Proceedings of the International Symposium on Conservation and Eco-friendly Utilization of Wetland in the Three Gorges Reservoir

Use of Plants for Remediation, Stabilization and Restoration of Aquatic and Terrestrial Ecosystems*

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Abstract: Plants can be used to remediate polluted soil or water (phytoremediation) by extracting and/or degrading pollutants[1-2] and for stabilization of soils and sediments [3] (phytostabilization) in order to prevent erosion and to minimize the release of contaminants from the solid matrix. A broad range of inorganic and organic pollutants can thus be processed by using suitable plants that are tolerant of the pollutants, generate high biomass, and are effective in uptake. As an example, water hyacinths can be used for extracting and degrading cyanide from gold mining process water that usually contains cyanide species and heavy metals in concentrations of toxicological concern. We determined a lethal dose (LC50) of about 13 mg cyanide/L for the water hyacinths and observed that under field conditions in a pilot scale wetland the plants became more effective after several applications in degrading cyanide even at high concentrations. Experiments with radio-labelled cyanide revealed that the carbon and nitrogen of cyanide in the plants were used to biosynthesize asparagine; thus the toxic cyanide was effectively transformed into a non-toxic, natural product [4]. Waste disposal sites can be remediated with plants both with respect to leaching - the percolating water may contain high concentrations of pollutants - and with respect to the stabilization of slopes in order to reduce erosion. We used the concept of dense vegetation on an industrial waste site and grew douglas firs that perform high evapo-transpiration rates throughout the year and thus reduce the amount of leachate from the dump site. For stabilization of the slopes it is possible to first install a stable, diamond-shaped network of living plants (willows), level up the network with soil and spray a mixture of suitable seeds of grass, shrubs or trees (truck wet application) which will further stabilize the soil during growth. This technique can be applied also to river banks for erosion control.

Key words: phytoremediation; cyanide waste; soil stabilization; leachate reduction; erosion control

Chinese Library Classification: X171; Q948.1 **Document Code**: A **Article ID**: 1672-6693(2012)03-0084-03

1 Use of Plants for Remediation of Process Water from Cyanide Gold Mining

Plants can be used to remediate polluted soil or water (phytoremediation) by extracting and/or degrading pollutants [1-2] and for stabilization of soils and sediments [3] (phytostabilization) in order to prevent erosion and to minimize the release of contaminants from the solid matrix (See plate1, color page Ⅲ).

A broad range of inorganic and organic pollutants can thus be processed by using suitable plants that are tolerant of the pollutants, generate high biomass, and are effective in uptake. As an example, water hyacinths, *Eichornia crassipes*, can be used for extracting and degrading cyanide from gold mining process water that usually contains cyanide species and heavy metals in concentrations of toxicological concern. Ponds in which process water is stored (of gold mining, for example) may contain high concentrations of free cyanide and cyanide containing complexes: the total cyanide concentrations can range up to 400 mg/L. Many accidents have been observed world-wide (See plate 2, color pageⅢ) that are related to technological cyanide use.

* **Received**: 02-15-2012

Fundation: German Research Fundation (DFG); German Ministry of Research Fundation (BMBF)

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Especially in mining sites where gold mining is managed by small enterprises, avoiding the high costs for detoxification of the process water by chemical treatment such as hydrogenperoxide, low-technology techniques are needed that can be used instead. Therefore we aimed to develop an easy and efficient method that can be used to decontaminate cyanide containing waste water. In phytotoxicity tests we determined a lethal dose (LC50) of about 13 mg cyanide/L for water hyacinths (See plate 3, color page Ⅲ) by using the plant respiration rates as toxic endpoint [4].

Under field conditions in a pilot scale wetland the plants became even more effective after several applications in degrading cyanide even at high concentrations. Radioactive, ^{14}C-labelled cyanide (10 mg/L) was shown to be effectively degraded even by plant cuttings of water hyacinths (See Fig. 4).

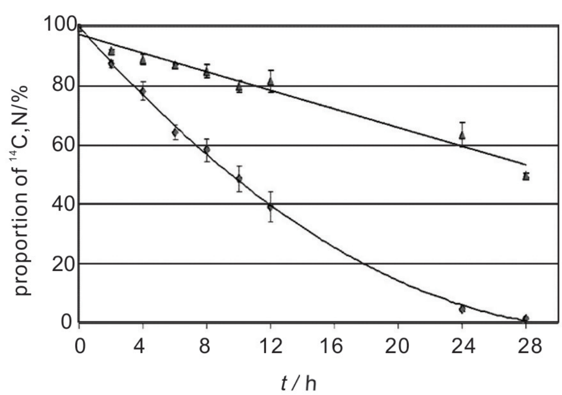

Fig. 1 Degradation of 10mg/L cyanide. 0.5 g leaf cuttings were placed in 15 mL autoclaved Hoagland solution.

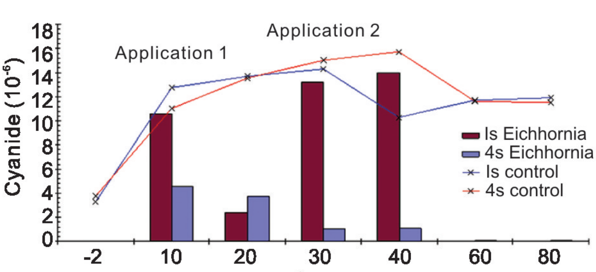

Fig. 2 Cyanide phytoremediation in a pilot scale wetland (6 m length, 0.7 m width, water column 0.3 m) planted with waterhyacinths.

Radio-analytical experiments revealed that the carbon and nitrogen of the cyanide molecule were used in the plant metabolism to biosynthesize the amino acid asparagine; thus the toxic cyanide was effectively transformed into a non-toxic, natural product [4].

Even more effective degradation of cyanide was observed under field conditions using a pilot scale wetland (103 L scale) grown with water hyacinths: after two applications of each 10 ~ 15 mg/L cyanide the effluent water contained non-detectable amounts of cyanide after a period of 20 hours after the first application (See Fig. 5), while in the non-planted control systems no significant degradation of cyanide was observed.

2 Use of Plants for Stabilization and Restoration of Terrestrial Ecosystems

Bioengineering is the use of living or dead plant materials, i. e. seeds, plants, parts of plants and plant communities, to provide technical engineering solutions. Soil bioengineering is now widely practiced throughout Germany, mainly for the treatment of erosion, unstable slopes and embankment stabilization. The result of soil bioengineering protection works are living systems which develop further and maintain their balance by natural succession, i. e. by dynamic self-control, without artificial input of energy. In a current project we use biological engineering techniques to stabilize unstable slopes and to reduce the amount of toxic leachate of an industrial dump site.

Waste disposal sites can be remediated with plants both with respect to leaching - the percolating water may contain high concentrations of pollutants - and with respect to the stabilization of slopes in order to reduce erosion. The Rhenania dump site between Aachen and Cologne, Germany, resulted from the deposition of residual production of potash mining until 1944. Due to the leaching of sulfides and heavy metal stockpile ingredients, there is a serious contamination on the local ground and surface waters (See plate 6, color page Ⅲ).

Over the years, a birch forest with fragmentary shrub and herb layer has established at the dump in a natural way (See plate 7, color page Ⅳ).

The proposed remediation plan[5] for the stockpile primarily aimed at reducing the amount of leachate. The more the volume of leachate from the dump site is reduced, the less money is necessary for treatment of the contaminated leaching water.

Basically, two concepts for the leachate reduction were possible (See plate 7, color page Ⅳ): first, to cover the stockpile with, for example, a drainage and blocking layer, and second to minimize the leachate rate by densification of the vegetation on the dump site.

The advantage of the latter concept is primarily due to the significantly lower costs and in addition in the sustainable handling of this ecosystem. In addition, by planting a dense vegetation cover on the dump site the slopes of the stockpile are stabilized against erosion.

Monitoring of the water-soluble sulfides at the ground trench of the polluted site showed that the highest leaching occurs during the winter months, which is due to the minimal evapo-transpiration rate of the actual existing birch forest defoliated in winter. This problem will most likely get worse in the future due to climate change with a projected increase in winter precipitation of 25% in the study area (See plate 8, color page Ⅳ). As a consequence, contaminants from the dump site will also be eluted in higher concentrations[7].

For deciduous forests almost the entire winter precipitation equals the leachate amounts. Therefore, trees with high, continuous evapo-transpiration, high stability against wind damage, formation of deep roots and high tolerance against pollutant stress were the best choice in planting on the dump site. Douglas firs were chosen as suitable trees which meet such criteria to a high degree. Other positive features of the Douglas fir are the possibility of being planted in the shade of the birch forest and their resistance against drought.

Taking into account the target biotope "mixed Douglas Fir-birch forest", the expected amount of leachate to the Rhenania dump has been calculated. The prognosis of the amount of leachate over time showed that after 20 years the polluted seepage water can be reduced by a factor of two. The success of the planting concept, however, depends on several factors such as the growth rate of the Douglas firs, the potential occurrence of plant diseases, nutrient deficiency, and the success rate of establishing Douglas firs in the existing birch forest to begin with.

Despite the potential risks, the stakeholders decided to realize the planting concept. The realization started in 2010 and 15 000 three year-old Douglas firs were planted in the birch forest. In the first year the planted Douglas firs exhibited good growth rates (See plate 9, color page Ⅳ).

A further important objective of the remediation plan is to protect the dump slopes from erosion. In order to achieve this goal, bioengineering techniques are used. For very steep slopes and highly erodible areas like river-banks, the installation of fascines has been tested. In general, branches of willow are used to build a fascine strand. The installation of timbering with living plants, but also with dead plants, is possible. The plant-network permanently stabilizes the soil structure and reduces erosion (See plate 10, color page Ⅳ).

After having created the fascines, the intermediate space is filled up with soil if necessary. Subsequently, the areas stabilized by the network are sown by hydroseeding, a technique for sowing a mixture of adhesives, nutrients, chopped straw and various plant seeds. Besides herbs and grass seeds, seeds of shrubs and trees can also be sown. This technique allows the rapid seeding of large areas (See plate 11, 12, color page Ⅳ). Following this approach, the steep slopes of the stockpile are protected against erosion and planted.

Acknowledgement: BMBF, Ministry for Education and Research, Germany.

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(Editors: Martin WILLISON, OU Hong-ye)