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Assessment of phytoremediation potential of native grass species growing on red mud deposits

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ABSTRACT

The present study deals with the remediation of red mud deposits through the naturally growing native grass species. On the basis of visual observation we noticed that *Saccharum bengalense* Retz. is a dominant grass species of vegetation on red mud deposits. The results showed that most of the elements are stabilized in root part of the plant except Fe, Zn and Cd. Therefore, it reveals that *S. bengalense* has the capability for phytostabilization of red mud deposits, is a promising species for the remediation and management of red mud deposits.

1. Introduction

Ever increasing amount of solid waste dumps like fly ash, red mud, sewage sludge and other mining wastes has become inevitable and consequences the toxicity of ecosystems and creates harmful environment. Due to increasing amount of these solid wastes, heavy metal pollution becomes a topic of social challenge. Furthermore heavy metal pollution creates unfavourable condition on soil microbes and plant growth just because of its inauspicious substrate chemistry (Pandey and Singh, 2012). Red mud is one of the main solid waste products generated from alumina industry, which inhibits the plant growth due to its high alkalinity and salinity (Mishra et al., 2016; Alshaal et al., 2013). Abandoned red mud land causes dust, air and water pollution which consequences the harmful environment for humans and livestock. Therefore, rehabilitation approach for these abandoned lands is very necessary that would make possible the substrate fertility and mitigation of global warming through phytorestoration (Pandey and Singh, 2012; Verma et al., 2014). Recent practices that would initiate the restoration are also quite beneficial for the biodiversity assessment of that barren dump sites. Towards the recovery of these sites, it is important concept that plant–microbe interactions induce such changes in soil properties during early primary succession which initiates the development of a vegetation ecosystem (Knelman et al., 2012). Through rhizodeposition and uptake of nutrients plant roots significantly influence the nutrients availability in the plant rhizosphere (Koranda et al., 2011).

Apart from this some naturally growing plant species showed a great promise in view of their best adaptation against these type of derelict lands (Gupta and Sinha, 2008; Maiti and Jaiswal, 2008; Rau et al., 2009). Some plant species such as *Arundo donax L.* (giant reed), *Lolium perenne*, *Trifolium pratense*, *Agrostis stolonifera*, *Fescue longifolia*, *Holcus lanatus*, *Trifolium repens*, and *Trifolium pratense* have been tested to restore abandoned red mud deposit sites in vegetated area (Alshaal et al., 2013; Courtney and Mullen, 2009; Courtney et al., 2009). It is well known that naturally growing plant species has more capability to restore easily waste dump sites compared to introduced plant species because of inherent capability (Pandey and Singh, 2011; Pandey et al., 2015). *Saccharum bengalense* Retz. is native grass species belongs to poaceae family (Fig. 1). It is locally known as Munj, Baruwa grass. This grass has extensive deep root system and fastens colonization that makes its growth suitable on barren red mud land. Previously this grass species has also reported for their adaptation on the abandoned fly ash lagoons (Pandey et al., 2012; Chauhan and Ganguly, 2011). Thus, *S. bengalense* is identified as a promising grass species for rehabilitation and restoration purpose. Keeping all these points in mind, the main objective of this study was to evaluate the phytoremediation potential of this naturally growing native grass species on derelict red mud deposits. (i) elemental analysis in plant parts and substrate; (ii) correlation between plant parts and substrate; (iii) evaluation of bioconcentration and translocation factor.

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Fig. 1. Naturally growing grass species *Saccharum bengalense* Retz. on Red mud deposit site.

2. Material and methods

2.1. Study site description

The plant and soil samples used in this study were collected from Hindalco Industries Pvt. Ltd. (lat. 24°12′0″N; long. 83° 65 2′0″E), Renukoot, a known iron rich site is situated in an area of Sonebhadra district of Uttar Pradesh, India. Annual rainfall measuring in this region is 1032 mm. Average temperature marks 32–46 °C in this area.

2.2. Collection of samples, preparations and chemical analysis

Rhizosphere (RS) and non-rhizosphere (NRS) RM samples of *S. bengalense* and their associated plant samples were collected in December 2014. These samples were collected on the basis of their coverage at site. RM samples were taken from the depth of (0 − 30) cm rooting zone. Homogenised red mud samples were oven dried and sieved by 2 mm stainless steel sieve and used to analyze the chemical parameters and elements. The pH and electrical conductivity (EC) of red mud were measured by using a pH meter and a conductivity meter (Orion Star A215), respectively. Water Holding Capacity (WHC) was analyzed by the method described by Black et al. (1965).

Collected plant samples were separated into three parts that is root, stem and leaf. These plant samples washed very carefully with deionised distilled water to remove adhered soil particles. After washing plant samples were oven dried at 80 °C overnight to obtain constant weight. Plant and Red mud samples (0.1 g) were digested for estimation of elements with 5:1 ratio of HNO3 and HClO4. After digestion process samples were filtered and volume was made up upto 50 ml with mili-Q water. Different elements concentrations were analyzed by atomic absorption spectrophotometer (AAS). Red mud total P in digested samples was analyzed by using the manual of Kalra and Maynard (1991).

2.3. Statistics

The results are expressed as mean ± standard deviation with three times independently using sufficient replicates. Pearson correlation coefficients applied between metal concentrations in the aboveground and underground tissues and soil factors with using Graph Pad prism software.

3. Result and discussion

3.1. Characteristics of abandoned Red mud site

Physicochemical properties and elemental analysis represented in Table 1. Red mud is highly alkaline in nature with an average pH of approximately 11.67. Solubility of salt content in red mud is represented as electrical conductivity (EC) of water extract. Average EC of non-vegetated Red mud was found 5076 (μS cm^{-1}).

Table 1
Physicochemical characterization of abandoned Red mud deposits (Mean ± SD).

Chemical characteristics	Values (N = 5)
pH	11.67 ± 0.21
EC(μS cm^{-1})	5076 ± 11.55
Total P (μg g^{-1})	113.0 ± 2.65
WHC	58.14%
Porosity	2.72%
Elements (μg g^{-1})	
Fe	145,533.33 ± 57.74
Cu	110.0 ± 13.23
Mn	441.67 ± 2.89
Zn	235.0 ± 5.00
Cr	30.33 ± 0.29
Cd	56.83 ± 0.29
Pb	361.00 ± 8.32

The average concentration of total P in the non-vegetated Red mud was found 113.0 μg g^{-1}. Various elements are investigated in red mud and their accumulation trend was found in following order Fe > Mn > Pb > Zn > Cu > Cd > Cr. Here in this study between all heavy and essential elements Fe was found maximum. Additionally heavy metals concentration in red mud is low in comparison to essential elements and varied greatly. Pb concentration was found maximum among all heavy metals which may indicate that it comes from large source of contamination.

3.2. Elemental analysis in plant parts and substrate

All essential and heavy metal concentration (except Fe) in plant tissue (root, stem and leaf) and soil are shown in Fig. 2A, B. This data analyze that significantly, very higher concentration of Fe was found in soil in comparison to all other essential and heavy metals, that's why it is shown separately in Fig. 2A.

While on other hand high Mn and Pb content was observed in rhizospheric RM sample of *S. bengalense* when compare to the Cr, Cd and Cu content. This is just because the capacity of some plants which can colonize the some part of elements into the soil (Nouri et al., 2009). The compartmentalization of elements in the plant parts shows that *S. bengalense* accumulated higher content of Fe (3571.5 and 9043.33, 5871.67 μg g^{-1}) in their underground (Root) and aboveground (Stem and leaf) parts rather than other essential and heavy metals due to the maximum concentration of Fe present in this particular site. Higher Zn, Cu and Mn content were accumulated in the root of plant when compare to the heavy metals like Cd and Pb except Cr. *S. bengalense* is a monocotyledons category of plant which accumulate generally the higher concentration of Pb in their root part when compare to stem (Fitzgerald et al., 2003). As we know that Zn and Cd both elements are very important for absorption and transportation mechanism of plants. Here in this study Zn depresses the Cd uptake because of its higher affinity with the plasma membrane (Mengel and Kirkby, 2001; Hart et al., 2005). The concentration of elements in shoots were maintained at low level which represented that metal tolerating strategy is widely evolved in the plant species growing in metal enriched area.

3.3. Correlation between plant parts and substrate

Various external (soil associated) and internal (plant associated) factors are responsible for the uptake of elements into plants, when grown in metal enrich substrata. So here in this part Pearson correlation coefficients was measured between elemental concentrations in the underground and aboveground tissues and soil factors for determination of connection between plants and soil factors , which are given below in the Table 2.

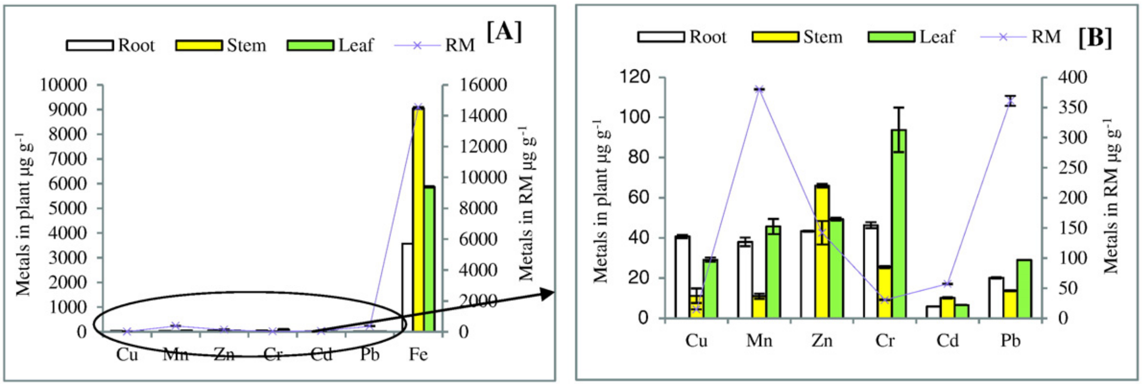

Fig. 2. Elemental concentration in root, stem, leaf of *S. bengalense* and in its rhizospheric Red mud.

In this study soil pH indicates highly significant negative correlation into Zn and Cd content of root tissue. Same significant negative correlation obtained between pH and Cu, Cd content into leaf of plant. Negative correlation and lack of correlation only implies that, sometimes these soil factors are not responsible for the metal uptake into plant parts (Keller et al., 1998; Greger, 1999). Beside it pH correlated significant positive relationship in Cd content of plant shoot. Soil EC is another important factor which affects the bioavailability of elements to plant. In case of EC positive significant correlation observed with Fe content in root of plant. Respectively same significant positive correlation found in Fe, Cu and Zn content in aboveground parts of *S. bengalense*. P had positive effect on Mn uptake by underground and aboveground tissues of *S. bengalense* but no any significant correlation was observed with other elements. This is due to the strong metal absorption tendency of p in rhizospheric zone (Kabata-Pendias and Pendias, 1984). Whereas sometimes high p level in rhizosphere may reduce the availability and uptake of metals by plants due to chemical reaction.

Table 2
Pearson correlation coefficients between element concentrations in the above-ground and below ground tissues and soil factors.

Belowground tissues (Root)	Soil factors		
	pH	P	EC
Fe	0.82	NS	0.99*
Cu	−0.89	NS	−1.00**
Zn	−0.97*	NS	NS
Mn	NS	0.96	NS
Cr	NS	NS	NS
Cd	−0.97*	NS	NS
Pb	NS	−0.93	NS
Aboveground tissues (Leaf)			
Fe	NS	NS	0.89
Cu	−1.00**	NS	−0.89
Zn	NS	NS	NS
Mn	0.93	0.86	NS
Cr	NS	0.92	NS
Cd	−0.97*	NS	NS
Pb	NS	NS	−0.94
Aboveground tissues (Shoot)			
Fe	NS	NS	NS
Cu	NS	NS	0.92
Zn	NS	NS	0.94
Mn	NS	0.84	NS
Cr	NS	NS	NS
Cd	0.97*	NS	NS
Pb	NS	−0.83	NS

NS no significant correlation.
* Correlation is significant at the 0.05 levels.
** Correlation is significant at the 0.01 levels.

3.4. Bioconcentration factor and translocation factor

Bioconcentration factor is a tool to estimate elemental accumulation ability of the plants from the substrate. It can be calculated for each plant part such as root, stem and leaf by the following equation as: Bioconcentration factor = Metal in plant part/Metal in substrate (Kumari et al., 2013). Translocation factor is an important asset to assessa plant's potential for phytoremediation purpose. It is based on the ratio of element in plant stem as compared to the plant root (Pandey et al., 2012). Bioconcentration factor values for all elements in root and leaf are lower than 1 except Cu and Cr (Fig. 3A, B). Previously it was reported that if bioconcentration factor value was found more than 1 then plant indicates the potential phytoremediator species (Zayed et al., 1998; Zhang et al., 2002). Here in this study bioconcentration factor values greater than one for Cu and Cr could possibly phytoremediate these elements from the dumped red mud site. The trend of translocation factor was found in following order Fe > Cd > Zn > Pb > Cr > Cu > Mn (Fig. 3C). This trend represents that in naturally growing *S. bengalense* on red mud deposits, only Fe (2.53), Cd (1.75) and Zn (1.52) can effectively transfer into leaf part. Whereas other elements like Cr, Pb, Cu and Mn were largely retained into root parts. Previously it was stated that if translocation factor was found maximum than 1, plant can be reported as metal accumulator and efficient for phytoextraction (Baker, 1981; Fitz and Wenzel, 2002). Here among all the elements analysedin *S. bengalense* was most efficient in translocating Fe, Cd and Zn. As we know that Fe and Zn are essential elements for the plant metabolism so higher translocation of both elements can easily understand.

4. Conclusion

The present study on *S. bengalense* Retz. was first report highlighting its phytostabilization potential which naturally growing on red mud deposit and has adaptive potential against its high alkalinity. Results indicate that the grass was capable of transferring the elements absorbed into the shoot to give higher translocation factors especially with Fe, Zn and Cd. Accumulation ability of elements into aboveground tissues is a positive indicator of its potential to serve as a phytoremediation. Besides above three metals, rest of the metals are stabilized in root part of the plant. Therefore, this plant could be used for phytostabilization as well as phytoextraction purposes. Furthermore, the plant being not consumed by animals in its mature stage but it could be possibly consumed in its young stage. The knowledge and insights provided here can be used for remediation and management of red mud deposits by practitioners and stakeholders through using this promising grass species.

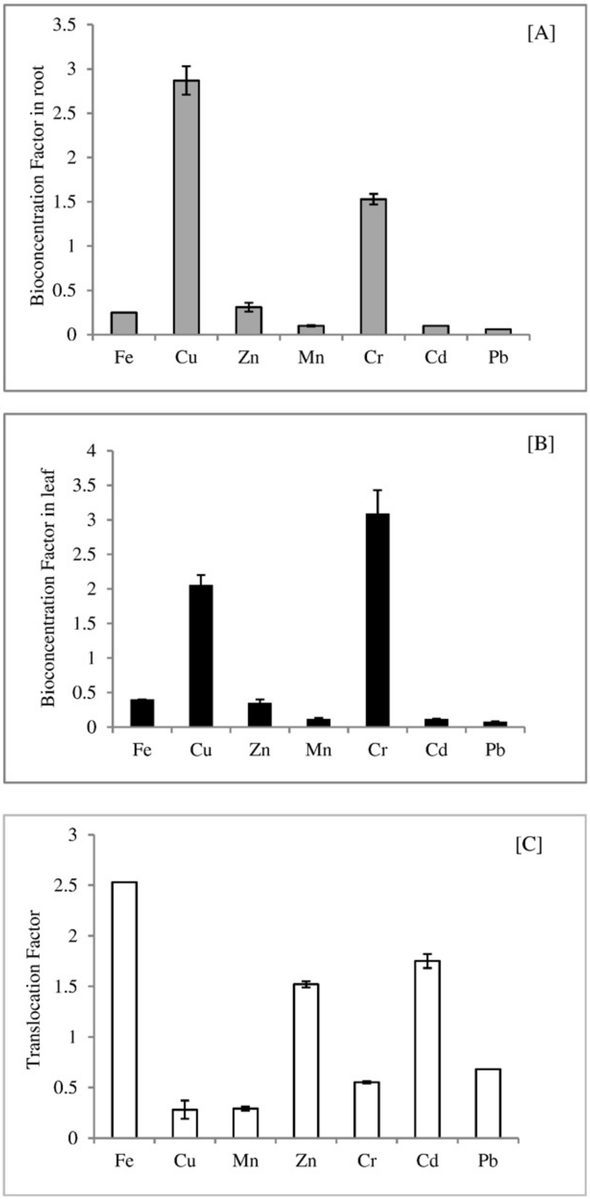

Fig. 3. Bioconcentration factor in root [A] and leaf [B] and Translocation factor [C].

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