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Biochar Effect on Water Evaporation and Hydraulic Conductivity in Sandy Soil

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ABSTRACT

Biochar, as a kind of soil amendment, has important effects on soil water retention. In this research, 4 different kinds of biochars were used to investigate their influences on hydraulic properties and water evaporation in a sandy soil from Hebei Province, China. Biochar had strong absorption ability in the sandy soil. The ratio of water content in the biochar to that in the sandy soil was less than the corresponding ratio of porosity. Because of the different hydraulic properties between the sandy soil and the biochar, the saturated hydraulic conductivity of the sandy soil gradually decreased with the increasing biochar addition. The biochar with larger pore volume and average pore diameter had better water retention. More water was retained in the sandy soil when the biochar was added in a single layer, but not when the biochar was uniformly mixed with soil. Particle size of the added biochar had a significant influence on the hydraulic properties of the mixture of sand and biochar. Grinding the biochar into powder destroyed the pore structure, which simultaneously reduced the water absorption ability and hydraulic conductivity of the biochar. For this reason, adding biochar powder to the sandy soil would not decrease the water evaporation loss of the soil itself.

Key Words: pore structure, pore volume, porosity, soil water retention, water holding capacity

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INTRODUCTION

There are large areas in China where plants and crops are hard to grow due to the shortage of water. Improper agricultural activities and severe drought due to climate change result in further soil degradation, *i.e.*, sandification and desertification, which permanently increases the evaporation water loss and decreases the soil water retention in these lands. According to the 4th round of national desertification and sandification monitoring carried out by the State Forestry Administration of China from 2005 to the end of 2009, the desertified land area of China was 2 623 700 km^2 and the sandified land area 1 731 100 km^2 (SFA PRC, 2011). The harsh situation of soil degradation imposes serious threats to nationwide ecological security. It is vital to make urgent efforts to mitigate or reverse the effects of desertification. One of the rigorous measures is the improvements of water retention in degraded soil and thus the soil fertility.

For this purpose, sustainable agricultural practices could be beneficial. Traditionally, China is an agricultural country. Plentiful biomass resource is produced from agricultural residues and livestock manure in rural area. Most of these biomass feedstocks are currently burned inefficiently (Zhang *et al.*, 2007; Wu *et al.*, 2008; Sun *et al.*, 2014). This is not only a waste of energy, but also a disaster to the local environment. One way to sustainably exploit the biomass resource from agricultural sector is to pyrolyse these agricultural wastes and to put the products (*i.e.*, biochar) in soils. As the solid product of biomass pyrolysis, biochar has been well considered as a soil amendment changing the soil water retention (Gaunt and Lehmann, 2008; Kinney *et al.*, 2012; Novak and Watts, 2013). The basic idea in this work is to use biochar in degraded or sandy soils for improving water evaporation loss and soil fertility and preventing desertification.

Biochar-type substances were discovered in Amazonian Dark Earths (Lehmann and Joseph, 2009). The biochar was added to soil as the result of forest fires, slash-and-burn agriculture and commercial production (Tryon, 1948; Wardle *et al.*, 2008). In such areas, the soil had better water retention compared with that without biochar addition (Beck *et al.*, 2011). Besides, the biochar has high level of resistance to be minera-

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lized to CO_2 (German, 2003; Fowles, 2007; Steiner *et al.*, 2007). Because of the stability of biochar, the cost to improve soil water retention by the addition of biochar could be relatively low (Lehmann, 2007a, b; Asai *et al.*, 2009). As a result of these discoveries, more and more researchers have turned their attention to biochar. When biochar was added in the soil, there was a significant increase in water retention capacity of the soil (Glaser *et al.*, 2002; Lehmann *et al.*, 2003; Beck *et al.*, 2011; Eastman, 2011; Karhu *et al.*, 2011; Baronti *et al.*, 2014; Tammeorg *et al.*, 2014). However, there are many factors that will influence the effect of the biochar on soil water retention and seem to exist an optimum application rate of biochar because of water repellence (Piccolo *et al.*, 1996). Soil types could also be a factor changing the effect of biochar on soil water retention. In some studies, biochar has a better water retention capacity in sandy soils than in other soil types (Tryon, 1948; Abel *et al.*, 2013).

Moreover, the effect of biochar on soil water retention also depends on its properties. Some characteristics of biochar have been studied in recent literatures (Novak *et al.*, 2012). However, further work still need to fully understand the effect of biochar on water retention. In our previous research, biochars were proved to have strong water holding capacity (WHC) (Zhang and You, 2013). Moreover, the relationships between the WHC of the biochars and the surface area, total pore volume, and porosity structure were analyzed. The total pore volume played a more important role than the surface area or surface functional groups in WHC for the chars with a relatively large pore size. Although the addition of biochar to soil has been found to increase soil water retention, few studies have been made on the mechanism of biochar's effect on soil water evaporation and on how to maximize the water retention of the biochar (Sohi *et al.*, 2009). In general, biochar could increase the water content in soil when applied to soils through two ways. One way is that it can increase the soil's water retention by retaining water in its pores by capillary force and reduce the mobility of the water (Tryon, 1948; Pietikäinen *et al.*, 2000; Karhu *et al.*, 2011). Because of the high porosity, biochar was thought to have much stronger water holding capacity than the soil (Pietikäinen *et al.*, 2000; DeLuca *et al.*, 2009). The other way was by changing the hydraulic properties of the soil (Asai *et al.*, 2009; Karhu *et al.*, 2011). The biochar added to the soil could improve soil aggregation by binding to other soil constituents (Piccolo *et al.*, 1996; Herath *et al.*, 2013; Soinne *et al.*, 2014). Moreover, the different pore size distribution between the biochar and the soil will also change the hydraulic conductivity of the soil.

In this research, a further experiment was done to study the biochar's effect on sandy soil water evaporation. Specifically, it was conducted to analyze the relationship between the characteristic of biochar and soil water retention capacity, elaborate the mechanism of biochar's effect on soil water evaporation, and help to choose the right biochar and application method. It would play an important role in guiding the use of biochar as a kind of soil amendment in decreasing soil water evaporation.

MATERIALS AND METHODS

Biochar and sandy soil samples

Four biochars were prepared from pyrolysis of pine (*Pinus sylvestris* var. mongolica Litv) and poplar (*Populus davidiana*) at 450 and 550 °C, respetively. In this research, the poplar biochars were labeled as Y450 and Y550, while the pine biochars were labeled as S450 and S550. It has been thought that pore size distribution in biochar particles is dependent on both raw materials and pyrolysis temperatures. The particle size of the biochar was about 5–8 mm in diameter after pyrolysis. The critical characteristics and pore size distribution of the biochars were given in the former research (Zhang and You, 2013).

The sandy soil sample used in this study was collected from a desert in Hebei Province, China (40° 30′ N, 115° 70′ E). The total annual precipitation in that region is about 370 mm. The soil is almost sandy, with the sand content of 995 g kg^{-1} and silt content of 5 g kg^{-1}, and is alkaline with a pH of 8.6. The average particle size of the sandy soil was 0.28 mm (Mastersizer 2000, Malvern Instruments Ltd., UK) and the porosity was 0.44. The bulk density was 1.50 g cm^{-3}, and the real density was 2.66 g cm^{-3}.

Water holding capacity

A water balance experiment was carried out to investigate the water transport between the sandy soil and the biochar particles when they were mixed together. Under certain water contents of the sandy soil and the biochar, the net water transfer between them will approach zero, *i.e.*, the steady state is reached. The experiment was done in the device shown in Fig. 1. The mixure of biochar Y550 and sandy soil was put in the column on the right. The container on the left was used to provide a constant water pressure for the soil column. Under this condition, the water content of the soil in the column would keep at a steady state. This design offered the convenience that the water distribu-