Catena 162 (2018) 29–39

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Effects of biochar addition on evaporation in the five typical Loess Plateau soils

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ARTICLE INFO

Keywords:
Biochar
Soil evaporation
Biochar particle size
Loess Plateau soils
Biochar addition amount

ABSTRACT

Soil evaporation is the main route of soil moisture loss and often exceeds precipitation in the arid and semi-arid regions of the Loess Plateau. This study was conducted to determine whether biochar addition could reduce soil evaporation in drylands. We measured the evaporative loss in five typical topsoils (0–20 cm) from the Loess Plateau, Shaanxi, China, that differed in texture (Eum-Orthic Anthrosol, Isohumisol, Loess, Sandy loess, and Aeolian sand) with five different biochar addition amounts (0, 10, 50, 100, and 150 g-biochar/kg soil) and three biochar particle sizes (2–1 mm, 1–0.25 mm, and < 0.25 mm). The results showed that biochar addition generally increased the soil average water content (by 35.6% in biochar treatments and 33.5% in control treatments) and effectively reduced soil cumulative evaporation (by 322.64 g in biochar treatments and 326.68 g in control treatments). In addition, the inhibition of evaporation was enhanced with increases in biochar particle size and addition amount. Biochar addition had contrasting effects in the two evaporation stages: Biochar decreased evaporation through capillary flow during the first stage of evaporation but increased evaporation during the second, diffusion-limited vapour transport stage, particularly in the Aeolian sandy soil. When expressed on a mass basis, the effect of biochar addition amount on the cumulative evaporation (CE) was dependent on biochar particle size. In the larger sized (2–1 mm and 1–0.25 mm) biochar treatments, the final CE decreased as the addition amount increased, but for < 0.25 mm particles, increasing the biochar addition amount increased the final CE due to the creation of micropores. However, biochar addition decreased the ratio of evaporative loss in all soils proportional to the biochar addition amount. Soil texture and biochar particle size were the main factors affecting soil evaporation. Biochar application has the potential to improve soil water availability in semi-arid lands, but the results will depend on the biochar particle size and addition amount.

1. Introduction

According to a report by the National Ministry of Agriculture of China, growing plants and crops is difficult in large areas of China due to water shortages (Zhang et al., 2016). Soil moisture is fundamental to agricultural construction and a key factor in determining the structure and functioning of ecosystems, particularly in arid and semi-arid regions where strong associations exists among the ecosystem productivity, surface energy balance, and water availability (Wu et al., 2014; Ma and Zhang, 2016; Liu and Shao, 2016). Severe drought may result in further soil degradation, i.e., sandification and desertification, which permanently increases evaporative water loss and decreases soil water retention in these lands. To improve the water use efficiency and soil structure characteristics, enhance soil water retention, and prevent desertification, soil amendments have been widely applied to soil (Agegnehu et al., 2015).

Traditionally, China is an agricultural country and has rich forest resources. Huge agricultural and forestry waste, such as crop straw, sawdust, branches and fruit, are produced by agricultural and forestry activities, representing not only a waste of energy (inefficient burning) but also a disaster to the local environment (Zhang et al., 2016). Therefore, how to renewable use of these waste has been a research hotspot. One method involves pyrolysis them and application of the products (i.e., biochar) to soils.

Abbreviations: CE, cumulative evaporation; CRP, constant rate period or stage I; FRP, falling rate period or stage II; final CE, total cumulative evaporation amount including the evaporation in stages I and II; initial CE, cumulative evaporation amount in stage I

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https://doi.org/10.1016/j.catena.2017.11.013
Received 15 December 2016; Received in revised form 29 October 2017; Accepted 8 November 2017

Table 1
Physical properties of experimental soils.

Soil type	Sampling site	Sand content (2–0.02 mm)/%	Silt content (0.02–0.002 mm)/%	Clay content (< 0.002 mm)/%	Soil texture	Soil bulk density (g/cm^3)
Eum-Orthic Anthrosol	Experimental field of ISWC,CAS Yangling county	32.55	35.08	32.36	Loamy clay	1.48
Isohumisol	Experimental field of Agricultural ecological experimental station, Changwu county	36.38	33.27	30.35	Loamy clay	1.48
Loess soil	Experimental field of soil and water conservation experimental station, Ansai county	60.61	20.51	18.88	Sandy clay loam	1.22
Sandy loess	Farmland of Mizhi village, Mizhi county	70.14	16.41	13.45	Sandy loam	1.25
Aeolian sand	Forest land in Liudaogou watershed, Shenmu county	92.15	4.52	3.34	Sand	1.56

Biochar is a carbon-rich product of the thermal decomposition of organic materials under a limited oxygen supply and at a relatively low temperature (< 700 °C) (Lehmann et al., 2006; Yan et al., 2010; Wang et al., 2017). The application of biochar as a soil amendment or slow-release fertilizer carrier or for carbon sequestration has recently attracted substantial attention (Marris, 2006; Lehmann, 2007) because biochar has a complex structure, extensive porosity, and a large specific surface area with rich organic functional groups that can improve the physical and chemical properties of soil (Sohi et al., 2009; Lehmann et al., 2011; Li et al., 2011). Increasing numbers of researchers have reported a significant increase in the water holding capacity of soil after biochar addition (Baronti et al., 2014; Zhang et al., 2016). Furthermore, biochar may enhance agricultural production due to its ability to absorb and retain nutrients in soil (Lentz and Ippolito, 2012), reduce the soil bulk density and increase the diversity and abundance of the soil biological community (Herath et al., 2013; Gong et al., 2008; Gomez et al., 2014; Kolb et al., 2009; Warnock et al., 2007). Biochar can also enhance soil porosity and water permeability, thus improving the soil water holding capacity (Herath et al., 2013; Kumari et al., 2014). Biochar has a moisture absorption capacity that is 1–2 orders of magnitude higher than that of soil organic matter (Accardi-Dey and Gschwend, 2002). The potential of biochar to improve water-holding capacity has been widely recognized (Asai et al., 2009; Lehmann and Joseph, 2009; Zheng et al., 2012; Akhtar et al., 2014; Wong et al., 2017).Therefore, biochar may play an important role in improving soil water relationships in agricultural systems, particularly the systems in the Loess Plateau.

The addition of biochar to soil will inevitably alter the physical and chemical properties of the soil (Liu et al., 2012; Herath et al., 2013), thereby affecting soil moisture and evaporation processes. Evaporation is a catenary physical process in which soil moisture flows through the soil surface in the form of water vapour into the atmosphere, and it is an essential part of the transformation of water from soil to surface water vapour in the soil-plant-atmosphere system (Zhao and Wu, 2004; Novák, 2012). In semi-arid environments, soil evaporation can exceed precipitation and limit normal vegetative growth (Alizai and Hulbert, 1970; Onder et al., 2009; Van Wesemael et al., 1996). Reducing soil evaporation is essential to maintaining agricultural production in arid areas (Raz-Yaseef et al., 2010).

Soil evaporation is characterized by two periods (Lehmann et al., 2008). A period with an initially high and relatively constant rate is termed stage I evaporation, which is supported by internal capillary flow (the constant rate period, CRP) (Yiotis et al., 2006). After a certain period (or mass loss), this CRP is followed by a period with a lower and gradually decreasing evaporation rate (stage II), reflecting a transition to diffusion-limited vapour transport (the falling rate period, FRP) (Bond and Willis, 1969; Or et al., 2013). Recently, increasing numbers of researchers have begun to consider the influence of biochar characteristics, such as the feedstock, pyrolysis temperature, particle size, amount added, intra-particle porosity, shape, and plasticity on soil evaporation (Eibisch et al., 2015; Hardie et al., 2014). Ibrahim et al. (2017) applied conocarpus biochar in sandy loam soil and found the cumulative evaporation was the lower (32.2–35.5 mm) in the biochar-treated soil than in the non-treated soil (40.9 mm), which suggested that biochar can reduce soil evaporation. But Zhang et al. (2016) found that adding biochar powder to sandy soil did not decrease the water evaporation loss, it may be related to soil texture and biochar particle size. Xu et al. (2016) reported that biochar effectively restricted soil evaporation at a low addition amount (5%) but promoted it at a high addition amount. Therefore, it is not clear whether the increase in water holding capacity after biochar addition can be maintained through the entire evaporation processes (Karhu et al., 2011). Furthermore, the effects of the particle size and addition amount of biochar on soil evaporation are also unclear. Evaporation is a comprehensive function that involves multiple soil properties, such as the soil texture and particle size distribution (Qiu et al., 1998), applying the biochar affects these properties, especially the soil porosity and its distribution via