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Application of green remediation on soil salinity treatment: A review on halophytoremediation

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ABSTRACT

The salinity of soil and water resources is one of the economically expensive challenges to achieve sustainable development across the world. Salinity, which is a major environmental issue for both arid and semi-arid regions, is highly stressful for vegetation and adds to other stresses including water scarcity, nutrient deficiencies and soil alkalinity. Remediation is a strategy to clean up pollutants from the plant root zone in order to reduce vegetation stress and enhance productivity. This strategy involves biological management of soil and water which often leads to increased soil infiltration and leaching of excess salts out of the root zone. Several methods of soil and water remediation have been proposed that can be classified into the two main groups of engineering-based remediation and green remediation. Green remediation is the use of vegetation to remove or contain environmental contaminants such as heavy metals, trace elements, organic compounds and radioactive compounds in soil or water. There has recently been increased interest in green remediation using halophytes, particularly in developing countries. This paper reviews the different methods of phytoremediation and their application in green remediation. It also describes how halophytes are an emerging means of desalination and how they can be used for phytoremediation of heavy metals.

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1. Introduction

In the last two decades, the technology of green remediation was introduced and developed widely. Use of natural system processes such as bioremediation (using microorganisms to remove or neutralize contamination) and phytoremediation (using plants to absorb, remove or break down contaminants) are two main practices of green remediation (Flathman and Lanza, 1998; Frankenberger et al., 1989; Mejáre and Bülow, 2001). One of the drivers for the increased use of green remediation technologies such as phytoremediation and bioremediation is the relatively low cost technology compared to engineering-based remediation approaches (Pilon-Smits, 2005). The problems of soil salinity persists as the agricultural land expands shrinking the cattle grazing land and the encroachment of saline soil vegetation grazing has compounded to loss of vegetation and impacted the cattle health (Di Bella et al., 2014). It also results in the degradation of both wetlands and wildlife habitats (Wang et al., 2012). The soil salinity also impacts farm lands by effecting on germination of crops and as a result a decline in overall agricultural output including the organic carbon mineralization (Kim et al., 2012; Setia et al., 2011). For instance, there was a mild change in the chemical properties of rice grain character under mild salt stress but as the stress increased the stress was impacting on yield (Thitisaksakul et al., 2015).

Not only the soil salinity issues are we dealing in the modern economy but it is the water salinity that also is an integral part of salinity problem. Promoting long-term sustainable water management necessitates a progressive strategy of decreasing pollutant discharges to the environment. Wastewater systems with different sources of domestic, commercial and urban effluents, generate both organic and inorganic contaminants (Saha et al., 2014). Organic pollutants are mostly anthropogenic and are often toxic being released to the ecosystem. Inorganic pollutants not only originates as a natural phenomenon in the earth crust or atmosphere but also by human activities such as mining, agriculture or military activities that enhance the release of pollutants to the environment causing harm to natural ecosystems (Nriagu, 1979; Pilon-Smits, 2005).

Different engineering-based remediation techniques have been developed over the last few decades to treat contaminated sites. Finding an appropriate remediation strategy is a difficult task (Bage et al., 2002). The most popular ones are (a) immobilization technologies (using barriers, reducing permeability and solubility) (b) toxicity reduction technologies (chemical treatment), and (c) separation/concentration technologies (soil removal, soil flushing and electro-kinetic extraction) (Mulligan et al., 2001). The high cost of these technologies was one of the obstacles that have delayed their worldwide adoption. In 2003, it was estimated that annual environmental remediation costs were $8 billion in the US and around $50 billion worldwide (Tsao, 2003).

In green remediation strategies, different vegetation species with different properties are selected to enhance pollutant accumulation. Generally, plants need to be fast growing, tolerant to contaminants, of high biomass capability, and with higher phytoaccumulative behavior (Kopittke and Menzies, 2005). Agronomic activities, supplementary irrigation, fertilization, and genetic engineering are other alternatives to increase or manipulate the rate of plant uptake (Abedin et al., 2002; Negri et al., 2004). Vegetation uptake varies for organic and inorganic pollutants. For organic compounds, there is no membrane transporter in the plants, so pollutant movement is mainly through diffusion while for the inorganic pollutants, uptake occurs through biological processes and movement is by membrane transporter. Incomplete knowledge of these biological processes has resulted to limitations in application and efficiency of phytoremediation techniques. However, what is obvious is that higher bioavailability of pollutants and more contacts between plants and their microbes would enhance remediation efficiency (Pilon-Smits, 2005).

Bioavailability of pollutants is correlated with soil and plant conditions, chemical properties and biological activities of the contaminants, and environmental parameters (Petruzzelli et al., 2015). Clay soils with their higher soil moisture holding capacity than sandy soils have more binding opportunities for chemical ions present in organic matter (Nwoko, 2010). The movement of contaminants in the soil is influenced by their volatility and hydrophobicity. Pollutant volatility measures the ability of a contaminant to move in the water. Hydrophobicity shows how pollutants can be transferred from soil/water to the plant expressed in terms of the octal water partition coefficient ($\log K_{ow}$) (Barbafieri and Tassi, 2011).

Salts are naturally available in the soil and groundwater. Higher than natural levels of soluble salt in the soil or water can result in salinity with hazardous risks for plant health and productivity. More than 75 countries around the world are struggling with salinity problems (Alaghmand et al., 2016; Qadir et al., 2007). It is estimated that at least 20% of the irrigated lands in the world are affected by varying levels of salt (Qadir et al., 2008) and that this costs approximately US$ 12 billion per year in 1995 costs (Ghassemi et al., 1995). Desalinization of soils by halophytes was first suggested by Boyko (1966). Since then several studies have been conducted to investigate the possibility of saline soil reclamation using different species of halophytes (Honey-Rosés et al., 2014). Some of these studies also refer to other advantages of halophytes such as their potential as forage and oil seed crops. There are approximately one billion ha of salt-affected areas in the world (Yensen and Beil, 2006), these being mainly located in the Middle East, Central Asia, Northern Africa and Australia (Alaghmand et al., 2013; Alaghmand et al., 2015). This remarkably vast area provides a significant opportunity for halophytology.

2. Salt-affected soil categories

Salt-affected soils can be grouped into saline soils, sodic soils and saline-sodic soils (Brady, 2002). Almost 40% of salt-affected soils in the world are saline and 60% are sodic (Qadir et al., 2006; Tanji, 1990). Saline soils are distinguished by the large content of soluble salts, sodic soils with higher levels of sodium ions and saline-sodic soils with an excess of salts and exchangeable sodium (Sastre-Conde et al., 2015) (Table 1).