Use of Biochar for Remediation of Contaminated Soils

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Abstract— Biochar is a soil conditioner with a porous structure and intense carbon, obtained by pyrolysis of various organic materials. Similar to charcoal, which has been widely used since ancient times, biochar can be obtained from various sources. A large number of organic materials can be used as raw materials, including mainly various plant materials and organic wastes. Biochars are physically highly light and have a porous structure and chemically have a high cation exchange capacity and alkaline character. Depending on the obtained material and pyrolysis conditions, differences in these properties can be observed. In recent years, there have been many research findings on the use of biochars in metal stabilization and phytoremediation studies in metal-contaminated soils, and it is accepted as a promising and alternative soil conditioner in the remediation of contaminated soils.

Keywords—Biochar, Contaminated soils, Phytoremediation

I. INTERACTION OF BIOCHAR IN THE SOIL SYSTEM

Biochar, as a soil conditioning material that has been increasingly accepted in recent years, increases soil biological activity and soil carbon accumulation, improves soil properties, increases soil fertility and soil quality [1]. The source and composition of the material, particle size, pyrolysis temperature and post-pyrolysis sizing processes have important effects on the properties of biochar and affect the interaction of biochar in the soil. Due to the wide range of variability of biochars depending on the material from which they are obtained, basic biochar properties such as surface area, pH, ash and carbon content may differ and their effects on the soil to which it is applied may differ.

It has been reported that biochars have a high adsorption capacity due to the large surface areas provided by their porous structures, and they provide metal stabilization especially in metal-contaminated soils [2] . It is stated that this stabilization may be due to the physical adsorption of metals or metalloids in the soil [2], as well as by their absorption by replacing them with cations such as Ca^{+2}, Mg^{+2}, K^{+}, Na^{+} [3].

The pH value of biochar increases with the pyrolysis temperature, resulting in higher ash content [4]. After the addition of biochar, higher pH values can reduce heavy metal precipitation in soils with low pH value and high metal mobility, and also reduce the mobility of heavy metals by changing their redox values [5].

The absorption mechanism of biochar for metals in soil is highly dependent on cations found in both biochar and soil.

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Some other compounds, such as carbonates, phosphates or sulfates, found in post-pyrolysis biochar ash can help stabilize pollutants and heavy metals in the soil by precipitation [6]. Biochars interact with the readily soluble bioavailable fraction of soil heavy metals, greatly limiting their availability [7]. Although the effects of biochars on metal stabilization in soil are mostly assumed to result from an increase in pH, the relative contributions of differences in biochar properties and different mechanisms in the soil are unknown.

II. INTERACTIONS OF BIOCHAR WITH HEAVY METALS

Heavy metals can be accumulated, leached and transported to plants depending on soil properties with their undegradable feature in nature. Biochar applications in soil improvement do not reduce the total metal content of the soil, but significantly reduce the bioavailability and mobility of metals [7]. Biochar applications significantly reduce the metals leached from the soil by leachate [8], and Cd, As and Pb concentrations decrease in plants grown in metal-contaminated soils [9].

It has been reported that the metal stabilization effect of biochars in soil is formed by the precipitation and complexation of metals with carbonate, sulfate and phosphate in biochar [10]. It has been reported that the immobilization of heavy metals by biochar is associated with metal lability, and heavy metal immobilization follows the order Cu+2 >Cd^{+2} > Ni^{+2} [11]. It has been reported that biochars obtained from different materials have different effects on metal availability in metal-contaminated soils [6], and metals in the organic bound fraction increase with both biochar applications in sequential extraction of soils [6,12].

As a result of heavy metal immobilization, biochars reduce the phytotoxicity of contaminated soils, resulting in an increase in seed germination rate and root length [13]. It has been reported that besides the material properties of biochar, the pyrolysis temperature has a significant effect on the metal availability of biochar in the soil, and biochars prepared at 700 ◦C give more effective results in metal stabilization [14].

III. USE OF BIOCHAR IN PHYTOREMEDIATION AND FERTILIZATION

Phytoremediation, which is defined as soil reclamation by growing some special plants in polluted soils has begun to gain more acceptance than expensive and mostly locally effective chemical methods such as immobilization and extraction technics used in soil improvement. Studies on phytoremediation have started to gain momentum after the 1990s, and it is still considered a new practice. Phytoremediation involves removing pollutants from the soil or stabilizing the pollutants in the soil by means of plants with various properties. Phytoremediation is divided into different groups such as phytoextraction, phytostabilization, phytovolatilization, phytodegradation according to their mechanism of action, and the selection of the appropriate plant species is important for the removal of the target pollutant in the soil. Phytoextraction refers to the use of hyperaccumulatory plants that relatively accumulate pollutants in high amounts. Phytostabilization involves the immobilization of pollutants in the soil by the secretions of plant roots; phytodegradation decomposes pollutants within the plant; Phytovolatilization refers to the removal of pollutants from leaves by transpiration. Among these techniques, phytoextraction technique is mostly used in the removal of heavy metals from the soil.

The feature of the hyperaccumulator plant is that it can accumulate heavy metals at a level 100 times higher than known plants without yield reduction [15]. In addition, rapid growth, tolerance to the toxic effects of pollutants, adaptation to local environmental and climatic conditions, resistance to pathogens and pests, easy cultivation and high biomass yield are desirable properties [16]. However, due to the fact that plants have adapted to different climatic and soil conditions in nature, the existence of plants that can accumulate all pollutants in every climate and soil condition is very limited. In this respect, the research of hyperaccumulator plants adapted to the ecological regions where pollutants are found constitutes most of the studies on this subject. Among these studies, it has been determined that some plants accumulate more heavy metals in their bodies. To date, more than 400 species have been described as hyperaccumulators, including more than 300 Ni hyperaccumulators [17]. In contrast to the element Ni, only a few plant species showed the potential to accumulate Cd, Cu, Pb and Zn [18]. Many phytoremediator plant groups belong to the Brassicales taxonomic order, and there are abundant hyperaccumulatory plants in the Asterales, Solanales, Poales, Malpighiales, Fabales, Caryophyllales and Rosales groups [19]. The effectiveness of the phytoremediation technique can be limited by the fact that plants show phytotoxicity mostly in areas with very high heavy metal concentrations. Another handicap is that such plants often grow slowly and produce little biomass, which limits the amount of metal uptake.

Soil chemical properties such as pH, lime, clay and other oxide compounds have a significant effect on the availability of heavy metals in the soil and their uptake by crop plants. As mentioned above, biochar can stabilize heavy metals in the soil and thus reduce their uptake by plants. In recent years, there have been many studies [12, 20] showing that biochars are used in phytoremediation studies due to their positive effects on plant growth and their ability to stabilize pollutants. The improvement in plant yield after biochar addition to the soil is generally attributed to effects such as increased water, cation exchange capacity, nutrient holding capacity and nutrient availability in the soil, increased biological activity, and regulation of extreme soil pH.

Biochars have very heterogeneous properties according to the source and pyrolysis conditions in which they are obtained, and in practice, they can sometimes give unexpected results in similar studies by being affected by parameters such as soil conditions and incubation time. Most of the experiments examining the effects of biochar or phytoremediators were carried out in short-term studies under laboratory conditions, and the ecological effects of a particular region were not taken into account. The decomposition processes of biochar in the soil were mostly ignored and focused on the targeted effects. Material selection and optimization of pyrolysis conditions are important to produce the desired standard biochar for standardization in experimental conditions.

There has been recent interest in combining phytoremediation with other potential plant uses, such as the production of bioenergy crops on contaminated soils. Although heavy metal-contaminated areas are not suitable for food production, growing bio-products in these areas can provide economic and environmental benefits such as supporting soil organic matter stocks, reducing soil pollutants [21] and reducing greenhouse gases [22].

IV. CONCLUSION

The regulating effects of biochar on soil chemical properties become important especially in soil conditions that limit plant growth such as low organic matter, extreme pH, low colloid content and especially salinity. In addition, the effects of biochars on metal stabilization offer a potential hope for the rehabilitation of contaminated soils and for plant production. However, there is a need for multidimensional studies, including ecological effects, on the subject of combining biochar applications with phytoremediation in polluted soils.

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