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Phytoremediation Potential of *Sesuvium Portulacastrum* on Remediating Salt Affected Soil

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Abstract

Sesuvium portulacastrum is a salt hyper accumulating plant and pioneer plant species used for desalination and phytoremediation. The plant tolerates abiotic constraints such as salinity and drought. It grows under severe salinity and it can be used for the remediation and restoration of salt contaminated soils affected from industrial effluents. Among the major water demanding industries, the textile industry has biggest impact on the environment related to primary water consumption and waste water discharge. Textile effluent has a large range of organic chemicals of high salinity, high colour and low biodegradability. Salinity exerts negative effects on plant growth and affects the biological stability of ecosystems.The experiment on salt uptake through salt enrichment study was conducted and also to assess the potential of *Sesuvium portulacastrum* collected from Pitchavaram in Chidambaram District of Tamil Nadu, India for the remediation of dye and textile contaminated area in Andipalayam, Mangalam and Palayakottai villages of Tirupur District of Tamil Nadu was studied upto 70Days After Planting (DAP). The results of the soil analysis revealed that, the initial EC of soil 13.04 dSm^{-1} is reduced to 7.37 dSm^{-1}(30 Days after planting (DAP) and 5.34 dSm-1(60DAP). The plant shoot length and root lengths were increased to 74% and biomass was increased to 94% in 5000mg/kg of Na enriched soils. The electrical conductivity and sodium content were decreased in *Sesuvium* grown soil enriched with different concentrations of Na. 77.8% of Sodium was removed from the soil in a span of 90 days.

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Keywords

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Introduction

Soil and environment are under tremendous pressure due to industrial expansion and discharge of effluents. During the past few decades industrial activities have increased greatly with rapid economic growth, this accomplished severe environmental pollution. Textile industry is a diverse sector in terms of raw materials, processes, products and equipment and has a very complicated industrial chain. Its biggest impact on the environment is related to primary water consumption (80–100 m^3/ton of finished textile) and waste water discharge (115–175 kg of COD/ton of finished textile, a large range of organic chemicals, low biodegradability, color and salinity). Therefore, reuse of the effluents represents an economical and ecological challenge for the overall sector[1]. The textile effluents have a high concentration of salts, through their accumulation in different trophic levels of ecosystem ultimately cause serious environmental impact in the neighboring receptors like agricultural land and water bodies[2].

Salinity is one of the major abiotic constraints, manifesting as osmotic stress at an early phase and ionic stress at later phases of plant growth, consequently affecting plants survival mechanisms at cellular, tissue and whole plant level[3,4]. More than 45 million hectares of irrigated land are affected by salt which account for 20% of total land and 1.5 million ha of land are taken out of production each year owing to high salinity level[5,4]. So, it is essential to reclaim the contaminated soil by natural way of using plants. Among the many feasible techniques, phytoremediation is a cost-effective and environmentally sound technology for remediation of salt affected sites.

Sesuvium portulacastrum (L.), a member of the family Aizoaceae, is an important halophyte in the category of "salt accumulator" plants which accumulates high salt concentration in their cells and tissues and overcomes salt toxicity by developing succulence.This plant has a distinct molecular and physiological flexibility that enables it to adapt and survive under various abiotic stress conditions[6-17].It has been observed that the growth characteristics of *Sesuvium* were improved upon exposure to optimum NaCl concentrations (100 to 400 mM) under in vitro and an increase in growth rate and halosucculence status (200 mM of NaCl) under ex vitro conditions[6,7,8,9,10,11].

The ability of *S. portulacastrum* to survive in adverse environmental conditions recognizes it as a possible candidate for the environmental protection[12,6,8,10,13-17].The evidence for the ability of this halophyte to desalinise an experimentally salinised agricultural soil (grown for 189 days) is provided[7] and confirmed the growth potentials of test culture *Hordeum vulgare* (barley) on the desalinised soil. There was a marked absorption of Na^+ ions by S. *portulacastrum* roots and their accumulation in the above-ground biomass up to 872 mg $plant^{-1}$ and 4.36 g pot^{-1} (about 1 t ha^{-1}). Similarly in a study among six species of halophytes studies, *S. maritime* and *S. portulacastrum* exhibited greater accumulation of salts in their tissues and higher reduction of salts in the saline land (upto 504 and 474 kg of sodium chloride respectively from the saline land from 1ha in 4 months time).Thus the characteristic feature of *Sesuvium* to accumulate high amount of salt in its tissues may be exploited for reducing salt levels in the potential agriculture soil and in the arid and semiarid regions by repetitive cultivation and harvesting of this plant in these areas.Hence, the present study aims to assess the phytoremediation potential of *Sesuvium* plant for the removal of salt from contaminated and salt enriched sites.

Materials and Methods

Sampling Location

Tamil Nadu textile city Tirupur, which has nearly 720 dyeing units, is ranked topmost in terms of generating hazardous waste. According to Tamil Nadu Pollution Control Board, an estimated 8,33,365.75 tons of hazardous waste is generated every year in Tirupur. Soil samples were collected from Andipalayam, Mangalam and Palayakottai villages of Tirupur District(Fig.1)

Soil Sample Collection

The Bulk soil samples were collected from dye and textile effluent contaminated sites, for conducting pot culture experiment. These villages represent the pollution status of Tirupur District and recorded high EC values (4.5 to 8.5 dSm^{-1}). The initial physico-chemical characteristics of the soils samples were analysed by standard operating procedures[22].

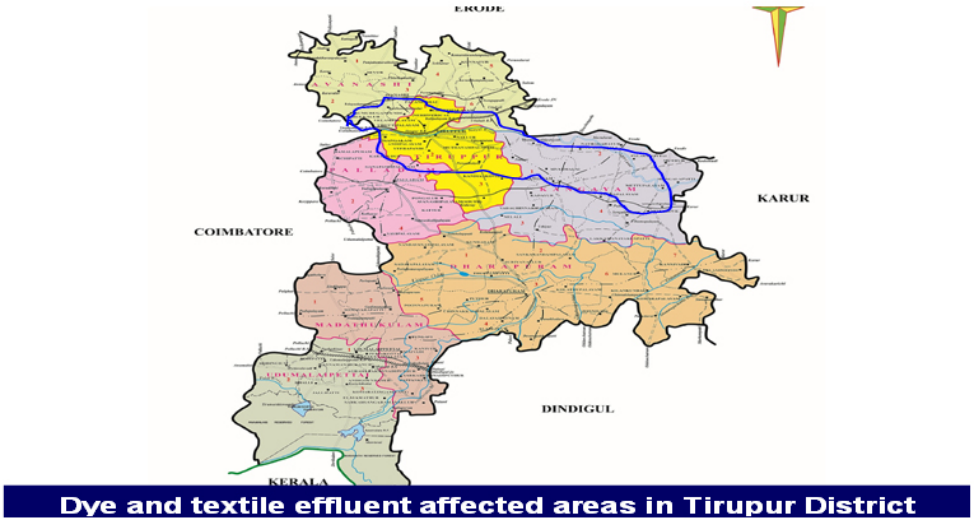

Fig. 1: Sampling Location

Plant Sample Collection and Identification

Pichavaram is the second largest Mangrove forest in the world. The salty marsh area of Pichavaram supports many halophytes. *Sesuvium* being a coastal plant also act as an inland plant and a mangrove associate and has shown to have nursing effects in mangroves. Salt hyper accumulating plant *Sesuvium portulacastrum* samples were collected for remediating the salt contaminated soils. The collected salt hyper accumulating plant was identified and confirmed as *Sesuvium portulacastrum* through Botanical Survey of India and used to assess the salt removal potential. The chemical constituents of the *Sesuvium* plant was analysed by standard operating procedures[22,26].Scanning electron microscope image of *Sesuvium portulacastrum* was also taken to observe the physiology of the plant (Fig.2).

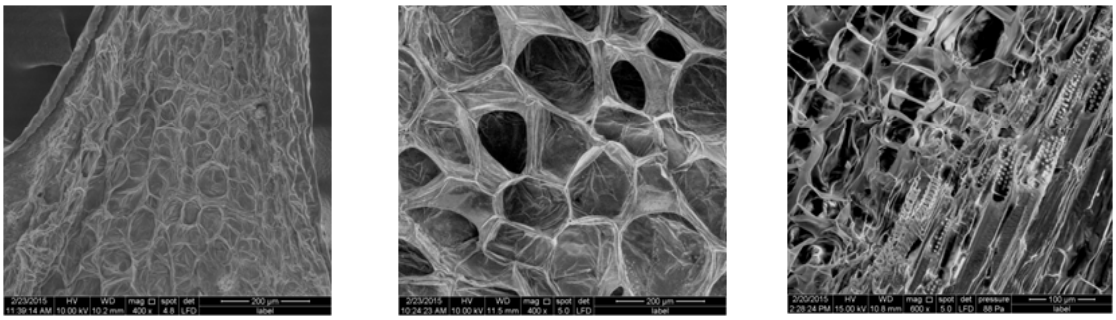

Fig. 2: Scanning Electron Microscope images of *Sesuvium* root, leaves and shoot

Experiment on salt uptake by *Sesuvium portulacastrum*

Pot culture and field study on salt uptake in high EC soils of Andipalayam, Mangalam and Palayakottai villages of Tirupur District was conducted to check the salt uptake potential, growth and establishment of *Sesuvium portulacastrum* plants. At periodical intervals (Month intervals) the soil and plant samples were collected and analysed for physico-chemical characteristics viz., pH, EC, Na, K, Ca and Mg, Cl and SO_4[23] and the role played by Sesuvium plants to remove the salt level. Observations reveal that *Sesuvium portulacastrum* is a proven plant for reclaiming salt affected soils.

Salt Enrichment

Soil was enriched with different concentration (2000, 3000, 4000 and 5000 mg kg^{-1}) of NaCl. A control without any salt addition was maintained to study the salt uptake by the plants. *Sesuvium portulacastrum* plants were planted in the salt enriched soils and further observation on salt uptake, physico- chemical characteristics of soil and physiological changes in the plant were observed.

Statistical Analysis

The data on various characters studied during the investigation were statistically analysed by the method given by[24] at a ($P<0.05$).

Results and Discussion

Establishment of *Sesuvium portulacastrum* in dye and textile effluent contaminated soils (Andipalayam, Mangalam and Palayakottai villages) of Tirupur District was observed and the growth of the plant was good in contaminated soil. At periodical intervals (Month) the soil and plant samples were collected and analysed for physico-chemical characteristics and the role played by *Sesuvium* plants to remove the salt level was also studied (Fig 3 and 4).

The initial EC of the soil is 13.04 dSm^{-1} in Mangalam village and is reduced to 7.37 dSm^{-1}(30 DAP) and 5.34 dSm^{-1}(60DAP) (Fig. 3). In Andipalayam soil initial EC is 8.97 dSm^{-1} which decreased to 5.31 dSm^{-1} (30 DAP) and 3.29 dSm^{-1} (60DAP). In Palayakottai soil initial EC is 4.38 dSm^{-1} which decreased to 2.30 dSm^{-1} (30 DAP) and 1.24 dSm^{-1} (60DAP). The initial sodium content of the soil is 3372 $mgkg^{-1}$ in Mangalam village is reduced to 820 $mgkg^{-1}$ (30 DAP) and 643 $mgkg^{-1}$ (60DAP) (Fig. 3). In Andipalayam soil initial sodium content is 2412 $mgkg^{-1}$ and decreased to 558 $mgkg^{-1}$ (30 DAP), 365 $mgkg^{-1}$ (60DAP). In Palayakottai soil initial sodium content is 1500 $mgkg^{-1}$ and decreased to 539 $mgkg^{-1}$ (30 DAP), 361 $mgkg^{-1}$ (60DAP).

At periodic intervals the role played by *Sesuvium* plants to remove the salt level was also studied by analyzing the plant characteristics such as pH, EC, Na, K, Ca and Mg (Fig. 4).

The initial EC of the *S. portulacastrum* plant collected from Pitchavaram is 12.09 dSm^{-1} which increased to 19.93 dSm^{-1} in Mangalam village soil (30 DAP), 19.87 dSm^{-1} in Andipalayam village soil (30 DAP) and 17.59 dSm^{-1} in Palayakottai village soil (30 DAP). The initial sodium content of the *S. portulacastrum* plant is 3.2% which increased to 4.4% in Mangalam village soil (30DAP), 3.7% in Andipalayam village soil (30 DAP) and 3.5% in Palayakottai village soil (30 DAP) (Fig. 4). On comparing, it is found that the uptake of salts by *Sesuvium* plants collected from Pitchavaram was high in soil from Mangalam village than other village soils- Na: 3.2% to 4.4%, K: 1.2% to 1.5%, Ca: 0.06% to 0.14%, Mg: 0.05% to 0.24%. The evidence for the ability of this halophyte to desalinize an experimentally salinised agriculture soil is provided[7] and confirmed the growth potentials of test culture *Hordeum vulgare* on the desalinized soil. There was a marked absorption of Na^+ ions by *S. portulacastrum* roots and their above ground biomass up to 872 mg $plant^{-1}$ 4.36 g pot^{-1}. Thus the characteristic feature of *Sesuviumto* accumulate high amount of salts in

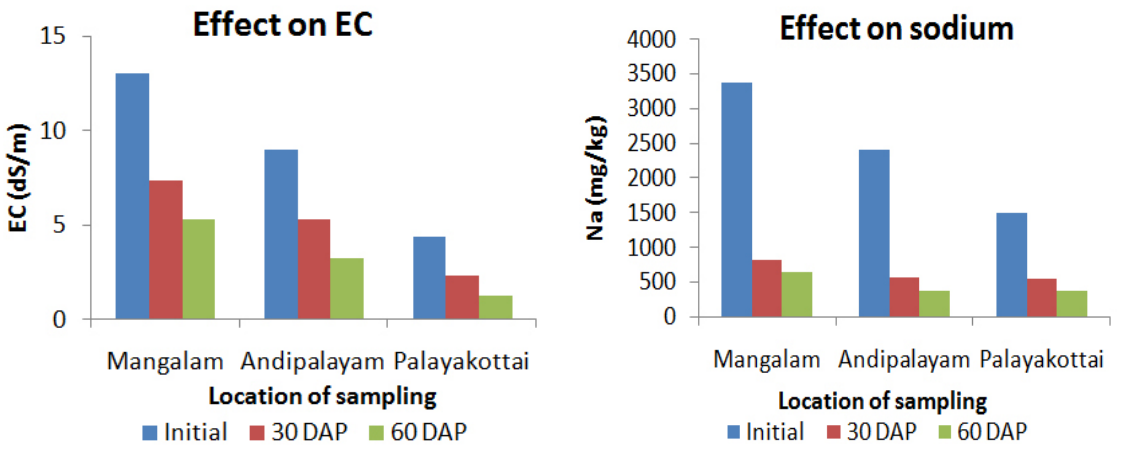

Fig. 3: Influence of S. *portulacastrum* on soil EC and sodium

its tissue may be exploited for reducing salt levels in the potential agricultural soil and in the arid and semi arid regions by repetitive cultivation and harvesting of this crop in these areas[21].

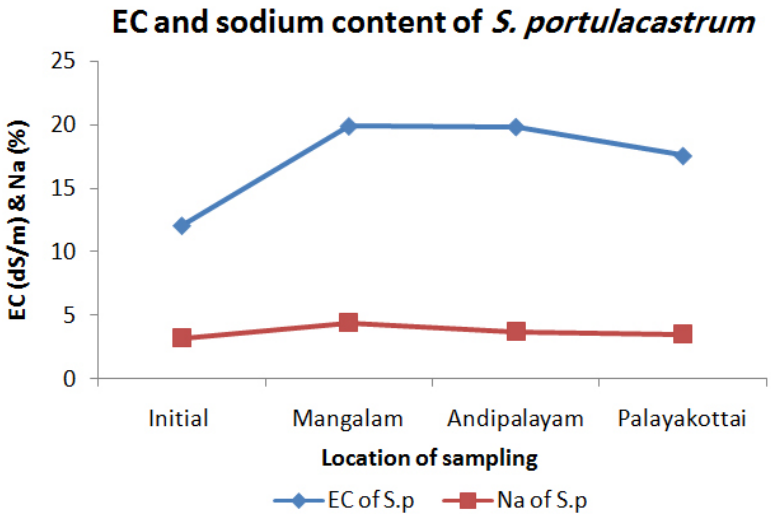

Fig. 4: Salt accumulation in S. *portulacastrum*

Salt Enrichment Study

Sesuvium portulacastrum plants were planted in the salt enriched soils and further observation on salt uptake, physico- chemical characteristics of soil and physiological changes in the plant were observed.

The EC of the soil was found to considerably decrease throughout the study period of 90 days at four increasing concentrations of Na salt (Table 1). At a NaCl concentration of 2000 $mgkg^{-1}$ 80% reduction in soil EC was seen in 90 days interval. The highest EC reduction was observed in soil enriched with 4000 $mgkg^{-1}$ of saltupto 82.5 % on the 90th day. It was also observed that among the four different concentrations of salt enriched soil, the EC reduction was upto 50.6% in the soil enriched with 4000 $mgkg^{-1}$ NaCl compared to other salt concentrations. Sesuvium plants established in salt enriched soils favored salt uptake which was evident in the decrease in Na in the soil (Table 1). The highest salt removal was seen in soil enriched with 3000 $mgkg^{-1}$ of NaCl salt upto 81.82 % in 90 days next to which 77.4% removal was observed in soil enriched with 2000 $mgkg^{-1}$ of NaCl salt. Fifty seven percentsalt removal was observed within a span of 30 days in soil enriched with 3000 $mgkg^{-1}$ of NaCl salt whereas approximately 45-49% removal was seen in other concentrations.

Table 1: EC and Sodium content of the soil in salt enrichment experiment

NaCl conc. ($mgkg^{-1}$)	Days interval							
	EC (dsm^{-1})				Na($mgkg^{-1}$)			
	0	30	60	90	0	30	60	90
2000	6.5	5.5	3.5	1.3	1990	1080	750	450
3000	7.7	4.8	4.2	1.8	2970	1250	980	540
4000	12.6	6.8	5.3	2.2	3970	2170	1750	1250
5000	15.8	7.8	6.4	4.9	4980	2530	2010	1550

Sesuvium plants established in salt enriched soils exhibited improved growth which was estimated in terms of shoot, root length (cm) and plant biomass ($gpot^{-1}$) (Table 2). Root length of the plants increased from an average of 10.8 cm to 38.15 cm in 90 days. 73.9 and 73.8% increase in root length was seen in soil enriched with 2000 $mgkg^{-1}$ and 5000 $mgkg^{-1}$ in 90 days. respectively. Similarly, a 73.7% increase in shoot length was observed in soil enriched with 2000 $mgkg^{-1}$ salt whereas 72.1 % increase was seen in 5000 mgkg-1 salt enriched soil in 90 days. Regarding plant biomass, a 94.32 % increase was seen in plants grown in 5000 $mgkg^{-1}$ salt enriched soil in 90 days which indicates increased succulence in the presence of salt.

Table 2: Growth parameters of *Sesuvium portulacastrum* in salt enrichment experiment

NaCl conc. ($mgkg^{-1}$)	Days interval											
	Shoot length (cm)				Root length (cm)				Plant biomass ($gpot^{-1}$)			
	0	30	60	90	0	30	60	90	0	30	60	90
2000	12.5	25.8	37.3	47.6	10.3	22.1	30.5	39.5	25	125	257	350
3000	12.8	28.7	38.2	45.6	11.6	23.5	29.7	33.5	23	157	273	432
4000	13.5	23.8	39.6	48.3	10.8	25.6	30.9	39.5	26	160	289	425
5000	13.8	25.4	37.5	49.5	10.5	22.5	30.6	40.1	23.5	137	235.5	413.5

Analysis of soil and plant samples revealed that the plants were efficient in salt uptake from enriched soils. The electrical conductivity and sodium content were decreased in *Sesuvium* grown soil enriched with different concentrations of Na. 77.8% of Sodium was removed from the soil in a span of 90 days. The two halophytes *S. maritime* and *S. portulacastrum* were reported to exhibit greater accumulation of salts in their tissues and high reduction of salts in the saline land and particularly, they could remove 504 and 474 kg of NaCl from the saline land from 1 ha in 4 months[37]. Decrease in soil EC and Na were reported 17when three halophytes *Sesuvium portulacastrum* L., *Arthrocne mumindicum* and *Suaeda fruticosa L.* were used for reclaiming salt affected soils. According to them, with regards to biomass production, shoot sodium concentration and the pot area, *Sesuvium portulacastrum* can extract 14 % of the salt that exists in the horizon 0-1 m of a soil having 10 % water and a salt concentration that exceeds 200 mM NaCl. Also, considerable increase in root and shoot length and biomass of S. portulacastrum plants were observed throughout the study period. Sesuvium can optimally uptake saline ions and carbon resources from the medium and allocate it to different parts of the plant resulting in increase succulence subsequently improving the growth, biomass and net photosynthesis rate of the plant [6,7,15,20,25-27,28-34]. *Sesuvium* plants accumulate the inorganic salts in the vacuole, mainly NaCl and organic solutes in the cytoplasm. Na^+ uptake into vacuoles requiresNa^+/H^+ antiporters in the tonoplast andH^+ AT Pases and perhaps PPIases to provide the proton motive force. Halophytes vacuoles may have a modified lipid composition to prevent the leakage of Na^+ back to the cytoplasm[12].

Conclusion

Sesuvium portulacastrum is a salt hyper accumulating halophyte which compartmentalizes the toxic Na^+ in the vacuoles and therefore membrane bound transport system regulating cytosolic (Na^+,K^+ and Ca^{++}) and ion accumulation by increasing the vacuolar volume. Environmentally, the plant's potential has been checked for its survival under different abiotic stress conditions that includes salinity, drought and heavy metal accumulation which makes *Sesuvium* a useful species as a heavy metal pollution indicator and for predicting soil salinity. Thus the characteristic feature of *Sesuvium* to accumulate high amount of salt in its tissues may be exploited for reducing salt levels in the potential agriculture soil and in the arid and semiarid regions by repetitive cultivation and harvesting of this plant in these areas.

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