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Effect of Bio char on Plant Growth and Aluminium Form of Soil under Aluminium Stress

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Abstract. Aluminium-enriched acid red soils in South China easily cause aluminium toxicity to plants, but biochip can improve soils and eliminate soil contaminations. In this project, biochip was used in potted plant control test to study the effect of biochip on plant growth in soil under acid aluminium stress and the migration and conversion of aluminium in plant-soil system. The fin dings show that the application of biochip increases the pH value of soil under aluminium stress significantly, changes the existing form of aluminium ion in soil, reduces the plants' absorption of aluminium, and alleviates the aluminium toxicity to plants, but too much biochip may inhibit the growth of plants. In this case, further study should be carried out as regards the volume and way of biochip input in practical applications as well as the timeliness of aluminium toxicity removal.

1. Introduction

More than 50% of arable soils belong to acid soils around the world [1]. The main problems of acid soils include low pH value, and too high concentrations of free aluminum and exchangeable aluminum. On the contrary, the pH value of natural soils is normally not less than 4, so it is less possible for H+ to directly cause toxicity, but indirect effect of low pH value in soil must be more significant, that is, too high concentration of aluminum, which inhibits the growth of plants in soil, i.e. aluminum toxicity [2,3]. The chemical forms of aluminum vary with environmental conditions. Under alkaline conditions, monomer hydroxyl aluminum polymerizes to show a series of polymeric hydroxyl forms. In a neutral environment, aluminum forms $Al(OH)_3$ solids. The aluminum of these forms has lower biological toxicity. When the pH value of environment is lower than 6.0, aluminum exists in the forms including Al^{3+}, $Al(OH)^{2+}$ and $Al(OH)^{2+}$, which are very toxic to plants [4-6].

Bio char is solid residue from biomass after thermal decomposition, so it can be produced from a variety of raw materials including agricultural and forestry wastes, e.g. woods, stalks and nutshells, as well as organic wastes generated in industry and city life, e.g. garbage and sludge. Now, it has become a hot topic in the domestic and overseas studies for its unique features of alleviating climate change and improving soil quality [7-10]. As revealed in the studies, bio char has stronger ability to absorb captions than other organic matters in soil. The application of bio char can significantly affect the forms and migration behaviors of heavy metals in soil. Bio char can not only directly absorb and immobilize the heavy metal ions in soil, but also reduce the migration of heavy metals from soil to plant system and reduce the genetic toxicity of soil contamination to plants by affecting the physical and chemical properties of soil including pH value, CEC and water-holding capacity. Meanwhile, bio char can improve the activity of microorganisms, which can facilitate the decomposition and deactivation of harmful matters in soil, so it has great potentials for soil recovery from contamination [11-14]. This study will provide new ideas for resource-based utilization of biomasses discarded in agriculture, as well as the theoretical basis for developing the practical, effective, safe and environment-friendly in situ immobilization technology for aluminum-contaminated soils.

2. Material and Method

2.1. Culturing of Test Plants
A 15cm long cutting of annual evergreen poplar (Populus×euramericana cv.A-61/186) was placed into white foam box containing 18L culture liquid. A piece of foam floated on the surface of culture liquid as a fixed support of the cutting. After placement, the cutting was cultured with tap water for 20d. After it rooted, Hoagland total nutrient admixture was used to culture the cutting for 15d. The seedlings with basically consistent growth were transplanted into 40 cm×40 cm plastic pots for stress test.

2.2. Treatment of Test Soil
Test soil was taken from the field with the neutral pH value. After removing any foreign matters, soil was dried in a shaded and well-ventilated place for 1 week, and then screened with 2mm mesh. The screened soil was equally divided and placed inside plastic pots. Three treatments were arranged by evenly mixing soil with bio char equivalent to 1%, 3%, 5% of its weight, and one portion of soil was not treated with bio char. Five pots were prepared for each portion of soil after treatment to apply aluminum stress.

2.3. Design of Aluminium Stress Test
By taking 3g AlCl3·6H2O and dissolving it into 20L de-ionized water, the pH value of liquid was adjusted between 4.3-5.0. At the early stage of stressing, 1L aluminum chloride solution was sprayed on each pot once a week, five times in total. At the late stage of stressing, normal water content was managed. After 5-month stressing, samples were taken to measure the relevant indicators. Meanwhile, a set of pots without plants and a set of soils without aluminum stress were kept as the controls.

2.4. Measurement Method
The pH value of soil was measured by using a PHS-4CT desk-type precision acidometer with digital display. A ruler was used to measure the height of seedlings every 30d. The aluminum of different forms were measured by taking the sequential extraction method [15].

3. Findings and Analysis

3.1. Effect of Bio char on the pH Value of Soil
The pH value of soil increases gradually with the input of biomass (Fig. 1). The pH value of soil under aluminum stress after being treated with 1% C, 3% C and 5% C increases by 0.32, 0.73 and 1.12 respectively compared with the pH value of soil without treatment. The pH value of soil without aluminum stress after being treated with 1% C, 3% C and 5% C increases by 1.11, 1.96 and 2.91 respectively compared with the pH value of soil without treatment. The pH value of soil under aluminum stress increases more significantly than that without aluminum stress. On one hand, bio char is alkaline, so it pushes up the pH value after being applied in the soil. On the other hand, the pores of bio char can absorb aluminum ions to some extent, and the aluminum ions can generate hydrogen ions after hydrolysis to make the solution acidic, so the decrease of aluminum ions will lower the amount of hydrogen ions in the solution, causing the rise of the pH value.

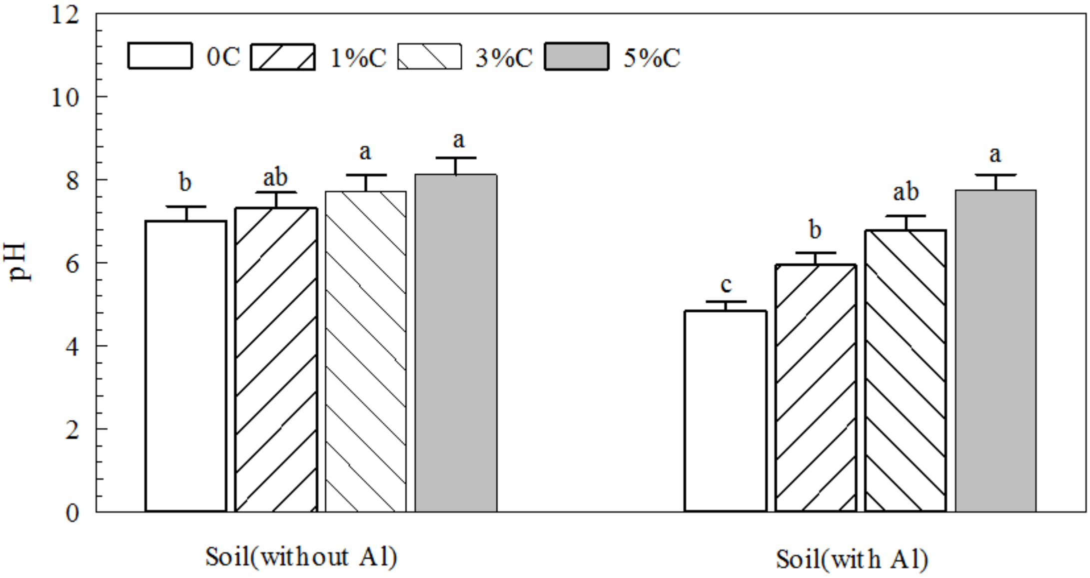

Figure 1. Effect of bio char on the pH value of soil under aluminum stress

Different letters indicated significant difference among treatments ($P<0.05$).The same below.

3.2. Effect of Bio char on Aluminium Form of Soil

When soil is under aluminum stress, the degree of aluminum toxicity closely relates to the existing form of aluminum. The aluminum in exchange state, which exists in the form Al^{3+} or $Al(OH)^{2+}$, is most toxic to plants, while the aluminum in absorbed state, which exists in the form $Al_2(OH)_2^{4+}$ or $Al_{13}(OH)_{32}^{7+}$, is less toxic. Moreover, the aluminum in complex state, which is mainly composed of hydrolytic polymeric macromolecules or colloidal molecules, has much lower toxicity and even loses toxicity, but its content is mainly affected by the pH value of soil [16]. When the input of bio char increases gradually, the content of aluminum in exchange state, which is most toxic to plants, decreases in the soil of potted evergreen poplar under aluminum stress (Fig.2), and it varies significantly between soil treated with 5% C and soil without using bio char or treated with 1% C. The content of aluminum in absorbed state increases and then decreases along with the input of bio char, but it does not vary significantly between soil treated with 1% C and soil treated with 3% C. The content of aluminum in complex state, which has the lowest biological toxicity, increases gradually along with the input of bio char, so it varies significantly between soil treated with 5% C and soil without using bio char. In other words, bio char can effectively change the form of aluminum in soil to alleviate the aluminum toxicity to plants. Meanwhile, the aluminum of such three forms in the soil without plants also varies in the same trend (Fig.3).

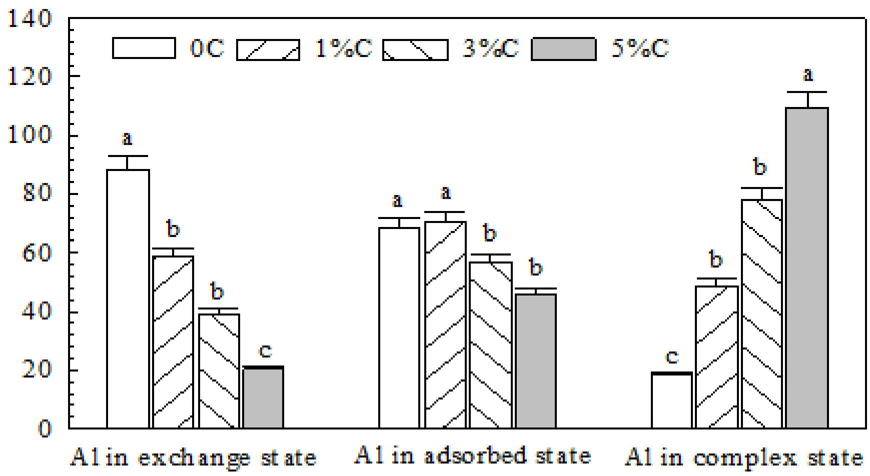

Figure 2. Effect of biochip on aluminium form of soil with plants

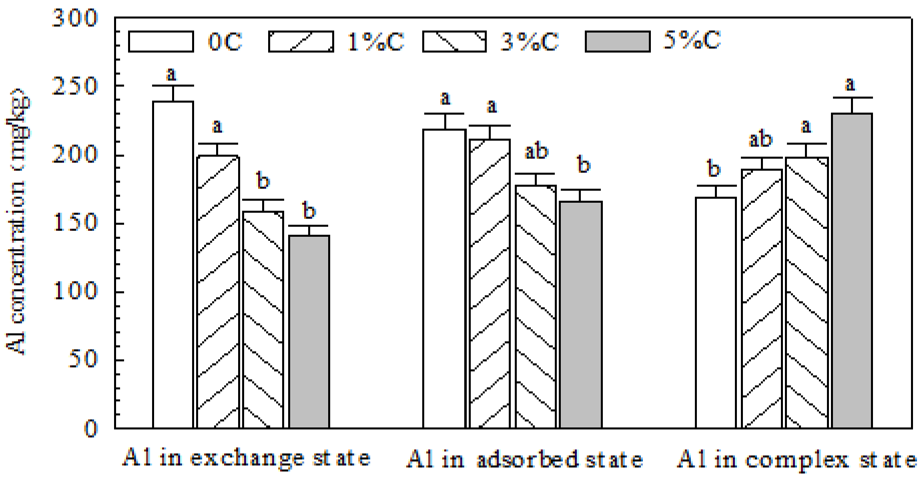

Figure 3. Effect of bio char on aluminum form of soil without plants

3.3. Effect of Bio char on Growth of Evergreen Poplar

Seedling height is one of external features demonstrating whether plants are exposed to aluminum toxicity. Different inputs of bio char affect the seedling height under aluminum stress (Fig. 4). When the stress lasts for 30d, the input of bio char has no significant impact on the seedling height of evergreen poplar under aluminum stress. When it lasts for 60d, the treatments with 1% C and 3% C can noticeably promote the growth of evergreen poplar seedlings, and such promotion to growth keeps increasing along with the duration of treatment. The evergreen poplar seedlings in soils treated with 5% C and without treatment do not have much difference in terms of growth at the early stage of stressing, but the seedlings in soil treated with 5% C gradually grow taller than those in soil without treatment as the treatment lasts, but such difference is not significant. In terms of effect on growth, there is 3%>1%>5%>without treatment. It implies that a proper input of bio char can significantly facilitate the growth of plants under aluminum stress, but too much bio char may change the form of aluminum, which has the highest biological toxicity, and inhibit the growth of plants at the same time.

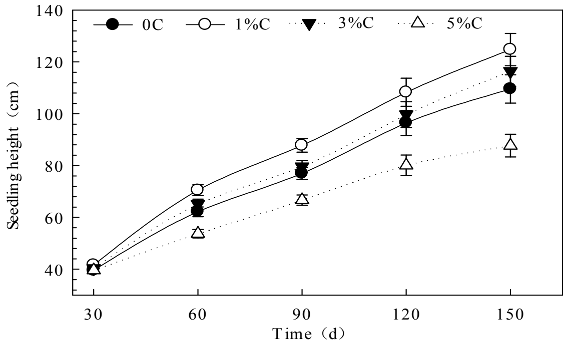

Figure 4. Effect of biochip on height growth of evergreen poplar under aluminium stress

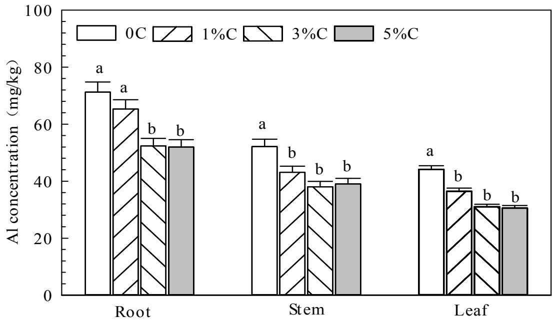

Figure 5. Effect of biochip on aluminium content of evergreen poplar under aluminium stress

3.4. Effect of Bio char on Aluminium Content of Plants

The application of bio char can lower the aluminum content of the roots, chalks and leaves of evergreen poplar (Fig. 5). The aluminum content of roots in soils treated with 1% C, 3% C and 5% C decreases by 8.34%, 26.48% and 27.01% respectively compared with that in soil without using bio char. The aluminum content of stalks in soils treated with 1% C, 3% C and 5% C decreases by 17.33%, 27.05% and 25.15% respectively compared with that in soil without using bio char. The aluminum content of leaves in soils treated with 1% C, 3% C and 5% C decreases by 17.39%, 29.70% and 30.72% respectively compared with that in soil without using bio char. Compared with the plants in soil treated with 1% C, the aluminum content of roots in soil without using bio char does not decrease significantly, but the aluminum content of stalks and leaves in soil without using bio char decreases significantly. The aluminum content of roots, stalks and leaves in soils treated with 3% C and 5% C decreases significantly compared with that in soils without using bio char and treated with 1%C, but there is not much difference between treatments with 3% C and 5% C.

4. Conclusion and Discussion

Acid soils inhibit the growth of plants severely, which mainly results from aluminum toxicity. The effect of bio char on the alleviation of aluminum toxicity to evergreen poplar varies with different inputs of bio char. The seedlings in soil treated with bio char equivalent to 3% of potted soil grow best, which is followed by those in soil treated with 1% C. The growth of seedlings under aluminum stress in soils without using bio char and treated with 5% C does not change significantly. With regard to the mechanism of alleviation, bio char can absorb the aluminum in soil to reduce the amount of aluminums absorbed by plants. Moreover, bio char can change the pH value of soil to modify the existing form of aluminum in soil, so that the content of aluminum in exchange state is lowered in soil to alleviate the toxicity of aluminum to plants. The input of bio char is significantly related to the change of aluminum ion form and the aluminum absorption of plants, but too much bio char may inhibit the growth of plants for the following reasons: too high content of base ion K and lower osmotic pressure inhibit the growth of crops [17]; too high pH value inhibits the growth of roots [18]; available nutrients are absorbed to lower the contents of nitrogen, phosphorus and trace elements (e.g. Fe), which inhibits the growth of crops [19,20]; bio char contains some toxic matters that inhibit the growth of crops [18-21].

After applying bio char in soils, the content of aluminum in exchange state decreases significantly, the content of aluminum in absorbed state increases and then decreases, and the content of aluminum in complex state, which has the lowest biological toxicity, increases gradually, due to the increase of bio char input. Hence, bio char can change the content of aluminum in various forms in soils. As pointed out in some studies, bio char can affect the aluminum in exchange state in acid soils by changing the pH value of soils. As the pH value of soils increases, the exchangeable aluminum is converted into hydroxyl aluminum after hydrolysis, and partially transformed into the hydroxide of aluminum or deposit of oxides [22], which matches with the findings in this study. Additionally, a great number of oxygen containing functional groups exist on the surface of biomass, and can interact with aluminum to generate coordination (chelate) compounds, so that the exchangeable aluminum of soils is converted into the poorly active organic aluminum in complex state, which alleviates the toxicity of aluminum to crops [23].

In the current production, soils with aluminum toxicity can be remediated physically, chemically and biologically [24-26]. Physical remediation is so costly that it is suitable only for treating the heavily contaminated soils of small area. Biological remediation has such advantages as low cost and no damage to the structure of soil fertility, but it is time consuming. Chemical remediation is often applied and studied. In this method, the application of amendments is a very economical way to remediate the aluminum contaminated soils, and an in-situ chemical treatment that has been applied in practice. Now, common amendments include limestone, phosphate and industrial wastes (molten slag and ground granulated blast-furnace slag), etc. These amendments have some problems to different degrees including unstable effect of immobilization, water eutrophication caused by phosphorus release, or new introduction of heavy metals. For its strengths including high stability, large specific surface area, and strong ion exchange capacity in the environment, bio char can be taken as an important amendment for treating aluminum stress. As revealed in the findings of this study, the application of bio char can significantly improve the pH value of soils under aluminum stress to change the existing form of aluminum ion, reduce the plants' absorption of aluminum, and alleviate the aluminum toxicity to plants, but too much bio char may have negative effect on the growth of plants and the physical and chemical properties of soils. Hence, further study should be carried out as regards the volume and way of bio char input in practical applications as well as the timeliness of aluminum toxicity removal.

Acknowledgments

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