadmium (4.93%), copper (71.4%) and zinc (46.4%) respectively].

4. DISCUSSION

EC, pH

In the present study, EC, pH and SAR content was reduced in the soil samples with corresponding increase in plant samples in *Suaeda monoica* cultivated in tannery effluent and salt treated soil after 125 days cultivation. Electrical conductivity is the most common measure of soil salinity and is indicative

Table 7: Chromium, Cadmium, copper and zinc content of the soil samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S. No	Days	Soil Cr (mg kg^{-1} dw)		Soil Cd (mg kg^{-1} dw)		Soil Cu (mg kg^{-1} dw)		Soil Zn (mg kg^{-1} dw)	
		Salt	Effluent	Salt	Effluent	Salt	Effluent	Salt	Effluent
1.	0	4.80±0.24	82.0±4.10	5.00±0.25	23.88±1.19	18.19±0.90	54.90±2.74	26.00±1.30	55.00±2.75
2.	25	4.67±0.23	79.7±3.98	4.96±0.24	23.05±1.15	17.78±0.88	52.40±2.62	25.50±1.27	53.60±2.68
3.	50	4.30±0.21	72.6±3.63	4.62±0.23	20.63±1.03	16.72±0.83	47.00±2.35	24.25±1.21	49.10±2.45
4.	75	3.70±0.18	62.6±3.13	4.18±0.20	17.55±0.87	14.39±0.71	39.90±1.99	22.45±1.12	42.40±2.12
5.	100	2.95±0.14	48.8±2.44	3.52±0.17	12.60±0.63	11.10±0.55	28.60±1.43	18.20±0.91	32.90±1.64
6.	125	2.85±0.14	46.0±2.30	3.30±0.16	12.10±0.60	10.50±0.52	28.00±1.40	17.90±0.89	31.40±1.57

Table 8: Chromium, Cadmium, copper and zinc content of the plant samples of *Suaeda monoica* cultivated in tannery effluent and salt treated soil

S. No	Days	Plant Cr (mg kg^{-1} dw)		Plant Cd (mg kg^{-1} dw)		Plant Cu (mg kg^{-1} dw)		Plant Zn (mg kg^{-1} dw)	
		Salt	Effluent	Salt	Effluent	Salt	Effluent	Salt	Effluent
1.	0	4.12±0.206	4.12±0.206	1.62±0.081	1.62±0.081	3.50±0.175	3.50±0.175	9.90±0.49	9.90±0.49
2.	25	4.14±0.207	8.00±0.400	1.63±0.081	3.30±0.165	3.68±0.184	6.20±0.310	10.20±0.51	12.00±0.60
3.	50	4.18±0.209	17.00±0.850	1.64±0.082	5.00±0.250	3.87±0.193	11.10±0.550	11.04±0.55	20.10±1.005
4.	75	4.20±0.210	29.00±1.450	1.66±0.083	8.00±0.400	4.60±0.230	18.40±0.920	12.29±0.61	33.20±1.660
5.	100	4.24±0.212	37.50±1.870	1.68±0.084	15.30±0.765	5.85±0.290	27.10±1.350	14.31±0.71	55.40±2.770
6.	125	4.28±0.214	40.89±2.04	1.70±0.085	17.50±0.780	6.00±0.300	29.20±1.460	14.50±0.72	60.20±3.010

of the ability of an aqueous solution to carry an electric current. Plants are detrimentally affected both physically and chemically by excess salts in some soils and by high levels of exchangeable sodium. Ravindran *et al*, (2007), while evaluating the capacity of six halophytes to desalinize saline soils, observed that *Suaeda maritima* and *Sesuvium portulacastrum* caused higher reduction of EC in the soil. Rabhi *et al*, (2008) conducted an experiment for bioreclamation of salt affected soils by using *Arthrocnemum indicum*, *Suaeda fruticosa* and *Sesuvium portulacastrum* and observed that these plants were able to decrease the soil electrical conductivity by absorbing soluble salts mainly sodium ions. Ayyappan *et al*, (2013) observed that in *Suaeda monoica* cultivated soil the EC which was significantly reduced from 5.1dSm^{-1} to 1.8dSm^{-1} after 120 days of cultivation. Correspondingly EC was increased from 3.9dSm^{-1} to 18.8dSm^{-1} in plant sample, showed reduction of salts in the field. Shekhawat *et al*, (2006) noticed that the pH of the soil was considerably modulated by halophytes plantations of *Salsola baryosma, Haloxylon recurvum* and *Suaeda nudiflora* and a considerable decrease in soil pH.

Sodium and Chloride and SAR

In the present study, maximum accumulation of sodium and chloride ions was found in *Suaeda monoica* and on the other hand, the sodium and chloride content in the soil declined drastically. Several halophytic plant species have been tried in the past for their possible use in reclamation of salt-affected soils (Ravindran *et al* 2007; Rabhi *et al* 2010; Koyro *et al* 2011; de Sousa *et al* 2012 and Ayyappan *et al* 2013). Increasing sodium chloride salinity increased the sodium content in *Suaeda glauca* (Yang *et al* 2008), *Suaeda altissima* (Meychik *et al* 2013), *Suaeda monoica* (Ayyappan *et al* 2013) and *Apera intermedia* (Yildiztugay *et al* 2014). In halophytes, increase in NaCl concentration gradually increased Na^+ accumulation more in leaves than in shoot or root. It has long been known that halophyte cells must have lower potentials within than outside the plasmalemma to retain cellular water and that the necessary osmotic adjustment in dicotyledons is largely achieved by Na^+ and Cl^- ions (Flowers, 1975). Based on numerous studies, several adaptive mechanisms were recognized in relation to heavy metal and salt tolerance, which include ion compartmentalization, osmolyte production, germination responses, osmotic adaptation, succulence, selective transport and uptake of ions, enzyme responses, metal/salt excretion, and genetic control (Koyro *et al* 2011; Lokhande and Suprasanna, 2012.

Sodium absorption ratio is usually a good indicator of the structural ability of the soil. In general SAR is employed to understand the equilibrium relation between soluble and exchangeable cations. Nasir (2009) conducted an experiment on Bioreclamation of saline sodic soil and concluded that SAR declined significantly in plots cultivated with *Atriplex hallimus*, *Atriplex numularia* and *Tamarix aphylla*. Rabhi *et al*, (2010) observed in *Sesuvium portulacastrum* cultivated soil, SAR decreased from 59 to 39 mmol l^{-1} and soluble Na^+ concentration from 1.4 to 0.9 mg g^{-1}. Ayyappan *et al*, (2013) noticed that SAR content was reduced from 16.94 to 3.23 meq/lit (80.9% reduction) in *Suaeda monoica* cultivated in saline agricultural land after 120 days of cultivation. REW

Chromium, Cadmium, Copper and Zinc

In the present study, maximum accumulation of chromium, cadmium, copper and zinc content was observed in *Suaeda monoica* cultivated in the tannery effluent treated soil and on the other hand, the soil chromium, cadmium, copper and zinc content declined maximum in *Suaeda monoica* cultivated soil. Recent studies focused on the phytoextraction or phytostabilization potential of halophytic plants such as *Tamarix smyrnensis* Bunge (Manousaki *et al*., 2009) and salt marsh plants (Sousa *et al*., 2008; Castro *et al*., 2009) *P. australis* (Bonanno and Giudice, 2010; Bonanno, 2011; Anjum *et al* 2012) and *Spartina maritima* (Duarte *et al* 2013) confirm the fact that halophytes are excepted to receive more and more attention by phytoremediation researcher.

In the present study, maximum accumulation of chromium content was observed in *Suaeda monoica* cultivated in the tannery effluent treated soil when compared to control. On the other hand, the soil chromium content declined in *Suaeda monoica* cultivated soil. Pahalawattaarachchi *et al*, (2009) reported that the concentration of Cr accumulated in leaves and root samples of *Rhizophora mucronata* were 16.78 µg/g and 9.33µg/g respectively. Bareen and Tahira (2011) observed that the greatest amount of Cr was bio-accumulated by leaves of *Suaeda fruticosa* followed by roots and stem. Thus, maximum accumulation of Cr in *Suaeda fruticosa* is up to 2521 mg kg^{-1} dry weight of shoots and *S. fruticosa* can be employed in rehabilitation of tannery effluent contaminated soil. Redondo-Gomez *et al*, (2011) identified salt marsh halophyte *S. argentinensis* was hyperaccumulate Cr and Suggested to restore Cr-contaminated soils. Redondo-Gomez (2013) reported that bio-accumulation of metals in roots and tillers of some species of the *Spartina* genus (e.g. *S. maritima* and *S. densiflora* Brongn) has been described as a feasible method for remediating waters and soils contaminated with heavy metals and has been found to be a Cr-hyperaccumulator.

In the present study, *Suaeda monoica* grown in tannery effluent treated soil showed maximum accumulation of cadmium content when compared to control. Similar studies on bioaccumulation of cadmium by other halophytes was recorded by in *Atriplex lentiformis* by Eisa *et al*, (2011), in *Chenopodium album* by Mazhari and Bahramian, (2012) and in *Limoniastrum monopetalum* by Manousaki *et al*., (2013). Salinity has been shown to affect positively the translocation of metals from the roots to the shoots of plants (Manousaki *et al*., 2008). Moreover, salinity also is known to increase Cd accumulation in plants through the increase of Cd mobility in soil and therefore Cd bioavailability in soil (Weggler *et al* 2004).

Similar to chromium and cadmium maximum bioaccumulation of copper content was observed in *Suaeda monoica* cultivated in tannery effluent treated soil. In accordance with our studies, Thomas *et al*, (2008) reported that *Mesembryanthemum crystallinum* can accumulate as much as 3500 ppm of copper in its tissue, making it a copper hyperaccumulator. Eid and Eisa (2010) observed that *Sporobolus* plant has the greatest efficiency for phytoremediation of Zn, Cu and Ni salts from contaminated soils. Kamaruzzaman *et al*, (2011) observed in *Anicennia marina* and *Rhizophora apiculata* accumulate Pb and Cu in their tissues and the results clearly shows the bioaccumulative properties of selected species of mangroves, it is suggested that steps be taken to plant the mangrove tress in areas contaminated with heavy metals like Pb and Cu.

Suaeda monoica cultivated in tannery effluent treated soil exhibited maximum accumulation of zinc content whereas soil samples showed reduction in the zinc content. In a recent study Cambrolle *et al*, (2013) reported that *Limoniastrum monopetalum* grow on sites with high concentrations of metals and in a greenhouse experiment it was found to exhibit hyper-tolerate to Zn and accumulate the metal and thus, to provide opportunities for zinc phytoremediation. Duarte *et al*, (2013) analysed heavy metal tolerance of halophytes in two salt marshes in Portugal with a view to using halophytes as bio-indicators of heavy metal contamination of estuaries. They concluded that *S. maritima* could be used as a potential bio-indicator of heavy metal contamination.

In the present study it is observed that *Suaeda monoica* potentially have high resistance to heavy metals that is strongly linked to characteristics for salt tolerance. Synthesis of osmoprotectants helps halophytes to resist heavy metal stresses. In order to maintain suitable water potential and to protect cellular structure in saline environments, halophytes synthesize osmoprotectants. Since heavy metals also induce secondary water stress and oxidative damage to cellular structure, the capacity of halophytes to synthesize these osmoprotectants may be involved in dealing with heavy metals. Antioxidants synthesis of halophytes improves resistance against oxidative stress caused by heavy metals during phytoextraction of heavy metals by *Suaeda monoica*.

5.CONCLUSION

In conclusion, *Suaeda monoica* plays a vital role in phytoremediation of heavy metals and salts. The duration of phytoremediation process depends upon the availability of heavy metals and salts present in soil. Repeated cultivation of *Sueada monoica* is required for removal of heavy metals and salts from tannery effluents.

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