Phytoremediation of Organic Polluted Soil

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The increasingly anthropogenic release of toxic contaminants has led to the contamination of organic chemicals, such as phthalic esters (PAEs), Polycyclic Aromatic Hydrocarbons (PAHs), Polybrominated Diphenyl Ethers (PBDEs), Polychlorobiphenyls (PCBs), Petroleum Hydrocarbons (PHC), pesticides, etc [1]. Remediation of organic-polluted soils is becoming an increasing challenge worldwide [2]. Phytoremediation is an emerging technology that utilizes plants to clean up organic pollutants and toxic metals in water, sediments, or soils [3]. Phytoremediation has been accepted and utilized widely because it is a cost-effective and environmentally friendly green technology with permanently removing the pollutants [4]. A large number of plant species have been found to be promising candidates for the phytoremediation of organic pollutants [5]. In general there are two approaches for the phytoremediation of organic-polluted soils based on the difference in remediative mechanism. First, organic pollutants can be taken up directly by plants, resulting in the sequestration or degradation of pollutants inside of plants [5], which is called phytoextraction. Second, organic pollutants can be degraded by plant-secreted enzymes or plant-modified microbial community in rhizosphere [5,6], which is called plant-assisted rhizoremediation.

Phytoextraction depends on the absorption, translocation, and metabolism of organic pollutants in plants. Some organic compounds are able to enter into plant cells by penetrating cell membrane easily. Medicag osativa and Tagetes patula are potential candidates for the phytoremediation of soils contaminated with PAEs and PAHs [7-9]. A field study indicates that M. osativa exhibits the largest Bio-Concentration Factors (BCFs) of PAEs comparing to other tested plant species, suggesting that the direct absorption and metabolism might be the main mechanisms for M. osativa-mediated phytoremediation of PAE-polluted soil [10]. Organic pollutants are artificial and thus lack membrane transporters in plant cells. The uptake of organic pollutants from soils by plant roots is mainly driven by simple diffusion based on their chemical properties and bioavailability [11]. The hydrophobicity of organic pollutants, evaluated by Kow, determines their efficiency of penetrating plant cell membrane [12]. To enhance the bioavailability of organic pollutants in soil, some amendments (e.g. Tween 80, citric and oxalic acids, biochar, and methylated-β-cyclodextrins) has been successfully applied in assisting phytoremediation of organic-polluted soils [13-15]. After entering into root cells, organic pollutants could be further translocated and metabolized in plants. The diffusion of organic pollutants from root sympatst to xylem apoplast is essential for their translocation from roots to shoots, which can be quantified by calculating the Transpiration Stream Concentration Factor (TSCF) [11,16]. Several detoxification enzymes are involved in the transformation and sequestration of organic pollutants in plants. Cytochrome P450 enzymes (CYP) play vital roles in the oxidative process for emulsifying highly hydrophobic pollutants [11,17]. Glutathione-S-transferases (GSTs) catalyze the conjugation between toxic organic pollutants and sulphhydryl (-SH) group of glutathione (GSH). GST-pollutants conjugates can be further transported and sequestrated from cytosol to vacuoles in plant cells [18].

Plant-assisted rhizoremediation refers to the strategy of phytoremediation ex planta. Plant roots not only secrete enzymes degrading organic pollutants [19], but also improve the degrading ability of microorganisms in rhizosphere [20]. Plant enzymes with the role of degrading organic pollutants have been well reviewed by Gerhardt and Nwoko, respectively [5,11]. These enzymes include laccase, nitrlase, dehalogenase, nitroreductase, etc. Although many microorganisms are capable of degrading organic compounds, microbial bioremediation approaches suffer a number of limitations for their widespread application [21]. Plants are able to improve the efficiency of microbial bioremediation of organic-polluted soils [22]. In a pot experiment, M. osativa improves soil microbial degradation ability to decrease benzo(a)pyrene concentration in soil rather than accumulates the pollutants inside of plant tissues [23]. Plant root exudates (e.g. organic acids, sugars, phenolics etc.) are commonly used as carbon and energy sources by soil microbes with the ability of degrading organic pollutants [24]. After planting M. osativa in crude oil-contaminated soil, 731 and 379 functional genes related to organic remediation were detected by microarray in rhizosphere and non-rhizosphere, respectively. This study suggested that the rhizosphere with relatively high populations of heterotrophic bacteria and hydrocarbon-degrading bacteria selectively increases the abundance of these specific functional genes [25]. In addition, plant exudates may increase the water solubility of organic pollutants, which stimulates the bioavailability of pollutants for both plants and microbes [11]. In return, microbial community also provides beneficial compounds or enzymes for protecting plants from the toxicity induced by organic pollutants [26,27]. The effective degradation of organic pollutants in soil by mycorrhiza-plants system has been extensively documented [22,28-30]. Actually, rhizoremediation is a complex degradation process with multiple fine interactions involving roots, rhizosphere soil, and microbes. The further understanding of the detailed mechanisms of these interactions is needed to better optimize the application of plant-assisted rhizoremediation.

However, the capability of using single plant species for the phytoremediation of organic-polluted soils is limited. Intercropping systems with multiple plant species are able to remarkably increase the efficiency of phytoremediation [31]. The enhanced degradation of organic pollutants by intercropping multispecies may result from the accelerated degradation rate of some recalcitrant organic pollutants.
and the elevated soil microbial biomass, microbial functional diversity, and degrading enzymes activities [10,32-34].

With the rapid development of biotechnology, transgenic modification of plants is becoming a powerful tool for enhancing the efficiency of phytoremediation of organic-polluted soil [35-37]. The genetically modified strategies are supposed to achieve the goals of enhancing the degrading rates of pollutants in planta or enhancing the release of degrading enzymes from roots leading to the accelerated degradation of pollutants ex planta [37]. The genes coding for CYP and GSTs are the usually modified targets for stimulating the degradation of pollutants [6].

References


