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Review

Economic importance of *SALIX* to the Ecosystem

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Economic importance of *Salix* is currently increasing and emerging in a wide array of practical applications to restore damaged ecosystems. *Salix* spp which are characterized by particular physiological adaptations and ecological resilience are predisposed to use in conservation and environmental projects in many climatic zones and adverse micro site conditions. The present paper throw light on the current use of willows well beyond wetland and riparian situations such as in phytoremedation (phytoextraction, phytodegradation, rhizofiltration and phytostabilization) based on literature review.

Key words: *Salix*, phytoremedation, phytoextraction, phytodegradation, rhizofiltration, phytostabilization, ecosystem.

INTRODUCTION

Stupendous increase in population over the years exceeding one billion, which is about 1/6th of the world population in our country India, exerts heavy pressure on our renewable and non renewable natural resources. This increasing pressure is responsible for huge depletion of these resources resulting not only in alarming deficit between demand and supply of forests based products, but also in ecological disturbances. In order to mitigate pressure on the forests, different kinds of trees like Poplars, *Eucalyptus, Robinia*, *Ulmus*, *Casuarina*, willows etc. are used on short rotation basis to fulfill the need of these products. Among the above mentioned species, *willows are worth* promising having multipurpose benefits. It is suitable for biological control of soil erosion, siltation, nutrient cycling, carbon sequestration, filtering of sewage, polluted water and phytoremedation (Verwijst 2001). In addition to this, its wood is suitable for veneer, pulp, plywood, laminated wood, reconstituted wood products, artificial limbs, fruit boxes, agriculture implements, furniture, tool handles and sports goods like cricket bat, polo balls.

Willows have a high wildlife value, providing rich habitat and food for diverse organisms (Hightshoe, 1998; Sommerville, 1992). There is evidence for a rich insect fauna (up to 450 species) associated with willows (Kennedy and Southwood, 1984). Numerous invertebrate herbivores from aphids to caterpillars feed on willows, and support a large food-web of higher trophic level organisms. Many animals depend on willows for food (mostly leaf, stem and bud tissue) and shelter; willows provide browse for large number of animals and willow wood is a preferred food and building material for beavers (Smith et al., 1978). Willow stands support a high density for breeding bird communities and wetland willow thicket provide stopover sites for about sixty bird species, the highest number for all studied habitats (Bates, 1951). Their overhanging crowns above streams supply cover, shade, and a source of food in the form of insects for fish. Opportunities for viewing moose as well as elk, deer, songbirds and waterfowl add to the recreational value of willow associations (Kowalchik, 2001).

A Willow belongs to the genus *Salix* and family *Salicaceae*. The word *Salix* is derived from Celtic 'Sal' meaning near and 'lis' meaning water. Willows range from prostrate shrubs to large tree over 30 meters high, but most are shrubs or small trees. They are usually found on damp ground or along river and stream margins. There are about 250 species of willows in the world mainly distributed in North Temperate Zone. Among them there are 50 species, utilizable as arborescent willow and few (around 15 species) that are tree willows. About five species of willow are distributed in tropical and subtropical region of the world. In India, there are around 33 species and most of them are categorized as shrubs except *S. tetrasperma*, *S. alba, S. daphnoides, S. fragils* and *S. babylonica*.

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Salix has become increasingly useful for environmental restoration, providing a cost effective material for stabilization and reclamation of disturbed landscapes, and phytoremediation, both riparian and upland erosion control and biomass production. Our objective here is to describe the use of *Salix* in phytoremediation: a method that uses plants to detoxify organic and inorganic pollutants in groundwater and soil (Perttu, 1993; Ballag et al., 1994).

The essential physiological characteristics that make *Salix* suitable for environmental restoration are as:

i) Superior growth and productivity even at juvenile stages; the highest capacity to convert solar radiation into chemical energy among woody plants under certain climatic conditions (Christersson et al., 1993; Wilkinson, 1999).

ii) Extensive fibrous root system in many shrub-type species, with the majority of fine- roots found in the upper 40–45 cm of the soil profile; continuous growth of fine roots from May through October (Gray and Sotir, 1996; Rytter and Hansson, 1996).

iii) High rates of evapotranspiration during the growing season (Persson and Lindroth, 1994; Lindroth et al., 1995; Ledin, 1998; Ebbs et al., 2003).

iv) Efficient uptake of nutrients (Ericsson, 1981; Elowson, 1999); high filtering capacity for nitrogen; ability to facilitate denitrification in the root zone (Aronsson and Perttu, 2001).

v) Tolerance of flooded or saturated soils and oxygen shortage in the root zone (Jackson and Attwood, 1996; Krasny et al., 1988; Aronsson and Perttu, 2001; Kuzovkina et al., 2004a); some species are tolerant to increased concentration of carbon dioxide and methane (Maurice et al., 1999).

vi) Ease of vegetative propagation due to preformed root primordia on the stems, and possibility of vegetative reproduction from horizontally lain willow rods (Carlson, 1950; Gray and Sotir, 1996).

vii) Vigorous re-establishment from coppiced stumps (Ceulemans et al., 1996; Philippot, 1996).

viii) Ability to accumulate high levels of toxic metals, especially Cd (Klang-Westin and Eriksson, 2003).

In addition, all *Salix* species are well adapted to light and moderate fire regimes, resprouting from roots or root crowns; some willows are considered drought tolerant, tolerant to deposition and resistant to moderate salinity (Kraebel, 1936; Mang and Reher, 1992; Gray and Sotir, 1996; Hightshoe, 1998; Kowalchik, 2001).

APPROACHES TO PHYTOREMEDIATION

Phytoextraction

Phytoextraction is attributed to the removal of a contaminant by uptake processes into the plant tissue using translocation. When this mechanism is active, the phytoremediation application requires that the contaminant is removed from the environment by harvesting the plant. Resistance of willows to some metals (Cd, Cu, Zn, Ni, Pb, Fe) and its ability to accumulate significant amounts of metal in plant tissues has been documented and suggested its possible use for metal extraction (Punshon and Dickinson, 1997; Ali et al., 1999; Watson et al., 2003; Ali et al., 2003; Keller et al., 2003; Kuzovkina et al., 2004b; Dickison and Pulford 2005; Dickinson et al., 2005; Vandecasteele et al., 2005; Dimitriou et al., 2006; Lewandowski et al., 2006; Vervaeke et al., 2006; Meers et al., 2007). The studies show much promise for decontamination of cadmium (Dickinson et al., 1994; Landberg and Greger, 1994; Greger and Landberg, 1999; Robinson et al., 2000; Klang-Westin and Perttu, 2002). While *Salix* should be defined as high accumulator of metal rather than a more efficient hyper accumulator as there is an essential advantage of *Salix* over herbaceous species for use in phytoextraction. Herbaceous hyper accumulators have shallow root systems, but willows are recommended for deeper soil contamination. A combination of high metal concentrations in tissues, extensive root system, perennial habit and high biomass results in high potential for removal of significant amounts of Cd at stem harvest about 2.6–16.5 g Cd ha^{-1} $year^{-1}$ (Keller et al., 2003; Klang-Westin and Eriksson, 2003; Lunackova et al., 2003). Profitable biomass production is an additional advantage of *Salix* over the herbaceous species, providing the farmer with an additional income during the restoration time (Eriksson and Ledin, 1999).

Phytodegradation

Phytodegradation results when contaminants are degraded within plants through metabolic processes or through degradation external to the plant through the effects of enzymes produced by the plant. Transformation, uptake and metabolism processes that occur within a particular application account for phytodegradation mechanisms. Uptake and transformation are dependent upon the contaminant hydrophobicity, solubility, and polarity while the ability of poplars to remove a large array of organic contaminants by absorption into plant roots is well documented, new evidence shows a favorable impact of willows on the fate of organic pollutants. Prairie Cascade willow (*Salix* x'Prairie Cascade') has shown vigorous growth on blackened soil produced by an oil spill and capability of cleaning the soil via stimulation of oil-degrading microbes associated with their roots (Thompson, 1998).

Willows have been recommended for recultivation of oil-mining areas in the Siberian taiga. Willow stakes planted in degraded areas without soil amendment quickly formed green cover, accelerating the disappearance of chemicals compared to bare land plots.

Faster sequestration of pollutants than in previous attempts, when herbaceous plants were seeded on an expensively imported layer of soil, had been recorded (Chralovich, 2000). There is evidence that a significant decrease of 57% in mineral oil concentration in the plots planted with willow as opposed to 15% on fallow plots, took place on disposal sites for dredged sediment (Vervaeke et al., 2003). Willows' ability to transport oxygen down to the root zone through aerenchyma formation may contribute to providing better conditions for bacterial growth. A study of planting of willows on landfill (Maurice et al., 1999) has shown that those sites have higher methane oxidation rates compared to plots without trees. Trees with their extensive root systems may provide a better environment for methane oxidizing bacteria thus allowing its emission into the atmosphere. Promising results in remediation of shallow aquifer sites contaminated with ethanol-blended gasoline spills using willow and its tolerance to increased levels of ethanol, has been reported (Corseuil and Moreno, 2001). In a laboratory experiment, cuttings of weeping willow (*Salix babylonica*) were able to reduce ethanol and benzene concentration in aqueous solution by more than 99% in less than a week through root uptake and sorption to plant biomass. It was suggested that uptake was significantly related to the plant's transpiration. Willows show possible utility for the remediation of sites contaminated with cyanide compounds. Transport and metabolism of cyanide and ferrocyanide by willow has contributed to the degradation of these contaminants in the wastewater from gold mining (Ebbs et al., 2003). While many plant species produce cyanide (mainly in the form of glycosides) for chemical defense and plant cells in general have a high capacity to eliminate free cyanide, there is some evidence that willow roots and leaves have the fastest rates of cyanide removal (Larsen et al., 2004).

Rhizofiltration and rhizodegradation

Rhizofiltration and rhizodegradation both use the beneficial symbiotic relationships between soil microbes and plant roots and exudates. Rhizofiltration extracts and captures contaminants, whereas, rhizodegradation goes one step further and destroys contaminants in the root systems. Rhizofiltration is more beneficial in applications requiring the removal of metals from groundwater or soil, whereas, rhizodegradation is more beneficial in applications that include organic contaminants. Another important feature of phytoremediation techniques is the relationship between root exudates and rhizodeposition. This relationship is important in stimulating aerobic biodegradation of the chemical substrate prior to plant uptake. As a plant grows, root systems expand progressively, and fine roots and root hairs die and decay as the roots grow outward. This process, known at rhizodeposition, allows the decaying root material to act as a substrate for enhanced microbial activity (Shimp et al., 1993). Root exudates are secretions that leak from epidermal or cortical cells of a plant root. These secretions are a result of metabolic activity as a plant consumes nutrients. Exudate composition varies between plants, but can include sugars, amino acids, organic acids, fatty acids, sterols, growth factors, nucleotides, flavanones, enzymes, and numerous other compounds. This process provides additional substrate for microorganisms, which may be essential to degrade soil contaminants. The rhizosphere can also influence other chemical processes, which may be critical to organic chemical biodegradation. Nitrogen fixation, solubilization of phosphorus, trace mineral transfer, and oxygen transfer all play important roles in the stimulation of microbial activity in the rhizosphere. Nitrogen, which is a limiting factor in plant growth, can be fixed in soils by several processes. The largest and most important of which is symbiotic or nonsymbiotic biological nitrogen fixation (Shimp et al., 1993). The symbiotic relationship between legume plants and heterotrophic bacteria allows nitrogen fixation to occur in plants. Some bacteria, such as *Azotobacter* and *Clostridium* are capable of nonsymbiotic nitrogen fixation, as well. These relationships result in more nitrogen for plant growth and, subsequently, more organic substrate for microbial consumption. This stimulates microbial activity and furthers biodegradation of organic contaminants before uptake into the plant. Species of genus *Salix* commonly growing along streams and swamp areas have been proposed as essential elements for vegetation filters, from which planting led to a substantial reduction of the polluted load (Elowson and Christersson, 1994; Kirt, 1994; Obarska-Pempkowiak, 1994; Perttu and Kowalik, 1997; Rosenqvist et al., 1997) and are considered as a potential remedy for improving quality of domestic, municipal wastewater and agricultural runoff. Physiological characteristics of *Salix* such as high rates of evapotranspiration, efficient nutrient uptake, tolerance of flooded conditions, and high biomass productivity, are crucial for the use of willows for vegetation filters. High accumulation of metal in their roots compared with other macrophytes and algae (Ali et al., 1999), the ability to transport oxygen down to the root zone through aerenchyma formation contributing to better conditions for bacterial growth, and harvestable biomass providing necessary lignin for composting operations add to the value of willows included into constructed wetlands.

Phytostabilization

Phytostablization can result in the fixation of mobile or toxic contaminants within the root zone either by immobilization through absorption and accumulation by roots, or precipitation within the soil in the root zone. Phytostabilization will occur through root zone microbes and soil chemistry as associated with the exudates and the production of carbon dioxide. Phytostablization can lower the solubility of metals and their mobility. This mechanism may enable stabilization of toxic metals and/or organic compounds to levels suitable for long-term monitoring in lieu of removal from the soil. Willows' ability to dry swampy soils is well known by farmers. Historical references have even mentioned that due to high rates of evapotranspiration (phreatophyte-type of vegetation), willows planted in areas affected by malaria were the most effective for drying up the earth (Going, 1903). The establishment of willow vegetative buffer zones or biocurtains, for capping landfills, sewage treatment plants, steelworks and waste dumps has been applied in phytostabilization projects that aim to control soil water (Craven, 1994; Hasselgren, 1994). Willows' ability to sequester heavy metals and other contaminants in their root systems, halting their circulation within the environment, can be of great practical use (Ettala, 1988). The dense root system, penetrating deep into the soil, high transpiration rates providing efficient control of soil water and high filtering capacity for pollutants, along with continuous growth of some species during the whole growing season, increase willows' metabolic potential and create an efficient dehydration plant while locking up the pollutants.

CONCLUSION

Salix as a fast-growing tree species has several advantages over herbaceous species, such as a deeper root system, high productivity and transpiration activity; it represents a promising resource in mitigating impacts of environmental degradation. Remediation by willow plantations can clean or mitigate hazardous waste, stabilize and restore a site and produce wood for fuel and cricket bat industry. Willows planted as vegetation filters will facilitate excess nutrient uptake, reduce soil erosion, provide habitat for numerous organisms above and below the water level, and enhance a site's visual characteristics.

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