Agricultural Water Management 185 (2017) 145–150

Contents lists available at ScienceDirect

Agricultural Water Management

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

Research paper

The benefic effect induced by biochar on soil erosion and nutrient loss of slopping land under natural rainfall conditions in central China

Li Zhi-guo[a,1], Gu Chi-ming[a,1], Zhang Run-hua[b], Ibrahim Mohamed[a,c,d], Zhang Guo-shi[a], Wang Li[a], Zhang Run-qin[a], Chen Fang[a,c,*], Liu Yi[a,*]

[a] Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academic of Sciences, Moshan, Wuhan, Hubei 430074, China
[b] Wuhan Academy of Agriculture Science and Technology, Vegetable Research Institute, Wuhan 430345, China
[c] China Program, International Plant Nutrition Institute, Wuhan 430074, China
[d] Soil Science Department, Faculty of Agriculture, Benha University, Moshtohor, Toukh, Kalyoubia 13736, Egypt

A R T I C L E I N F O

Article history:
Received 19 November 2016
Received in revised form 17 February 2017
Accepted 21 February 2017
Available online 6 March 2017

Keywords:
Slope land
Biochar
Soil and water losses
Nutrient loss
Runoff

A B S T R A C T

The effects of biochar on runoff and loss of soil and nutrients in the subtropical regions of China are rarely documented. Two field experiments, an orchard and a cropland field were set up, involving two treatments: biochar (BC) and no-biochar (NBC). The effects of BC on runoff volumes and ratios, sediment yield and the level of nutrient losses were monitored and evaluated over three years (2014–2016). Results showed that the treatment of BC induced a significant reduction in the runoff and nutrients losses. By plotting the data collected for the BC application, we observed that the average annual runoff decreased by 19–28%, whereas the average annual sediment yield by 11%. The cumulative values of total nitrogen (N) and phosphorus (P) losses were also substantially minimized by the BC treatment compared with the NBC one ($P < 0.05$). However, the average annual concentrations of total N and P losses as obtained from the BC plots (16.21 mg L^{-1} and 0.72–0.99 mg L^{-1}) were still high, and exceeding the wastewater discharge standard (N: 15 mg L^{-1} and P: 0.5 mg L^{-1}). In addition, under tillage conditions, the BC application led to larger sediments yield (6.5 g m^{-2}) in contrast with the NBC treatment (5.5 g m^{-2}). In general, these findings can suggest that BC exhibits a vital efficiency in the control of soil erosion process, but there is a risk of increasing sediment loss under tillage conditions, which might need to be made up by combined with biological and agronomic managements such as straw mulching or adding polyacrylamide into soil in order to control further soil erosion.

1. Introduction

Soil erosion is one of the most serious environmental problems in the world (Adimassu et al., 2014; Doan et al., 2015), because it leads to not only soil degradation and decline of land productivity, but also many secondary environmental problems such as flooding, river siltation, and water pollution with transported sediments and pollutants (Zhuang et al., 2015). Recent researches have shown that soil erosion even probably causing global warming via loss of soil organic carbon (Li et al., 2017; Nearing et al., 2004). Therefore, conserving soil from being eroded by water is very important to recover land productivity and protect ecological environment.

In hilly areas of central China, like Danjiangkou Reservoir areas, with rapid economic expansion and a growing demand for food, an increase in utilization and development of sloping land in rural areas have led to more pressure on soil erosion and the associated impact on the environment (Liu et al., 2012; Xu et al., 2015). According to statistical data, soil erosion in Danjiangkou Reservoir has expanded to 39 thousand km^2 by 2013 (Zhuang et al., 2016). Loss of topsoil each year is up to 169 million tons, resulting in overall reduction in soil quality (Gu et al., 2016). Large amounts of organic wastes and nutrients in rural areas have entering water bodies (Zhu, 2015), and decreasing water quality provided by the reservoir, and adversely influencing the success of the South-North Water Transfer Project (Song et al., 2011; Zhu, 2015). Over the years, local government has encouraged farmers to take up and apply some conservation measures, such as hedgerows, reduced tillage and straw mulch, to conserve soil (Gu et al., 2016; Zhuang et al., 2016), but the spread and utilization get limit because of those measures perceived problems. Hedgerows reduced crop yields due to compe-

* Corresponding authors.
E-mail addresses: lzg250@126.com (Z.-g. Li), fchen@ipni.ac.cn (F. Chen), lyle3521@126.com (Y. Liu).
[1] These authors contributed equally to this work and should be considered as co-first authors.

http://dx.doi.org/10.1016/j.agwat.2017.02.018
0378-3774/© 2017 Published by Elsevier B.V.

tition for water, nutrients and light and made tillage inconvenient (Sun et al., 2008). Reduced tillage resulted in more weeds and lower yield than conventional tillage (Wozniak and Kwiatkowski, 2013). Straw mulch could be a suitable measure, but the common crops produced little straw residue so it is not widely available for use (Peng et al., 2016). Thus, finding appropriate ways for using organic agricultural and rural wastes as well as minimizing the soil erosion and nutrients losses from slopping land is an urgent task.

The application of agricultural and forest residues as soil amendments or fertilizers can be proposed as an ideal platform to enhance soil quality through reducing its erosion and nutrients loss (Kuoppamaki et al., 2016; Sadeghi et al., 2016). Biochar (BC) represents a novel and promising approach for achieving the above-mentioned goals. BC is a pyrogenic carbon and can be produced by heating the crop wastes, wood or diverse biomasses under low or oxygen presence (Mohan et al., 2014; Tripathi et al., 2016). Biochar has become a soil amendment due to its multiple positive in improving water holding capacity and soil structure (Mangrich et al., 2015), nutrient retention (Uzoma et al., 2011) and soil microbial biomass (Lehmann et al., 2011). Acorroding to the stable porous aromatic structures and recalcitrance of BC in soils (Xia et al., 2016), its application is expected to exhibit a prolonged effect on carbon sequestration (Amini et al., 2016; Mohd et al., 2013) and contaminant remediation processes (Inyang et al., 2016). Application of BC to the soils has a tremendous impacts on the fertilities and nutrient-use efficiency, and this highly affects the productivity of crops (Ahmed and Schoenau, 2015; Usman et al., 2016). Furthermore, the incorporation of BC into the soils could influence soil organic matter (SOM) levels and aggregation stability (Hua et al., 2014; Obia et al., 2016). The reduction of soil erosion by maintaining SOM and improving soil aggregative stability should be considered as an important task (Doan et al., 2015; Haregeweyn et al., 2015). Historically, the research undertaken over the past decades has revealed the superior potential of BC in reducing surface runoff and enhancing water infiltration (Lee et al., 2015; Peng et al., 2016).

Lack of relevant quantitative data does not confer comprehensive knowledge about the impact of BC on soil erosion and nutrient losses (Doan et al., 2015; Jien and Wang, 2013; Sadeghi et al., 2016). Citrus and the rotation of corn and wheat are the main planting patterns in our investigated region. Up to the present, the areas of the two planting patterns have reached about approximately 20,000 and 13,000 hm^2, which are making up more than 90% of the local cultivated area (Gu et al., 2016). Thus, two experiments are performed on citrus orchard and wheat-corn fields in the Danjiangkou Reservoir area to determine the effects of BC (made from rural organic wastes) on runoff, sediment yield and loss of major soil nutrients, *i.e.*, N and P, from a medium sloped land surface under natural rainfall conditions.

2. Material and methods

2.1. Site and biochar description

This study was performed from 2014 to 2016 on two sites: citrus orchard (twelve-year-old) and cropland (reclaimed for more than twenty years), which were located in the Danjiangkou Reservoir area at Hubei province, Central China (N 32°36′–33°48′, E 110°36′–111°49′). This region was characterized with a typical subtropical monsoon in the north subtropical zone. The annual average precipitation was 750 mm, while the mean annual temperature was 15.7 °C (Cheng et al., 2013). The investigation locations had yellow cinnamon soils as described by the Chinese Soil Classification System (National Soil Survey Office, 1992). The slopes of orchard and cropland sites were 15% and 10%, respectively. The orchard soil had the following properties: pH 6.5, organic matter 0.91%, total N 0.09%, total P 0.22%, total potassium (K) 2.02%; available nutrients (given in mg kg^{-1}): N 101.8, P 16.0 and K 106.3. The cropland soil had a higher pH (7.3) and organic matter (1.1%) but lower contents of total N (0.1%), P (0.08%), K (0.16%), and available nutrients (also given in mg kg^{-1}): N 61, P 11.8, and K 120.

The BC employed in this experiment was provided by HSNE (Henan Sanli New Energy Co.), and produced from rice straw over 5–6 h at 500 °C. The size of BC was about 0.25 mm and its physicochemical properties were: pH 9.5, EC 3.36 dS m^{-1}, total organic C 29.3 g kg^{-1}, N 1.83%, P 1.43%, K 18.9%, Ca 13.4 g kg^{-1}, Mg 6.2 g kg^{-1} and CEC 64.76 cmol kg^{-1}. The BC had also a high specific surface area of 14.5 m^2 g^{-1} and pore volume of 15.3 cm^3 g^{-1}.

2.2. Experimental design

Two treatments of biochar application (BC = 20 t ha^{-1} and NBC = 0 t ha^{-1}) in four replicates were randomly arranged in a complete block design. Six runoff plots with sizes of 4.5 × 9 m for orchard and 3 × 10 m for cropland were performed for each site and separated by concrete borders. A tank was connected at the base of each plot in order to collect the runoff and sediment. The BC was broadcasted onto the soil surface of each plot and subsequently mixed at a depth of 0–30 cm with a plough prior to the experiment inception in September 2014. The orchard soil contained citrus trees and with 1.5 × 3 m spacing and the rows arranged perpendicularly to the slope. Each citrus tree was fertilized annually (in December) with 0.5 kg N (urea), 0.3 kg P_2O_5 (superphosphate) and 0.4 kg K_2O (potassium oxide). No tillage was applied after BC application for this experiment. The cropland soils were grown with wheat (*Triticum aestivum* L.) in the winter and with maize (*Zea mays* L.) in the summer. The wheat and maize were sown at the beginning of October and June, and harvested in early June and middle of September, respectively. The wheat and maize crops were fertilized each year with N (225 and 128 kg ha^{-1}), P_2O_5 (90 kg ha^{-1} for both crops), and K_2O (120 and 75 kg ha^{-1}), respectively. The residues from last season's crops were usually incorporated with a rotary tiller at a depth of 30 cm before the sowing of next season's crop. In order to manage the weeds, herbicide glyphosate was sprayed in each plot within two days before sowing but during the growing season, the weed were removed manually.

2.3. Sampling and analyses

The daily rainfall was recorded with a rain gauge that located near to the experimental site. The runoff volume and sediments yield for each experimental plot were monitored after each producing rainfall event. In order to analyze the samples, the collected runoff and sediments were thoroughly mixed and divided into 500 mL stock composite samples (or kept the entire sample if under 500 mL), and stored at 4 °C until the investigation. The sediments were retained after filtration (using the paper type Whatman no. 1, pore size 0.45 μm) was dried at 105 °C for 24 h, and subsequently weighed and compared with weight of the second filter paper of the same size after filtration of an equal volume of pure water as a control (Adimassu et al., 2014). A fraction of unfiltered sample was analyzed for the total N and P (TN and TP); whereas another part of the filtered sample was investigated for the dissolved N and P (DN and DP). The traces of N and P were extracted using an alkaline potassium persulfate digestion and then determined by ultraviolet spectrophotometer and molybdenum blue colorimetry approaches. The particulate N and P (PN and PP) were estimated by the following formulas: PN = TN − DN and PP = TP − DP. The soil and nutrient losses of each plot were calculated based on the runoff volume, sediment, and also nutrient concentrations within the runoff.