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MULBERRY FOR ENVIRONMENTAL PROTECTION

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Abstract

Mulberry (*Morus alba* L.) is a woody, deciduous and economically important tree, with moderate tolerance to various environmental stresses (drought, water-logging, salinity, heavy metals etc.). Mulberry leaf has been used to rear the silkworm *Bombyx mori* L., process tea and as fodder for livestock. The mulberry fruit is good for human consumption due to its highly nutritious and medicinal properties. In this review, the role of mulberry on remediation of the heavy metals, organic compounds polluted soil and dirty atmosphere has been discussed along with recent developments in mulberry research. The outline of the ecological functions of mulberry was also drawn and discussed for its developed root system, rapid growth rate, resistant to some special pressures.

Key words: Mulberry; Heavy metal; Soil remediation; Ecological function; Phytoremediation; Environment protection.

Introduction

Recently, with the rapid development of industry, the modernization of agriculture, transportation and over-intensive urban population, the introduction of anthropogenic toxic pollutants to the atmosphere, soils and ground water have caused serious threats on the self-purification capacity of the receiving environment. Consequently, the exposure and potential effect of the accumulated chemicals is of great concern to both human body and the ecosystem.

Phytoremediation is a green and promising technology, which is taking advantage of plants to absorb, transfer, degrade, or detoxify heavy metals and toxic organic compounds (Susarla *et al*., 2002). It is a relatively new technology and is considered as a novel, efficient, cost-effective, eco-friendly technology with better public acceptance.

Mulberry is a perennial, woody and deciduous plant, belonging to the family *Moraceae* and genus *Morus* native of China (Ramesh *et al*., 2014). In mulberry, a total of 150 *Morus* species was recognized, but only 68 species were given more importance, based on their use in silkworm rearing, medicinal value and sweetness of fruit (Rao *et al*., 2013). The Chinese scientists classified the genus *Morus* into 14 species and 1 variety (Huo, 2002) and the scientists in Turkey thought that there are at least 100 kinds of known mulberry varieties with 24 mulberry species and 1 subspecies (Ercisli & Orhan, 2007). China is the largest producing country of mulberry and silk worldwide and mulberry is distributed all over the country (Huo, 2002), being grown from the basin of 10 m above sea level to 3600 m on the Tibetan plateau, from western Sinkiang Hotan desert to the coastal beach in the east, from the most north of Heilongjiang province to the south of Hainan Island (Jian *et al*., 2012). Mulberry trees are also found that they can grow in a wide range of climate (from temperate to subtropical regions of the Northern Hemisphere to the tropics of the Southern Hemisphere), topographical and soil conditions. They are extensively distributed all over the districts from the tropics to the sub-arctic and from sea level to the altitude as high as 4000 m (Ercisli & Orhan, 2007; Vijayan *et al*., 2014). At the temperature of 40℃~ -40℃, the precipitation of 300 mm or above, the soil pH value of 4.5 ~ 9 range, the mulberry trees can develop naturally (Du *et al*., 2001).

Mulberry is an extraordinary multipurpose plant. The most important application is the proprietary food for the silkworm, *Bombyx mori*. The whole body of mulberry is a treasure. In mulberry leaf, fruit, stem and root, there are many kinds of organic chemicals of great medicinal value, which have anti-microbial, anti-hyperglycemias, anti-hyperlipidemias, antidiabetic, chemo-prevention, and anti-oxidative potential (Qin *et al.*, 2010; Khurana & Checker, 2011; Jian *et al*., 2012; Sharma *et al.*, 2015). The other applications of mulberry were described in a number of earlier reports (Ercisli & Orhan 2007; Qin *et al.*, 2010; Vijayan *et al*., 2011; Liu & Willison 2013; Ramesh *et al*., 2014). This paper focuses on the latest developments in applications of mulberry for remediation of polluted soils and the atmosphere. Additionally, the different ecological functions of mulberry are also discussed.

The role of mulberry in environmental management

Application of mulberry in soil remediation

Heavy metals: Large amounts of heavy metals have been discharged into soil annually due to various anthropogenic activities, such as mining, excessive fertilizer application, and wastewater irrigation in agriculture, resulting in severe contamination of soils worldwide (Wang & Björn, 2014; Tan *et al.*, 2015). The presence of excessive heavy metals in soils may lead to bad results to surrounding ecological systems, groundwater, plant, animal and human health (Houben *et al*., 2013; Nazarian *et al.*, 2016). Heavy metal pollution has the characteristics of concealment, non reversibility, long-term and serious consequences (Xu *et al*., 2015). Soil contamination by heavy metals has proved to be a serious global environmental issue, so developing an innovative, effective and sound remediation technology is necessary (Zeng *et al*., 2011; Zhong *et al*., 2015).

Phytoremediation is one of the most effective methods to remediate heavy metals in soils. So far, there are about 360 kinds of hyperaccumulators and most of them belong to Cruciferae (Huang, 2013). Although the role of hyperaccumulators in the remediation of heavy metals contaminated soil has shown a high potential, the practical application of these plants is limited due to the shallow roots, slow growth, dwarf plant, low biomass and small accumulation of dry matter (Wang *et al*., 2008). So the total amounts of heavy metal uptake and accumulate by hyperaccumulator is not much and repair efficiency is not high (Cunningham *et al*., 1995; Bao *et al*., 2010).

A lot of papers proposed that the utilization of some woody plants could be an effective solution to remove or stabilize the heavy metals in the polluted soils (Pulford & Watson, 2003; Peng *et al.*, 2012; Delplanque *et al.*, 2013; Zhou *et al.*, 2015). Mulberry also has the potential to remediate heavy metals contaminated soils (Zhou *et al*., 2015). Mulberry is a perennial woody tree with the characteristics of extensive root systems, rapid growth, high biomass production, ease in establishment and management, wide distribution and ability to grow under a wide of soil conditions (Hegde & Fletcher, 1996). Although the heavy metal concentration in mulberry is lower than that of the hyperaccumulators, the total amount of heavy metal migration is still considerable because of the large amount of mulberry biomass.

The developed root system of mulberry is helpful for itself to absorb soil nutrients, to a certain extent, also conducive to the absorption of metals in the soil (Jothimani *et al*., 2013). Ren *et al*. (Ren *et al*., 2009) researched the effects of different Pb levels on the growth of mulberry and folia quality by a way of combining pot experiment and indoor test together. The result showed that plant height had an ascending trend at lower concentrations of Pb (≤200 mg/kg dry soil). When the Pb concentrations in the soil were more than 200 mg/kg dry soil, the growth of mulberry and mulberry leaf quality began to be obviously inhibited. Zhou *et al*. (Zhou *et al*., 2015) investigated the transportation characteristics of Pb in the food chain of soil-mulberry-silkworm by pot experiment and concluded that the concentrations of Pb in different organs of mulberry were in the order of roots>stems>leaves and mulberry planting and silkworm feeding could be a potential way in remediation of Pb-polluted soils. The migration ability of Cd in mulberry was better than that of Pb (Prince *et al*., 2001) and Cd was mainly accumulated in roots, followed by stem. The Cd in leaves, however, was little. When the concentration of Cd in soils was in the range of 8.49~75.8 mg/kg, about 40% of Cd absorbed by mulberry was concentrated in roots, about 16% in leaves (Chen *et al*., 1999). Even the concentration of Cd in soils reached 145 mg/kg, the lethal concentration of mulberry, the Cd in mulberry leaves was only 3.32 mg/kg (Wang, 2002). Many papers have proved that there were a few differences in the growth and development of silkworms, the production and quality of cocoon when the silkworm was fed on leaves from the mulberry cultivated in polluted field areas. Developing sericulture may be a safe, economical, eco-efficient utilization of heavy metals contaminated areas (Wang *et al*., 1998; Tan, 2008; Yan *et al*., 2014; Jiang *et al*., 2015).

Mulberry is a crop which has relatively high economic value in Asia, which possesses the tolerance and enrichment ability to certain concentrations of Cd. When the Cd in soil was less than 22.3 mg/kg, the output of mulberry leaves was higher than or equal to that of control. The production of mulberry leaves was reduced and the leaves shown some toxic symptoms when the Cd concentration was above 22.3 mg/kg (Chen *et al*., 1996). However, Wang *et al*. (Wang *et al*., 1998) conducted a micro-plot experiment and drew the conclusions that the growth and leaves production of mulberry were not affected obviously when the concentration of Cd in soils was less than 10 mg/kg. When the Cd concentrations were in the range of 20~40 mg/kg, the output of mulberry leaves was decreased 10%~30%. The mulberry tree was impending death when the Cd concentration was reached 145 mg/kg. Fifty percent of Cd absorbed by mulberry was gathered in their roots and only 10% of which was in their leaves. Mulberry had also a strong resistance of toxicity of Pb, Zn and As in soil and could grow normally without obvious toxic phenomenon in contaminated soil with 734 mg/kg Pb, 1194 mg/kg Zn, 53 mg/kg As (Tan, 2008). Zhang *et al*. (Zhang *et al*., 2012) studied the enrichment ability of mulberry to four kinds of heavy metals (Cu, Pb, Cd and Zn) by planting mulberry trees in Liuyang Qibaoshan mining area, Hunan Province. They concluded that the content of each metal was discriminating in different parts of mulberry (root, stem, leaf and bark) and the amount of Cu, Pb, Cd and Zn migrated by mulberry in every square meter plough layer soil was 12116.1 mg, 7409.83 mg, 2056.4 mg and 254532.8 mg, respectively.

The heavy metal uptake by mulberry is influenced by the mulberry species, growth stages and growth duration, the physic-chemical properties of soil, the kinds of heavy metals and duration of experiment and so on. Lots of papers have been reported that mulberry could remediate heavy metals polluted soils and planting mulberry and feeding silkworm could be an effective way to remediate the heavy metals contaminated soils (Table 1). However, some problems should be paid attention to. Because of the different enrichment ability of different genotypes of mulberry to the heavy metal, the gene of mulberry should keep the same when we study the interaction between heavy metal and mulberry. In addition, there has not been an effective way to treat the heavy metals accumulated in the plants, which is also a barrier to restrict the market application of the phytoremediation.

Organic compounds: As a matter of fact, the definition of taking advantage of plants to remediate organic chemical pollutants contaminated soils was on the basis of the phenomenon that disappearance rate of organic pollutants is faster in vegetated soils than surrounding non-vegetated bulk soils. Generally, the degradation of organic contaminates by plants has concentrated on chlorinated solvents, explosives and petroleum hydrocarbons (Burken & Schnoor, 1996; Alkorta & Garbisu, 2001). In the last few years, lots of scientists have put forward the potential of phytoremediation to remediate the polynuclear aromatic hydrocarbons (PAHs) (Olson & Fletcher, 1999; Olson *et al*., 2003; Mueller & Shann, 2006), polychlorinated biphenyls (PCBs) (Leigh *et al*., 2002; Tu *et al*., 2011) and trichloroethylene (TCE) polluted soils (Newman *et al*., 1999; Lewis *et al*., 2015).

The phytoremediation of organic pollutants have two different patterns. One is the direct phytoremediation, and the other one is the phytoremediation explanta (Salt *et al*., 1998). The phytoremediation explanta is on the basis of the root exudates secreted by plants, which contribute to the growth and metabolism of all kinds of fungi and bacteria in the rhizosphere (Anderson *et al*., 1994). There are some organics, such as phenols, organic acids and saccharides in root exudates, which could play the part of nutrition sources for the growth of microbes that are in a position to degrade some organic chemicals.

Table 1. Summary of some reports on remediation of heavy metals by mulberry.

Heavy metals	Variety	Cultivation	Stage	Growth duration	Main parameters studied	Ways	References
Cd or Cu	/	soil culture	stem cuttings	95 days	MI: mobility index AF: accumulation factor	lab	(Prince *et al.*, 2001)
Cd	Hu sang-197	soil culture	/	7 years	Cd contents in roots, stems, branches and leaves	micro-plot experiment	(Wang, 2002)
Cd	/	soil culture	one year old	3 years	Leaf yield, chlorophyll, Cd contents in roots, stems, leaves IR: ingestion rate DR: digestion rate	micro-plot experiment	(Wang *et al.*, 2004)
Cu	Kanva-2	solution culture	stem cuttings	25 days	Dry matter yield, water potential, malondialdehyde (MDA), Peroxidases (POD)	lab	(Tewari *et al.*, 2006)
Zn	Kanva-2	solution culture	stem cuttings	40 days	Dry matter yield, water potential, Chlorophylls, H_2O_2, Total carotenoids	lab	(Tewari *et al.*, 2008)
Co	/	soil culture	/	75 days	Co concentration, Body length, body weight and mortality rate of larvae, Co contents in leaves	micro-plot experiment	(Ashfaq *et al.*, 2009)
Pb	/	soil culture	/	75 days	Amount of Pb in leaves, larvae and faeces, body length, weight and mortality rate of larvae	micro-plot experiment	(Ashfaq *et al.*, 2009)
Cd or Cr (III) or Ni	/	soil culture	One-year seedlings	21 days	BCF: bioconcentration factor TF: translocation factor Metals contents in root, stem, leaf	lab	(Rafati *et al.*, 2011)
Cr (III)	/	soil culture	/	75 days	Amount of Cr (III) in leaves, larvae and faeces, body length, weight and mortality rate of larvae	micro-plot experiment	(Ashfaq *et al.*, 2012)
Mn	Kanva-2	solution culture	stem cuttings	75 days	Dry matter yield, RWC: relative water content, Chlorophylls, H_2O_2	lab	(Tewari *et al.*, 2013)
Cd, Cr and Pb	/	soil culture	Four-year mulberry	20 days	Metals contents in root, stem and leaf BCF: bioconcentration factor	field	(Zhao *et al.*, 2013)
Cr (VI)	/	soil culture	/	90 days	Accumulation of Cr in leaves,larvae, feaces and silk glands Body length and body weight	field	(Shoukat *et al.*, 2014)
Pb	Nongsang-14	soil culture	One-year-old mulberry	90 days	MTs: metallothioneins TF: translocation factor Pb contents in soluble fraction, organelle and cell wall of leaf	lab	(Zhou *et al.*, 2015)
Cu, Pb, Zn and Cd	Husang-1	Soil culture	/	1.5 years	Contents of heavy metals in root, leaf, skin and bone of mulberry BCF: bioconcentration factor TF: translocation factor	field	(Zhang *et al.*, 2012)

The flavones in fine roots of mulberry trees were proved to promote the growth of a degrader of PCBs, the bacterium Burkholderia sp. LB400 (Donnelly *et al*., 1994; Leigh *et al*., 2002). Fletcher and Hedge (Fletcher & Hegde, 1995) screened 17 perennial plants that could deliver phenols to help the growth of PCB-degrading microorganisms and concluded that mulberry have many advantages that would contribute to its use in phytoremediation. Leigh *et al*. (Leigh *et al*., 2002) examined the growth dynamics of mulberry fine root and the results showed that the fine root was related to rhizosphere remediation process of organic pollutants. 58% of mulberry fine roots died annually and the flavones in the dead roots could favor the growth of a PCB-degrading bacterium.

Application of mulberry in air control: Mulberry could improve the air quality for its strong photosynthesis, fast growth and high biomass. One hectare of mulberry could absorb 1 ton of carbon dioxide one day and release of 0.73 tons of oxygen, which could be utilized by 1000 people for breathing (Tan *et al*., 2010). However, Qin *et al*., reported that 1 hectare of mulberry could absorb carbon dioxide 49.29 tons a year and release oxygen about 35.85 tons through preliminary estimate (Qin *et al*., 2010). Mulberry is a good carbon sink tree. According to the data, 1 ha mulberry trees were able to absorb about 6.24×10^4 kg of CO_2 and released 4.60×10^4 kg of O_2 each year (Jian *et al*., 2012).

With good characteristics in tree form, the color of the leaf, vitality, ductility and resistibility, mulberry is a perfect plant used for the city landscape (Jian *et al*., 2012). Mulberry leaves are able to reduce wind speed, and leaf surface can adsorb and detain the large particle dust. Generally, one hectare of mulberry can strand 27.2 tons of dust a year (Tan *et al*., 2010). Therefore, mulberry is good green tree species and has been cultivated on both sides of the road (Fig. 1).

Mulberry leaf has strong absorption ability for atmospheric pollutants. In sericulture industry, If the mulberry garden was located near the industrial zone, especially the sericultural farmers, who lived in which under the downwind direction of perennial winds of the industrial park, often appeared poisoning phenomenon in the silkworm, *Bombyx mori*, due to consumption of mulberry leaves contaminated by atmospheric pollutants(Huang & Wang, 2012). Mulberry can effectively absorb industrial waste gas, such as sulfide, fluoride, chloride and nitrogen compounds (Liu, 2011). Moreover, mulberry, which has a strong resistance, large absorption ability for sulfur dioxide, and the ability to resist fluoride, absorb fluoride, is a good clean air species (Qin *et al*., 2010; Tan *et al*., 2010). When fumigated in SO_2 volume fraction of 0.79×10^{-6} for 6 h, 1 kg of dry mulberry leaves can absorb SO_2 5772.6 mg. One m^3 of mulberry garden can absorb SO_2 gas 20 mL a day (Qing *et al*., 2010). The content of fluoride in mulberry leaves reached 30 ppm when mulberry leaves were exposed to the atmosphere of 1.5 ppb HF for 24 h (Xu & Wang, 1991). Xu *et al*. (Xu & Wang, 1991) carried out a series of non-periodical and periodical continuous examinations of F content in leaves of 8 mulberry varieties and the results showed that the absorption and accumulation capability of F varied with the mulberry varieties and the “Jianchi” and “7311” had the highest F absorption capability. Moreover, Lu *et al*. (Lu & Li, 2002) examined the absorption and purification ability of some green tree species for the main air pollutants by the fumigation test, and the results indicated that mulberry is the tree species with high fluorine content (>0.45 mg/g dry leaves). Later, Lu *et al*. found that mulberry has a strong retention and absorption ability to Pb and Cd by measuring the absorption and accumulation of heavy metals in atmospheric by green tree leaves in a heavy industrial area. The retention and absorption content of mulberry for Pb was 15.7 kg / hm^2 leaf weight a year, highest among 24 kinds of tested tree species. While the absorption amount of Cd a year was 0.797 kg/hm^2 leaf weight, just less than that of *Populus nigra var. italica×P. cathayana* (Lu & Li, 2006).

Application of mulberry in ecological environment management

Water retention: Planting mulberry can effectively improve soil permeability, reduce surface runoff and retain water (Fig. 2). When it is raining, first of all the rain beat on the leaf thus reducing the momentum of the rain. Besides, a part of rain flows along the branches into the ground, reduces rainfall in the land. At the same time, the interception of mulberry leaves to the rain delays the fall time of rain, reducing soil erosion. The canopy interception of mulberry trees could account for 15%~40% of the rainfall (Tan *et al*., 2010). In addition, the penetration rate and coefficient of permeability of soil in a mulberry garden was 1.91 and 3.07 times of that of open land, respectively (Zhang *et al*., 1997). So 50%~70% of rainfall could penetrate into the ground, becoming groundwater. Owing to canopy interception and garden storage for rainfall, the actual rainfall just formed a small water flow, which was only 4% of the rainfall. At last, the weed below mulberry could also build a barrier, which reduce flow speed, without the formation of runoff and soil erosion (Tan *et al*., 2010).

Windbreak and sand-fixation: Mulberry can be used for forestation, windbreak and sand fixation for its drought resistant, cold resistant, barren resistant, wide adaptability and distribution in China (Wang *et al*., 2010). Mulberry, which can still grow and develop naturally in arid, semi arid desert area where the amount of precipitation was less than 150 mm, has extremely strong vitality (Dai *et al*., 2009). In the north of China, such as Xinjiang, Shaanxi, Beijing and other places, mulberry has become one of the preferred species for windbreak and sand-fixation. But in the south, mulberry would be not only a preferred species used for the management of tailings reservoir (Fig. 3), but also a right choice for the treatment of the stony desertification area (Fig. 4). The current water erosion area in China is 3.68×10^6 km^2 and desertification land is 1.69×10^6 km^2, accounting for 38.2% and 17.6% of the national land area, respectively. Badly, the water erosion is increasing at a speed of 10000 km^2 per year. Mulberry possesses developed root system, the vertical distribution of which could reach up to 4 m. The root horizontal distribution of mulberry trees is 4~5 times of the crown area, sometimes even as high as seven or eight times (Dai *et al*., 2009). The buried depth of the taproot, which has been grown for 3 years, would exceed 1.5 m, lateral root and rootlet could be extended more than 4 m^3. The underground root system is a huge network structure, which has a sound effect on soil and water conservation. The mulberry field can hold more 20 m^3 water, less 3 times sand than that of open land(Wang *et al*., 2010). According to the surveys in the arid and semi-arid areas of the North China, the total root length of one year old mulberry reached 100 m and that of 10 years old could reach 10000 m. Crown diameter of 1 year old planting stock in the sand reached 1 m and diameter of its root to the surrounding radiation is more than 4 m. In an arid sandy land of 42 degrees north latitude, annual rainfall of 300 mm, the biomass of the mulberry tree was 5 times of locust and elm at the same age of 30 years. So mulberry is a better candidate than the other tree species in the sand, soil and water conservation and ecological function (Dai *et al*., 2009).

Modified saline soil: Accounting for 1/4 of the arable land, the saline land area in China is more than 3.6×10^{11} m^2, and there are about 9.2×10^{11} m^2 of arable land being faced with salinization (Zhao *et al*., 2015). Mulberry is a suitable tree species for improving saline alkali soil (Fig. 5). It can grow normally in the range of pH 4.5~9.0 and 0.2% soil salinity (Ke, 2008). Mulberry could survive at pH value 8.3~9.5 when planted in parts of the saline alkali soil in Heilongjiang Province, China. Three years later, the soil salt content decreased significantly, the water content was obviously increased, soil physical and chemical properties improved (Gao & Han, 2013).

Fig. 1. Mulberry trees planted on both sides of the road, Urumchi, China

Fig. 2. Mulberry planted in bare soil of a high mountain, Hunan, China.

Fig. 3. Mulberry planted in a tailings reservoir, Hunan, China.

Fig. 4. Mulberry cultivated in a stony desertification area, Hunan, China.

Fig. 5. Mulberry trees planted in the saline soil in Karamay city, Xinjiang, China.

Restoration of drawdown zone: The Three Gorges Dam is the largest dam in the world, which created a drawdown area of 348.93 km^2 between 145 m and 175 m above sea level around its reservoir (Wang *et al*., 2012). The drawdown zone of the Three Gorges reservoir, which is an ecological transition and a buffer zone between the land and the reservoir, is China's largest artificial wetland and submerged for more than half year in winter and exposed in summer. Large area of the drawdown zone in the Three Gorge Reservoir and sensitive ecological and environmental problems, have important influences on the normal operation of reservoirs, water environment quality and the production and life of local people. Once its eco-health and stability are damaged, which will directly endanger the ecological safety of the whole reservoir area and even the Yangtze River Basin (Yuan *et al*., 2013). This has become a serious environmental problem for the local government and the national attention (He *et al*., 2007).

Widely distributed mulberry in the river on both sides of the floodplain is the best example of that Mulberry has a certain tolerance to water-logging. According to the survey, the mulberry forest at the growth period flooded 20 d or longer will not die, which is rare in other dry land crops (He *et al*., 2007). Wang *et al*. (Wang *et al*., 2012) investigated the effect of winter flooding on vascular flora and explored flood-tolerant species for vegetation reconstruction in drawdown area. It was concluded that mulberry exhibited high tolerance to winter flooding and may be potential candidates for vegetation restoration. He *et al*. (He *et al*., 2007) analyzed anti-season water-logging resistance characteristics of mulberry, reported that mulberry could grow better when it has been submerged in water level above 10 m for more than 6 months. And it was demonstrated that it is feasible to develop the ecological economy of sericulture in the reservoir area. Willison *et al*. (Willison *et al*., 2013) thought that mulberry tree is one of the very few plants that could be used for the vegetation restoration of the Three Gorges Reservoir. Liu and Willison (Liu & Willison, 2013) also provided evidence of the physiological function of mulberry tree adaptation to environmental pressures, which made it the reasonable utilization in vegetation restoration for the drawdown zone. However, the ecological function and environmental benefits of mulberry should be carefully verificated and only in this way can the potential of mulberry be fully and properly used.

Conclusions and Outlook

Affected by many kinds of natural and social economic environment factors (urbanization, the loss of rural population, environmental pollution, etc.), the development of the traditional silk industry is facing many difficulties, which has been disturbed the management ideas and methods continued for thousands of years. Based on the premise of developing mulberry ecological industry, the organic combination of economic benefit and ecological benefit can be realized, so that the traditional silk industry will gradually transform into a new type of ecological silk industry, so as to realize the sustainable development in a very real sense.

China has rich mulberry resources and large number of mulberry varieties. On account of the wide distribution, high biomass, developed root and a wide range of ecological adaptability, the mulberry has a good ecological effect in the application of soil and water conservation, desertification control, saline and alkali land management, and sand protection forest in recent years, especially the restoration of heavy metals in soil.

In order to make full use of mulberry to protect environment, make mulberry as a good plant species as soon as possible to apply to the soil and air pollution remediation, the basic researches should be carried out in the future are as follows: (a) The screening and cultivation of mulberry varieties with strong resistance to heavy metals, salt, cold, drought and water logging. (b) Physiological, biochemical and molecular mechanisms of mulberry to remediate heavy metals and organic chemicals polluted soils along with the rhizosphere effect. (c) When application of mulberry to remediate heavy metals polluted farmland, the mulberry leaves were used to feed silkworm at the same time, more attention should be paid to the management of silkworm excrement, preventing secondary pollution.

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Reference

Alkorta, I. and C. Garbisu. 2001. Phytoremediation of organic contaminants in soils. *Bioresour. Technol.*, 79(3): 273-276.

Anderson, T., E. Kruger and J. Coats. 1994. Enhanced degradation of a mixture of three herbicides in the rhizosphere of a herbicide-tolerant plant. *Chemosphere*, 28(8): 1551-1557.

Ashfaq, M., S. Ahmad, M. Sagheer, M. Hanif, S. Abbas and M. Yasir. 2012. Bioaccumulation of chromiumi (iii) in silkworm (bombyx moril.) in relation to mulberry, soil and wastewater metal concentrations. *J. Anim. Pl. Sci*., 22(3): 627-634.

Ashfaq, M., S. Ali and M.A. Hanif. 2009. Bioaccumulation of cobalt in silkworm (*Bombyx mori* L.) in relation to mulberry, soil and wastewater metal concentrations. *Process Biochem.*, 44(10): 1179-1184.

Ashfaq, M., M.I. Khan and M.A. Hanif. 2009. Use of morus alba–bombyx mori as a useful template to assess pb entrance in the food chain from wastewater. *Environ. Entomol.*, 38(4): 1276-1282.

Bao, T., L. Sun, T. Sun and Z. Niu. 2010. Research progress in strengthening measures for phytoremediation of soils contaminated by heavy metals. *Environ. Sci. Technol.*, 33(12F): 458-462.

Burken, J.G. and J.L. Schnoor. 1996. Phytoremediation: Plant uptake of atrazine and role of root exudates. *J. Environ. Eng*., 122(11): 958-963.

Chen, C., H. Gong and K. Wang. 1996. Effect of cd on quality, physiological and biochemical characteristics of mulberry leaves and its mechanism. *Chin. J. Appl. Ecol.*, 7(4): 417-423. (In Chinese)

Chen, C., H. Gong, K. Wang, J. Tang and J. Wan. 1999. The adsorption, accumulation and migration of cadmium in the system of soil mulberry and silkworm. *Acta Ecologica Sinica*, 19(5): 664-669.

Cunningham, S.D., W.R. Berti and J.W. Huang. 1995. Phytoremediation of contaminated soils. *Trends Biotechnol.*, 13(9): 393-397.

Dai, Y., H. Zhu, H. Du, J. Zhang and B. Wen. 2009. The economic value and ecological function of mulberry. *Protect. Forest Sci. & Technol.*,(1): 78-80. (In Chinese)

Delplanque, M., S. Collet, F. Del Gratta, B. Schnuriger, R. Gaucher, B. Robinson and V. Bert. 2013. Combustion of salix used for phytoextraction: The fate of metals and viability of the processes. *Biomass Bioenergy*, 49: 160-170.

Donnelly, P.K., R.S. Hegde and J.S. Fletcher. 1994. Growth of pcb-degrading bacteria on compounds from photosynthetic plants. *Chemosphere*, 28(5): 981-988.

Du, Z., J. Liu, G. Liu, Z. Hu and J. Zhang. 2001. Study on mulberry trees as both water and soil conservation and economy trees. *Guangxi Sericulture*, 38(3): 10-12. (In Chinese)

Ercisli, S. and E. Orhan. 2007. Chemical composition of white (morus alba), red (morus rubra) and black (morus nigra) mulberry fruits. *Food Chem.*, 103(4): 1380-1384.

Fletcher, J.S. and R.S. Hegde. 1995. Release of phenols by perennial plant roots and their potential importance in bioremediation. *Chemosphere*, 31(4): 3009-3016.

Gao, Q. and W. Han. 2013. The thinking of planting mulberry to develop and improve saline-alkali land in heilongjiang province, china. *Agri. Develop. & Equip.*, (5): 6-6. (In Chinese)

He, X., Z. Xie, H. Nan and Y. Bao. 2007. Developing ecological economy of sericulture and vegetation restoration in the water-level-fluctuating zone of the three gorges reservoir. *Sci. & Technol. Review*, 25(23): 59-63. (In Chinese)

Hegde, R.S. and J.S. Fletcher. 1996. Influence of plant growth stage and season on the release of root phenolics by mulberry as related to development of phytoremediation technology. *Chemosphere*, 32(12): 2471-2479.

Houben, D., L. Evrard and P. Sonnet. 2013. Mobility, bioavailability and ph-dependent leaching of cadmium, zinc and lead in a contaminated soil amended with biochar. *Chemosphere*, 92(11): 1450-1457.

Huang, F. and D. Wang. 2012. The introduction to mulberry to ecological restoration. *North Sericulture*, 33(4): 52-54. (In Chinese)

Huang, X. 2013. Research on industry transformation of china sericulture Southwest University, Chongqing. (In Chinese)

Huo, Y. 2002. Mulberry cultivation and utilization in china. FAO Animal Production and Health Paper pp: 11-44.

Jian, Q., H. Ningjia, W. Yong and X. Zhonghuai. 2012. Ecological issues of mulberry and sustainable development. *J. Resour. & Ecol.*, 3(4): 330-339. (In Chinese)

Jiang, S., X. Yan, X. Gong, R. Huang, M. Lei, Y. Jiang, T. Long, C. Jia and Z. Qin. 2015. The analysis of silkworm rearing experiment at a farmland excessive of cadmium and lead in autumn. *North Sericulture*, 36(1): 15-17. (In Chinese)

Jothimani, P., S. Ponmani and R. Sangeetha. 2013. Phytoremediation of heavy metals-a review. *Int. J. Res. Studies in Biosci.*, 1(2): 17-23.

Ke, Y., 2008. Mulberry adaptability to salinity and its salt-tolerant mechanism and application to saline-alkali soils. *Chinese Academy of Forestry*, Beijing. (In Chinese)

Khurana, P. and V.G. Checker. 2011. The advent of genomics in mulberry and perspectives for productivity enhancement. *Plant Cell Reports*, 30(5): 825-838.

Leigh, M.B., J.S. Fletcher, X. Fu and F.J. Schmitz. 2002. Root turnover: An important source of microbial substrates in rhizosphere remediation of recalcitrant contaminants. *Environ. Sci. Technol.*, 36(7): 1579-1583.

Lewis, J., U. Qvarfort and J. Sjöström. 2015. Betula pendula: A promising candidate for phytoremediation of tce in northern climates. *Int. J. Phytorem.*, 17(1): 9-15.

Liu, Y. 2011. Application prospect of mulberry plants to vegetation restoration in three gorges reservoir area. *Science of Sericulture*, 37(1): 0093-0097. (In Chinese)

Liu, Y. and J.M. Willison. 2013. Prospects for cultivating white mulberry (morus alba) in the drawdown zone of the three gorges reservoir, china. *Environ. Sci. Pollut. Res.*, 20(10): 7142-7151.

Lu, M. and C. Li. 2006. Adsorption and purification ability on the greening tree species to heavy metal pollutants of the atmosphere *Shandong Forest. Sci. & Technol*., 3: 31-32. (In Chinese)

Lu, M. and Y. Li. 2002. Research on absorption and purgation ability to atmosphere pollutants of some garden plants. *J. of Shandong Inst. of Architecture and Engineering*, 17(2): 45-49. (In Chinese)

Mueller, K.E. and J.R. Shann. 2006. Pah dissipation in spiked soil: Impacts of bioavailability, microbial activity, and trees. *Chemosphere*, 64(6): 1006-1014.

Nazarian, H., D. Amouzgar and H. Sedghianzadeh. 2016. Effects of different concentrations of cadmium on growth and morphological changes in basil (*Ocimum basilicum* L.). *Pak. J. Bot.*, 48(3): 945-952.

Newman, L.A., X. Wang, I.A. Muiznieks, G. Ekuan, M. Ruszaj, R. Cortellucci, D. Domroes, G. Karscig, T. Newman and R.S. Crampton. 1999. Remediation of trichloroethylene in an artificial aquifer with trees: A controlled field study. *Environ. Sci. Technol.*, 33(13): 2257-2265.

Olson, P.E. and J.S. Fletcher. 1999. Field evaluation of mulberry root structure with regard to phytoremediation. *Biorem. J.*, 3(1): 27-34.

Olson, P.E., T. Wong, M.B. Leigh and J.S. Fletcher. 2003. Allometric modeling of plant root growth and its application in rhizosphere remediation of soil contaminants. *Environ. Sci. Technol.*, 37(3): 638-643.

Peng, X., B. Yang, D. Deng, J. Dong and Z. Chen. 2012. Lead tolerance and accumulation in three cultivars of eucalyptus urophyllaxe. Grandis: Implication for phytoremediation. *Environ. Earth Sci.*, 67(5): 1515-1520.

Prince, S., P. Senthilkumar and V. Subburam. 2001. Mulberry-silkworm food chain–a templet to assess heavy metal mobility in terrestrial ecosystems. *Environ. Monit. Assess.*, 69(3): 231-238.

Pulford, I. and C. Watson. 2003. Phytoremediation of heavy metal-contaminated land by trees—a review. *Environ. Int.*, 29(4): 529-540.

Qin, J., N. He, X. Huang and Z. Xiang. 2010. Development of mulberry ecological industry and sericulture. *Science of Sericulture*, 36(6): 0984-0989. (In Chinese)

Qing, N., C. Ni, H. Lv and D. Liang. 2010. The discussion of ecological circular economy mode of sericulture in hangzhou *Bulletin of Sericulture*, 41(3): 49-51. (In Chinese)

Rafati, M., N. Khorasani, F. Moattar, A. Shirvany, F. Moraghebi and S. Hosseinzadeh. 2011. Phytoremediation potential of populus alba and morus alba for cadmium, chromuim and nickel absorption from polluted soil. *Int. J. Environ. Res.*, 5(4): 961-970.

Ramesh, H., V. Sivaram and V.Y. Murthy. 2014. Antioxidant and medicinal properties of mulberry (*Morus* sp.): A review. *World J. Pharm. Res.*, 3(6): 320-343.

Rao, D.M.R., K. Jhansilakshmi, P. Saraswathi, A.A. Rao, S. Ramesh, M. Borpuzari and A. Manjula. 2013. Scope of pre-breeding in mulberry crop improvement-a review. *Sci. Weekly*, 1(6): 1-18.

Ren, L., S. Song, W. Lan and J. Huang. 2009. Research on impact of soil lead pollution on growth of mulberry tree and quality of mulberry. *Resource Development & Market* 25(7): 583-585. (In Chinese)

Salt, D.E., R. Smith and I. Raskin. 1998. Phytoremediation. *Annu. Rev. Plant Biol.*, 49(1): 643-668.

Sharma, A., V. Krishna, P. Kaur and R. Rayal. 2015. Characterization and screening of various mulberry varieties through morpho-biochemical characteristics. *J. Global Biosci.*, 4(1): 1186-1192.

Shoukat, M.A., S. Ashraf, M. Ali, Z. Iqbal, M.I. Shahzad, H. Chaudary, N. Sial and Z. Batool. 2014. The effect of cr (vi) on silkworm (*Bombyx mori*) fed on *In vitro* accumulated mulberry leaves *Asian J. Agri. Biol.*, 2(2): 119-128.

Susarla, S., V.F. Medina and S.C. McCutcheon. 2002. Phytoremediation: An ecological solution to organic chemical contamination. *Ecol. Eng.*, 18(5): 647-658.

Tan, C., Y. Feng and H. Long. 2010. The important role of mulberry in low carbon and ecological economy of china. *Sichuan Canye*, 1: 12-15. (In Chinese)

Tan, X., Y. Liu, Y. Gu, G. Zeng, X. Wang, X. Hu, Z. Sun and Z. Yang. 2015. Immobilization of cd (ii) in acid soil amended with different biochars with a long term of incubation. *Environ. Sci. Pollut. Res*., 1-8.

Tan, Y., 2008. Possibility of planting mulberry in mining polluted farmland. Guangxi University, Nanning. (In Chinese)

Tewari, R.K., P. Kumar and P.N. Sharma. 2006. Antioxidant responses to enhanced generation of superoxide anion radical and hydrogen peroxide in the copper-stressed mulberry plants. *Planta*, 223(6): 1145-1153.

Tewari, R.K., P. Kumar and P.N. Sharma. 2008. Morphology and physiology of zinc-stressed mulberry plants. *J. Plant Nutr. Soil Sci.*, 171: 286-294.

Tewari, R.K., P. Kumar and P.N. Sharma. 2013. Oxidative stress and antioxidant responses of mulberry (*Morus alba*) plants subjected to deficiency and excess of manganese. *Acta Physiologiae Plantarum*, 35(12): 3345-3356.

Tu, C., Y. Teng, Y. Luo, X. Sun, S. Deng, Z. Li, W. Liu and Z. Xu. 2011. Pcb removal, soil enzyme activities, and microbial community structures during the phyto remediation by alfalfa in field soils. *J. Soils Sediments*, 11: 649-656.

Vijayan, K., P.J. Raju, A. Tikader and B. Saratchnadra. 2014. Biotechnology of mulberry (morus l.)-a review. *Emir. J. Food Agric*., 26(6): 472-496.

Vijayan, K., A. Tikader, Z. Weiguo, C.V. Nair, S. Ercisli and C.-H. Tsou. 2011. Morus. In: Wild crop relatives: Genomic and breeding resources: Tropical and subtropical fruits, (Ed.): Kole, C. Springer Berlin Heidelberg, Berlin, Heidelberg: pp: 75-95.

Wang, H., B. Meng and H. Han. 2010. The discussion on mulberry as a green afforestation tree species. *North Sericulture*, 31(1): 45-47. (In Chinese)

Wang, K. 2002. Tolerance of cultivated plants to cadmium and their utilization in polluted farmland soils. *Acta Biotechnologica*, 22(1-2): 189-198.

Wang, K., C. Chen, H. Gong, J. Wan and G. Zhang. 1998. The models of agro-ecological regulation and safe efficient utilization of farmland polluted by cadmium. *China Environ. Sci.*, 18(2): 97-101. (In Chinese)

Wang, K., H. Gong, Y. Wang and S. Van Der Zee. 2004. Toxic effects of cadmium on morus alba l. And bombyx moril l. *Plant Soil*, 261(1-2): 171-180.

Wang, Q., X. Yuan, H. Liu, Y. Zhang, Z. Cheng and B. Li. 2012. Effect of long-term winter flooding on the vascular flora in the drawdown area of the three gorges reservoir, china. *Pol. J. Ecol.*, 60(1): 95-106.

Wang, X., Y. Liu, G. Zeng, L. Chai, X. Song, Z. Min and X. Xiao. 2008. Subcellular distribution and chemical forms of cadmium in *Bechmeria nivea* (L.) gaud. *Environ. Exp. Bot.*, 62(3): 389-395.

Wang, Y. and L.O. Björn. 2014. Heavy metal pollution in guangdong province, china, and the strategies to manage the situation. *Frontiers in Environ. Sci.*, 2: 9.

Willison, J.M., R. Li and X. Yuan. 2013. Conservation and ecofriendly utilization of wetlands associated with the three gorges reservoir. *Environ. Sci. Pollut. Res.*, 20(10): 6907-6916.

Xu, H. and J. Wang. 1991. Study on capability of the absorption of f by different mulberry varieties. *Rural Eco-Environ*., 4: 59-62. (In Chinese)

Xu, N., Y. Yu, P. Mao, X. Du, X. Peng and X. Shi. 2015. Research progress of remedying the heavy metal contaminated soils with mulberry, *J. of Agri.,* 5(1): 37-40. (In Chinese)

Yan, X., X. Gong, R. Huang, S. Jiang, M. Lei, T. Long, C. Jia and Z. Qin. 2014. Analysis of sericulture experiment in farmland with cd and pb content over range. *Hunan Agri. Sci.*, 22: 34-36. (In Chinese)

Yuan, X.-z., Y.-w. Zhang, H. Liu, S. Xiong, B. Li and W. Deng. 2013. The littoral zone in the three gorges reservoir, china: Challenges and opportunities. *Environ. Sci. Pollut. Res.*, 20(10): 7092-7102.

Zeng, G., Z. Liu, H. Zhong, J. Li, X. Yuan, H. Fu, Y. Ding, J. Wang and M. Zhou. 2011. Effect of monorhamnolipid on the degradation of n-hexadecane by candida tropicalis and the association with cell surface properties. *Appl. Microbiol. Biotechnol.*, 90(3): 1155-1161.

Zhang, G., J. Yang, X. Zhao, K. Feng and X. Gao. 1997. Study on the root system distribution mulberry and its characteristics of soil and water conservation. *Science of Sericulture*, 23: 59-60. (In Chinese)

Zhang, X., Y. Wang, Y. Jie, W. She, H. Xing and S. Zhu. 2012. Effect of heavy metal home position elimination on the elimination on themulberry in mining area soil. *Chinese Agricultural Sci. Bulletin*, 28(7): 59-63. (In Chinese)

Zhao, D., J. Du, C. Chen, Y. Dong, M. Liang, L. Hua, H. Zhu and Z. Wang. 2015. Research progress on saline alkali stress of mulberry. *Shangdong Agricutural Sci.*, 47(5): 132-135.(In Chinese)

Zhao, S., X. Shang and L. Duo. 2013. Accumulation and spatial distribution of cd, cr, and pb in mulberry from municipal solid waste compost following application of edta and (nh4) 2so4. *Environ. Sci. Pollut. Res.*, 20(2): 967-975.

Zhong, H., Y. Jiang, G. Zeng, Z. Liu, L. Liu, Y. Liu, X. Yang, M. Lai and Y. He. 2015. Effect of low-concentration rhamnolipid on adsorption of pseudomonas aeruginosa atcc 9027 on hydrophilic and hydrophobic surfaces. *J. Hazard. Mater.*, 285: 383-388.

Zhou, L., Y. Zhao, S. Wang, S. Han and J. Liu. 2015. Lead in the soil–mulberry (*Morus alba* L.)–silkworm (*Bombyx mori*) food chain: Translocation and detoxification. *Chemosphere*, 128: 171-177.

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