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Bioaccumulation And Translocation Potential Of Na^+ And K^+ In Native Weeds Grown On Industrially Contaminated Soil

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Abstract: Use of the naturally growing plants to remove the inorganic contaminants from the soil as well as water is a sound technology in the recent years. The study was performed in salinity affected soil to examine the efficacy of bioaccumulation potential of sodium and potassium by 12 naturally grown weeds. The wasteland soil was found having higher bulk density (BD), water holding capacity (WHC), electrical conductivity (EC), organic carbon (OC) and nitrogen, phosphorus and potassium (NPK) than the control (garden) soil. The average values of Na^+ and K^+ were found in plant parts 750 and 1094 µg g^{-1} dry weight respectively. The Na^+/K^+ ratio was found highest in the *B. pertusa* (0.8). Translocation factor (TF) ranged from 0.6 to 1.2 for Na^+ and 0.5 to 0.9 for K^+. Na^+ and K^+ removal from the wasteland soil and waste substrates was most effective with the use of *P. panicum, S. munja, S. spontanum, P. purpureum* and *D. clorata,* because these plants accumulated significant higher amount of Na^+ and K^+ in their tissue. These weed plants found to have a great potential for the phytoremediation of industrial wasteland in the investigated area.
Keywords: Bioaccumulation; enrichment factor; industrial area; phytoremediation; salinity; translocation factor.

Introduction

The environmental stresses trigger a wide range of plant responses, ranging from altered gene expression and cellular metabolism to changes in growth, biomass accumulation, and plant productivity[1-8] and it may also affect the uptake and transport of toxic substances inside the plants. Salinity is a major problem of the soil ecosystem in the arid, semi-arid and coastal regions throughout the world[9-11]. The global range of primary salt-affected soils is about 955 M ha, while secondary salinisation affects about 77 M ha, with 58% of these in irrigated areas. About 21.5 million hectare of land is salt affected in Asia alone and India having 8.6 million hectare out of them. The major ions responsible for salinization of soil are Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-. High salinity is one of the most important environmental stresses impeding crop growth and severely reduces agricultural yields and productivity[12]. The soil salinity affects seed germination; alter plants metabolisms through osmotic stress, ion specific effects and oxidative stress[13]. Several reports are available which indicate that many crops have tolerance power towards the salinity e.g. Barley[12] and Chick pea etc.[14]. Sodium ion can compete with K^+ and inhibit transport and metabolic processes depending on K^+. Since Na^+ is frequently present at higher concentrations than K^+ in soils, most plants must have transport systems with high selectivity for K^+ against Na^+. The objective of present study was planned to evaluate the phytoextraction potential of different naturally growing plant species especially weeds for the reclamation of salinity affected wasteland.

Materials and methods

Site description

The study area is located at Sandila Industrial Area, Uttar Pradesh, India, located between 26º 53' and 27º 46'north latitudes and between79º 41' and 80º 46'east longitudes (www.mapsofindia.com), average temperature 23ºC, average rainfall 970 mm.[3,5] Certain industries *i.e*. Cotton mill, Vegetable oil mill, Steel Industry (all closed now) have discharged and safe yeast industry, milk powder factory, chemicals factory etc. (all operating), discharging their effluents in the water and soil of the area. The soil was completely barren at the time of sampling was performed during January, May and September month of the year.

Sampling and analysis of metals in soil and plants

On the basis of the existing information and agricultural background 8 locations were selected for soil and plant sampling. Composite soil samples were collected from 0 to 20 cm soil layer, mainly from the root zone (rhizosphere) from each site. The concentrations of metals in soils were determined in the Environmental Laboratory of BBA University of Environmental Science, Lucknow, India. For the metal analysis, soil and plant samples were dried in oven to constant weight and digested in conc. HNO_3 and $HClO_4$ in 5:1 for soil and 3:1 for plants (v/v) ratio at low temperature till a white residue was obtained. Double distilled water was used to maintain final known volume[15]. The samples were analyzed using VARIAN AA240FS make Fast sequentional AAS with flame (FAAS).

Translocation Factor (TF) and Enrichment Coefficient (EC)

The translocation factor (TF) or mobilization ratio was calculated to determine relative translocation of metals from the growing medium to other parts (root and shoot) of the plant species[16-17]. The enrichment coefficient (EC) has been calculated to derive the degree of contamination and heavy metal accumulation in growing medium (drain water) and in plants growing on contaminated site [18].

Statistical analysis

All treatments were replicated for six times (n=6). Results were analyzed using One-way ANOVA (SPSS statistical package and MS excel). The difference between treatments were considered significant at $p<0.05$.

Results and discussion

Soil properties

The bulk density (BD) of wasteland soil was 2.05, which was higher than that of BBA University campus soil used as control. The water holding capacity (WHC) of Sandila industrial area (SIA) soil was 64.17 in comparison to 51.91 observed for the control soil. Soil pH plays an important role in maintaining the availability of nutrients and thus affects the plant growth. The pH of SIA was alkaline in nature (8.42). Electric Conductivity (EC) of the SIA soil was 2.14dS m^{-1}, which was about 5 fold higher than that of the control soil. Organic Matter (OM) is an important component of the soil fertility, which provides nutrients to the vegetation after decomposition. The SIA soil had about 20 fold higher % organic carbon than that of the garden soil. The % organic carbon in wasteland soil indicates higher accumulation of organic substances in the soil. Soil quality was defined in many different ways, [19] have defined soil quality as the ability of soil to support crop growth, including factors such as tilth, aggregation, organic matter content, soil depth, water holding capacity, infiltration rate, pH changes and nutrient capacity[20-23]. The water content and availability of ions of a soil solution are, indeed, the major factors affecting its apparent electrical conductivity, which justifies the assessment of salinity from apparent EC measurements[24-25].

Na concentrations in plant parts

The accumulation of Na in the weeds and their parts naturally grown in the industrial wasteland soil were shown in Table 1. The maximum accumulation of Na was found in *P. panicum* and minimum in *C. arcutus*. The sodium concentration range in the shoot of the weeds were 891.67 to 476.95 (µg g^{-1} d wt), however, in the roots it was 1158.51 to 601.73 (µg g^{-1} d wt). The weeds, *S. munja*, *S. spontanum*, *D. ciliaris*, *E. burmanica* were accumulated higher amount of Na in the shoots as compared to the roots.

Potassium concentrations in plant parts

The highest K concentration was measured in *P. panicum* (1298.16 µg g^{-1} d wt in plant), while the lowest were in *C. arcuatus* (780.71µg g^{-1}d wt). The concentrations of K in plant shoots were ranged from 859.3 to 446.32 µg g^{-1}d wt with an average value 6.52.5 µg g^{-1}d wt, whereas in plant root ranged 1900.39 to 1004.1 µg g^{-1}d wt with an average value 1457.24 µg g^{-1}d wt (Table 2).

Table 1. Sodium accumulation (µg g^{-1} µg g^{-1} d wt) in weeds and their parts (shoots and roots) growing in industrial wasteland soil

Plants name	Plants (µg g^{-1} d wt)	Shoot (µg g^{-1}d wt)	Root (µg g^{-1}d wt)
B. pertusa	804.02±59.81^{bc}	587.39±46.21^{def}	1020.65±73.41^{b}
C.cambogiensis	798.88±51.14^{cd}	738.87±40.50^{bc}	858.88±61.78^{cd}
C. arcuatus	614.23±45.79^{de}	476.95±37.52^{f}	751.51±54.05^{de}
C. dactylon	630.98±46.49^{de}	496.66±37.94^{f}	765.3±55.04^{de}
C. difformis	731.79±55.70^{cd}	509.91±38.95^{f}	953.68±72.45^{bc}
C. rotundus	816.60±60.02^{bc}	598.1±41.41^{def}	1035.1±78.64^{ab}
D. aegyptium	725.35±53.25^{cd}	550.34±38.10^{ef}	900.37±68.40^{bcd}
D.colorata	902.11±70.22^{ab}	645.72±52.43^{cde}	1158.51±88.01^{a}
D. ciliaris	749.39±61.94^{cd}	832.46±73.26^{ab}	666.32±50.62^{ef}
E. burmanica	634.15±52.19^{de}	666.56±58.66^{cd}	601.73±45.71^{f}
P.flavidum	643.88±52.02^{de}	514.78±45.30^{f}	772.97±58.72^{de}
P. panicum	930.67±65.74^{a}	891.67±61.73^{a}	969.68±69.7^{bc}
S. munja	833.55±58.74^{bc}	902.69±62.49^{a}	764.41±54.98^{de}
S.spontanum	720.85±51.72^{cd}	792.44±56.73^{ab}	649.26±46.70^{ef}

All the values are means of three replicates ± S.D. Different letters indicate significant differences between mean at *p<0.05* (DMRT) analyzed by one way ANOVA

Table 2. Potassium accumulation (µg g^{-1} d wt) in weeds and their parts (shoots and roots) growing in industrial wasteland soil

Plants name	Plants (µg g^{-1}d wt)	Shoot (µg g^{-1}d wt)	Root (µg g^{-1}d wt)
B. pertusa	996.76±98.59^{cd}	756.92±99.90^{ab}	1236.6±97.29^{bc}
C.cambogiensis	1240.80±114.60^{a}	636.95±84.07^{bcd}	1844.64±145.12^{c}
C. arcuatus	780.71±76.28^{e}	557.32±73.56^{cde}	1004.1±78.99^{c}
C. dactylon	806.58±77.39^{cde}	567.55±74.91^{cde}	1045.6±79.87^{c}
C. difformis	890.43±89.41^{cde}	707.37±96.81^{abc}	1073.49±82.00^{c}
C. rotundus	1013.46±96.13^{bc}	767.76±105.08^{ab}	1259.16±87.17^{bc}
D. aegyptium	913.22±85.81^{cd}	667.83±91.40^{bc}	1158.6±80.20^{bc}
D.colorata	1109.36±113.99^{b}	859.3±117.61^{a}	1359.41±110.38^{b}
D. ciliaris	1123.39±110.94^{b}	494.23±67.64^{de}	1752.54±154.23^{b}
E. burmanica	924.80±92.29^{cd}	446.32±61.09^{e}	1403.28±123.49^{b}
P.flavidum	828.54±86.92^{cde}	573.34±78.47^{cde}	1083.74±95.374^{c}
P. panicum	1298.16±112.43^{a}	719.12±94.91^{abc}	1877.21±129.95^{a}
S. munja	1233.64±103.19^{a}	566.89±74.82^{cde}	1900.39±131.56^{a}
S.spontanum	1074.90±91.49^{bc}	481.5±63.55^{de}	1668.3±119.43^{a}

All the values are means of three replicates ± S.D. Different letters indicate significant differences between mean at *p<0.05* (DMRT) analyzed by one way ANOVA.

Potassium (K^+) is an essential element for plant growth and is an extremely dynamic ion in the soil system. As anion, potassium is highly mobile in the plant system but only moderately mobile in the soil system [26-27]. Along with other elements like chlorine, sodium and lithium, potassium is called a non-constitutive element, as it does not form component/compounds in the plant system[28]. Potassium plays an important role to enhance tolerance capacity of the plants such as rice[29], tomato[30-31], cucumber and pepper[32] and strawberry[33]. Under salinity stress, potassium translocated back to the root in excess of the plant's requirements[34]. One author has reported synergy between cation (K^+ or Ca^{2+}) accumulation and myo-inositol for breaking of the symmetry of bud growth[35]. The results of the present study showed a variation in sodium and potassium levels within plan species. For the relationship between salt tolerance and ion effects, it was suggested that plant species differ in the degree of Na^+ and K^+ toxicity affecting their growth[36]. Salinity not only caused high Na^+ accumulation in plants but also influenced the uptake of essential nutrients such as K^+ and Ca^{2+} through the effects of ion selectivity. Decline in K^+ accumulation because of salinity stress, has been widely reported in many crops like wheat, sorghum etc.[37-38]. In those species that retain Na^+ in woody roots or stems, there is a strong correlation between Cl^- exclusion and salt tolerance. This indicates the higher ratio of Na^+/K^+ resulted in the decrease in the growth rates.

Enrichment coefficient (EC)

The Enrichment coefficient (EC) values of all studied samples for Na and K which varied between 0.30 to 1.30 for Na and 0.20 to 0.65 for K. The highest EC were observed in *S. spontanum* and *D. ciliaris* for Na and for K in *D. colorata* and *C. difformis*. Enrichment coefficient is an important factor when considering the phytoremediation potential of a plant species [39-40]. The enrichment coefficient>1 shows a special ability of the plant to absorb metal ions from soils and transport it to aerial parts[41]. Plants can immobilize heavy metals through absorption and accumulation by roots, adsorption onto roots, or precipitation within rhizosphere[42].

Translocation factors (TF) of Na and K in weeds grown in industrial wasteland soil

The translocation factors for Na were ranged from 0.70 to 1.20, with the highest value in the sample of *P. panicum* and *S. munja* while the lowest was found in *C. arcuatus*. A plant's ability to translocate metals from the roots to the shoots is measured using the TF, which is defined as the ratio of metal concentration in the shoots to the roots. TF higher than 1 indicates a very efficient ability to transport nutrients from roots to shoots, most likely due to efficient metal transport systems[43]. The results indicated that the translocation factors of plant species were higher than 1 in this study (Fig.1). Na can be toxic to photosynthetic activity, chlorophyll synthesis and antioxidant enzymes if available in higher amount[44]. Translocation factors for K ranged from 0.45 to 0.90, with the highest value in the sample of *D. colorata* and the lowest in *E. burmanica* (Fig. 2). Tolerant plants tend to restrict soil–root and root–shoot transfers, and therefore have much less accumulation in their biomass, while hyperaccumulators actively take up and translocate metals into their aboveground biomass.

In the present investigation, 12 different plant species naturally grown on the industrially contaminated soil was studied and found *C. cambogiensis, D. aegyptium and D. ciliaris* species were found efficient for Na and K reclamation from contaminated soils. These plants can be grow easily on contaminated wasteland soil and subsequently may be used as a raw material for commercial extraction of metals.

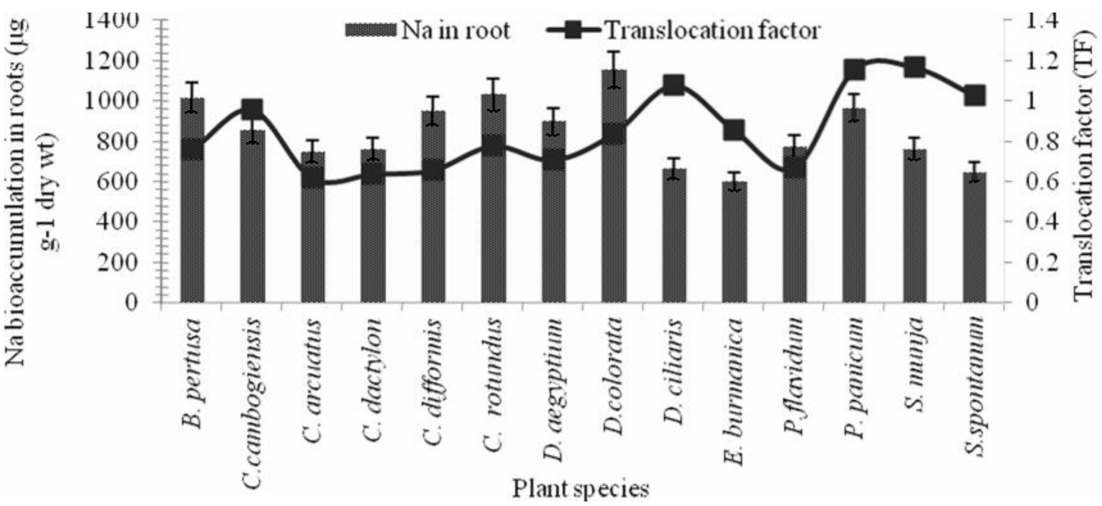

Figure 1. Translocation factors of Na in weeds grown in industrial wasteland soil

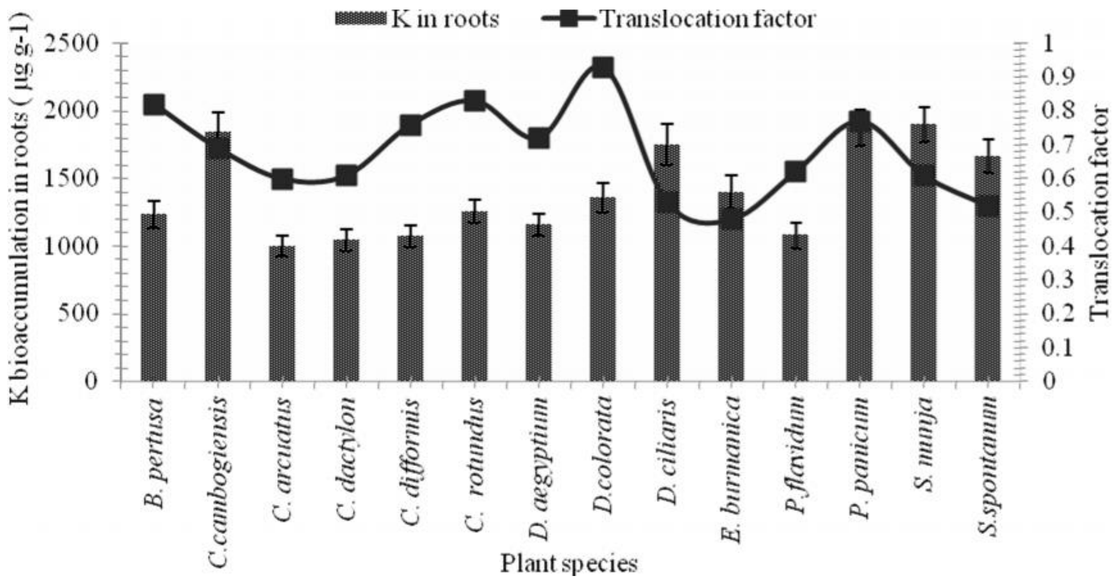

Figure 2. Translocation factor of Na in weeds naturally grown in industrial wasteland soil.

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