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Review Article

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Mixed plant operations for phytoremediation in polluted environments – A critical review

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ABSTRACT

In this article, a theoretical approach is focusing on the use of mixed plants to remediate polluted environmental media. Essential conditions should be performed, particularly in supporting plant growth, the safety factor for consumers and the use of amendments in improving the efficiency of phytoremediation. In general, it takes more than one type of the plant to be more effective in restoring a polluted environment. For this purpose, the selected plant species must synergistically eliminate the types of pollutants present in the environmental media. Thus, the mixed plants process becomes very effective in removing many of the pollutants on site. In practice, mixed plants operations could be selected from one or a combination of simultaneous, sequential or alternating patterns, all of which must be adapted to polluted media conditions.

KEYWORDS: Essential conditions, amendment, simultaneous, sequential, alternating

INTRODUCTION

Environmental pollution events generally have a negative impact, both structurally and functionally. For example, plant leaf necrosis is an example of structural damage from the impact of metal contamination on the soil. Next is the death of plants to be the examples of functional damage. In any event of pollution there is a need for environmental restoration, so that it can be reused according to its function, or it can be used for other purposes. For the purpose of restoring a polluted environment, there are physical, chemical and biological processes. Physical processes include soil washing. Concurently, an example of a chemical process is the addition of an organic substance amendment to the soil. Meanwhile, biological processes can be carried out microbiologically and using plants. In practice, these processes are difficult to work alone, meaning that more than one process is required to restore environmental quality. The spectrum of these processes is quite broad and developing, and therefore this paper focuses on biological processes. These biological processes include the role of microbes, known as bioremediation, and plant processes, known as phytoremediation. The bioremediation process can work without the involvement of plants, for example adding microbial cultures to oil-polluted water. Meanwhile, phytoremediation includes the role of root microbes and the plants themselves. Thus, phytoremediation includes the presence of bioremediation, but not the other way around. The result of the phytoremediation process is the result of collaborative work between root microbes, which is commonly known as rhizodegradation, and various plant functions to localize, absorb and degrade pollutants.

The roles and functions of phytoremediation have proven to be a lot of recovery of multi-media environmental pollution: air, water, soil. In addition, plants absorb environmental carbon dioxide, and provide oxygen to the environment, as well as additional aesthetic benefits [1-3]. However, phytoremediation has limitations, because the process is slow [4] according to the plant growth process. It is well known that the growth rates of plants differ from one another. A single plant may also only handle certain pollutants [5], but in the field, contaminated environments contain many pollutants. This is what underlies the need and importance of studying phytoremediation using a mixture of plants.

The use of mixed plants is expected to eliminate various pollutants in a polluted area, both land and water. This has also been suggested in efforts to green the environment [6], which of course includes phytoremediation applications. Therefore, this theoretical study describes the essential conditions of plants and the environment, which aims to achieve an optimal phytoremediation process.

Conditioning of plants and environment

Based on the observations of Chekol *et al*. [7] demonstrated that pollutant-plant-soil interactions are highly specific, and this specificity determines the effectiveness of the phytoremediation scheme. The effectiveness of the phytoremediation was further confirmed by similar studies, which also involved a microbiological remediation process [8-10]. The specificity requires ensuring that no plant will die during the remediation process. Mixed plants must be able to absorb specific pollutants, for example cadmium which is related to plant species, but zinc is associated with soil [11]. Similar results were obtained in remediation of soil contaminated with some heavy metals and oils [12-14]. In addition, each plant must be able to work synergistically, including with root bacteria [2,3]. This fact directs attention to conducting a specification test of pollutants that can be removed by mixed plants.

On the other hand, it is necessary to ensure that each pollutant can be eliminated. In dealing with this problem, range finding tests [15,16] are needed for various plants in growing media that contain various pollutants according to the actual conditions of the polluted environment. This range finding test requires a time scale, which can show the presence of plant growth, as an indicator that plants are alive, and are able to undergo the phytoremediation process. Plant growth is important during the phytoremediation process, therefore the factors that support plant growth must be well preserved. In addition, it is important to pay attention to the choice of plant species for phytoremediation applications, especially for post-harvest handling [17-19].

The use of plants to eliminate pollutants from the environment also makes them pollutant collectors. This becomes an important concern after harvest, regarding further handling, whether for consumption of living things or for conversion of other products, such as compost, and others. As a safety factor for consumers and to shorten procedures, it is advisable to use non-consumptive plant species that are locally available, as well as to demonstrate the certainty of adaptive plants on site. When using consumptive plant types, which are quite widely applied in the remediation process [20-22], it is necessary to carry out a phytotoxicity test to determine the translocation of pollutants in plants, as well as the phytoaccumulation of pollutants.

Several studies have shown that the use of amendments increases the efficiency of phytoremediation. Especially for contaminated soil, inorganic amendments such as lime, and organic such as compost or chelates EDTA and EDGA have the effect of increasing soil remediation from heavy metal contamination [23,24] and oil [25,26]. The use of amendments also has a positive effect, namely being able to improve soil physical properties, such as increasing porosity, moisture content and soil aggregation. The physical condition of the soil supports the plant process and the rhizodegradation process by microbes [26]. Although the amendments can improve remediation efficiency, the use of EDTA metal chelates can improve metal leaching, therefore good management is needed in phytoremediation operations [27,28].

Environmental conditions that support the growth of plants and microbes are water content, especially for polluted soil. The water content in the soil determines the remediation performance [29,30] so that it is necessary to adjust it. There are two status of soil conditions, namely water-saturated and unsaturated water. For water-saturated soil conditions, water can be poured into the soil, which results in anaerobic conditions. Soils with anaerobic status are suitable for increasing the effectiveness and efficiency of endosulfan phytoremediation [31-33]. However anaerobic soil conditions may not apply to all pollutants. In such case, it is necessary to have aerobic conditioning.

In general, the aerobic soil conditions are conducive to the microbiological degradation of organic pollutants. The way for aerobic conditioning is to regulate the soil water content, which is kept unsaturated water. In addition, aerobic conditions are carried out by turning the ground or through an aeration system. Therefore, to phytoremediate various pollutants in an area it is necessary to schedule soil saturation and soil aeration, which are expected to reduce various types of pollutants.

Single in Comparison with Mixed Plants

Ramamurthy & Memarian [34] reported Cd, Pb and engine oil could be treated by single plant, i.e. the Indian mustard: *Brassica juncea*. However, it was enhanced by addition of non-ionic surfactants Triton X-100 and Tween 80 on the removal of mixed contaminants.

Interesting research results come from Li *et al*. [35], who conducted an experiment using the *Vetiveria zizanioides* plant. It is found that the submerged plant zone is the best condition for restoring water quality, compared to the non-vegetation zone. Particularly, it is the ability of plants to break down organic matter in the form of chemical oxygen demand (COD), and to eliminate ammonia and total phosphorus. Next, the water temperature shows that it is lower than the water without plants. Finally, the dissolved oxygen (DO) water from the vegetation zone shows more stability compared to the water from the zone without vegetation. These results need further attention for mixed plant applications.

The study of endosulfan sulfate elimination by several plant species was carried out by Somtrakoon *et al*. [5]. The types of plants used are sweet corn (*Zea mays*), cowpeas (*Vigna sinensis*), and cucumber (*Cucumis sativus*). This study evaluated the extent of removal of endosulfan sulfate from soils with different cropping patterns, whether cultivated alone or together in experimental pots. This study found that endosulfan sulfate was removed mostly in treatments in which sweet corn was grown alone. Endosulfan sulfate is also removed from the soil mostly in remediation, where cucumbers or cowpeas are grown independently. The results showed that monocrops were the most efficient way to restore soil contaminated with endosulfan sulfate. So far, it is not certain what determines that mixed crop cultivation is not effective for eliminating endosulfan sulfate from the soil. Furthermore Somtrakoon *et al*. [36] conducted a similar study to remediate anthracene and fluorene contaminated soil. This process uses three plant species (sweet corn, cucumber, and winged bean), through single crop cultivation and multiple crop co-cultivation. The facts obtained show that winged bean is the most effective plant for phytoremediation when grown alone. However, with the combination of winged bean and corn plants, phytoremediation actually increases its effectiveness. These results indicate that there is an effect of plant species, which can produce phytoremediation effectiveness in mixed plants. The results obtained by these researchers are important to be followed up in their follow-up research, which indicates the influence of plant species in the application of mixed plant phytoremediation effectively and efficiently.

Fraser *et al*. [37] tested four types of aquatic plants namely *Scirpus validus*, *Carex lacustris*, *Phalaris arundinacea*, and *Typha latifolia* in reducing the nitrogen and phosphorus of leachate content by using constructed wetland at various concentrations of N and P. The study was conducted by comparing the single plant treatment system from each of the four plants, and mixed plants treatment. The nutrient uptake of the four plant species has different effectiveness in the decrease of N and P. In the low concentration of both substances, *Scirpus validus* with single plant treatment system has lower efficiency than the four plants in mixed plants treatment system. In high concentrations, the four plant species did not produce significant differences in the efficiency of the reduction of the substance. These results were different from those of Noor *et al*. [38], which showed that single-treatment plant *Typha latifolia* was very effective against nutrient depletion, and the results confirmed the results of Yalcuk and Ugurlu [39].

Furthermore, the research of Hechmi *et al*. [40], who have carried out mixed plant studies to restore pentachlorophenol (PCP) contaminated soil. The treatment variations were for single plants and a mixture of four plant species, namely white clover, ryegrass, alfalfa, and rapeseed. Phytoremediation results for two months of cultivation showed that a mixture of white clover, raygrass, alfalfa, and rapeseed significantly increased PCP degradation. The mixed plant cultivation of rapeseed and alfalfa resulted in higher PCP phytoremediation efficiency compared to single plant. Meanwhile, alfalfa eliminated PCP the most in the monoculture system. A similar study was also conducted by Chen *et al*. [41], which resulted in the fact that PCP can be eliminated well by plant root exudates. Further confirmation is the report of Li *et al*. [42], which resulted in the fact that the mixed plants significantly increased the dissipation of polychlorinated biphenyls (PCBs). In addition, mixed plants of fescue and alfalfa was most beneficial for soil bacteria and enzyme activity. These results demonstrated the superiority of mixed plant phytoremediation for the particular species used. This invites further research on the effects of plant species exudate production in eliminating environmental pollutants.

Batty & Anslow [43] studied the phytoremediation of zinc and the effects of pyrene by *Brassica juncea* and *Festuca arundinacea* in contaminated soil. Compared to the control treatment, plant-free media, zinc was effectively removed from the soil by the role of the mixed plant. Zinc accumulates in plants, which was affected by the presence of pyrene. However, *B. juncea* growth was significantly reduced if zinc and pyrene were supplied in combination. Zinc was primarily associated with root tissue for *F. arundinacea*, whereas *B. juncea* contains a higher concentration in shoot tissue.

The phytoremediation of soil contaminated with polycyclic aromatic hydrocarbons (PAHs) was investigated by Muratova *et al*. [44]. The researchers studied the ability of plants to support and enhance the microbial degradation of pollutants in the rhizosphere as the main mechanism. The type of plant determines the formation of specific rhizosphere, which have a high degradation potential for these contaminants. Comparison of PAH degradation in unplanted soil, and in soil planted by reeds (*Phragmites australis*) and alfalfa (*Medicago sativa*) was observed in a two-year potting experiment. Both plant species were able to remediate PAH contaminated soil with an elimination efficiency of over 60%. Studies of the rhizosphere, rhizoplane, and soil microflora that were not planted in experimental pots showed that alfalfa stimulated the rhizosphere microflora in soil contaminated with PAHs, which was more effective than reed. Alfalfa clearly increases the total number of microorganisms and the population rate decreases the PAH. The potential for degradation of rhizosphere microflora against PAH was higher than that of reed rhizosphere degradation activity. The results were confirmed by the study of Nwaichi *et al*. [45] who conducted field experiments to investigate the removal and/or absorption of PAH and certain metals (As, Cd, Cr) from crude oil-contaminated agricultural soils. The researchers concluded that the use of mixed plants coupled with soil amendments resulted in a significantly increased activity of the biota community, thereby promoting ecosystem restoration.

For comparison with the remediation of polluted environment, in the application of sewage treatment in wetlands, it was also found the effect of mixed plants in eliminating pollutants. Plant mixtures of *Lemna minor*, *Typha latifolia*, and *Scirpus acutus* were more effective and efficient at eliminating pollutants than monoculture applications. The next result was that mixed plant operations were suitable using a sequential method, ie flow into the compartment sequence of each different plant species [46-48].

Plants Operation

Mixed plants operation here defined as, first, the use of more than one species in a plot; in this case referred to as simultaneous mixed plants. In agriculture, it was known as the polyculture or intercropping pattern. For this case, the application was suitable for remediation of static or fixed polluted media such as polluted soil and polluted lake water. Similarly, it was the treatment of sewage in wetland systems. There was no limit to the number of species of plants that were used for this purpose.

The second was the use of each type in a separate plot, the one and the other plot was a sequential process; in this case referred to as sequential mixed plants. In this case, the cropping pattern may be monoculture sequentially, or sequential polyculture, or a combination thereof. For this case, the application was suitable for remediation of movable polluted media such as polluted river water, ex-situ treatment, and also for wastewater treatment. The number of plant species used was limited in accordance with the availability of treatment facilities.

The third was the use of plants interchangeably in a plot; hereinafter referred to as alternating mixed plants. It was the same as rotation cropping pattern, which used different types of plants in rotation on a single plot. For this case, the application was suitable for remediation of static or fixed polluted media.

Application of mixed plants actually was a realistic approach. There was rarely a single plant species in an ecosystem in the field, unless it was a cultivation of plants with specific controls to produce a particular product.

During plant operation there were many possible occurrences of plant residue entering the soil. The incident actually benefited the soil condition as it would improve the remediation process. The study of Wang *et al*. [49,50] suggested that both the soil microbial biomass carbon and nitrogen contents could be substantially increased by returning of two or more than two-plant-species residues into soils, which could then contribute to the enhancement of vegetation restoration and soil fertility.

CONCLUSIONS

Phytoremediation using mixed plants, like using single plant, is a specific interaction between plants, pollutants and the environment. Plant conditioning to the polluted environment is very important, especially for the synergy between plant species in order to eliminate various pollutants. Regulating water content for polluted soil, and/or conditioning the anaerobic/aerobic status of the environment generally requires operational management in accordance with plants and pollutants as well as environmental media. The advantages of mixed plant phytoremediation are strongly influenced by the selection of plant types and the types of pollutants in the environmental media.

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