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Agronomic benefits of biochar as a soil amendment after its use as waste water filtration medium☆

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ABSTRACT

In many water-scarce countries, waste water is used for irrigation which poses a health risk to farmers and consumers. At the same time, it delivers nutrients to the farming systems. In this study, we tested the hypotheses that biochar can be used as a filter medium for waste water treatment to reduce pathogen loads. At the same time, the biochar is becoming enriched with nutrients and therefore can act as a fertilizer for soil amendment. We used biochar as a filter medium for the filtration of raw waste water and compared the agronomic effects of this "filterchar" (FC) and the untreated biochar (BC) in a greenhouse pot trial on spring wheat biomass production on an acidic sandy soil from Niger. The biochar filter showed the same removal of pathogens as a common sand filter (1.4 log units on average). We did not observe a nutrient accumulation in FC compared to untreated BC. Instead, P, Mg and K were reduced during filtration while N content remained unchanged. Nevertheless, higher biomass (*Triticum* L. Spp.) production in BC (+72%) and FC (+37%) treatments (20 t ha^{-1}), compared with the unamended control, were found. There were no significant differences in aboveground biomass production between BC and FC. Soil available P content was increased by BC (+106%) and FC (+52%) application. Besides, mineral nitrogen content was reduced in BC treated soil and to a lesser extent when FC was used. This may be explained by reduced sorption affinity for mineral nitrogen compounds on FC surfaces. Although the nutrients provided by FC decreased, due to leaching in the filter, it still yielded higher biomass than the unamended control.

1. Introduction

During the next two decades, global population and corresponding food demand are projected to increase rapidly (United Nations Department of Economic and Social Affairs Population Division, 2015). As the cultivated land area can hardly be increased; this will lead to the need for further intensification of agricultural production. However, some agriculture practices; like poor water and nutrient management or shortened fallow periods, are already a major driver of environmental degradation (Tilman et al. 2001, 2002), such as soil erosion and eutrophication of water bodies. Therefore, the development and use of more efficient soil fertility management practices that lead to a closing of nutrient cycles is needed (Tilman et al., 2013).

Biochar, the solid product of pyrolysis, received much attention during the last years for its potential to sequester carbon (C) in soils, to increase soil fertility (Biederman and Harpole, 2013; Hussain et al., 2017; Jeffery et al., 2017), to increase nutrient use efficiency (Steiner et al., 2008b), to reduce nutrient leaching losses (Laird et al., 2010; Singh et al., 2010) and to immobilize contaminants in soil (Zhang and Ok, 2014).

Another possible application of biochar could be its use for waste water treatment and nutrient recovery. Carbon materials are well known for their use in water filtration systems (Tchobanoglous et al., 2003). Several researchers proposed to use biochar as a sorbent for contaminants, such as organic or inorganic compounds

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and microbial contamination from water (Ahmad et al., 2014; Inyang and Dickenson, 2015; Mohan et al., 2014; Yavari et al., 2017; Zama et al., 2017). Potential mechanisms are mainly sorption processes to the large surfaces and hydrophobic interactions. Waste water treatment with biochar focusing on nutrient recovery has received much less attention (Ghezzehei et al., 2014). In many developing countries, urban agriculture substantially contributes to food supply and may cover up to 90% of its perishable vegetable consumption (Drechsel and Dongus, 2009). During dry periods, irrigation is common where water is available from open sewage channels. The irrigation with untreated waste water is a serious health risk to the farmer and the consumer (Abaidoo et al., 2010).

A simple sand filtration system can reduce *Escherichia coli* (*E. coli*) in wastewater by 2,6 log units and nitrate and phosphate (P) by 22% and 91%, respectively (Langenbach et al., 2009). In another study, a biochar-sand filter removed up to 3 log units more *E.coli* from storm water than sand alone (Mohanty et al., 2014). Kätzl et al. (2014) reported the reduction of 2 log units of *E.Coli* from raw waste water with a slow biochar filter. This reduction can be explained by electrostatical attraction of bacteria to a biological film developing on the surface of the filter material (Stevik et al., 2004).

Only very few attempts have been made to use biochar for nutrient reclamation from waste water, so far. Streubel et al. (2012) tested the removal of P from an anaerobic digest lagoon and captured 1.9 g P kg^{-1} biochar. Sarkhot et al. (2013) used biochar to recover nutrients from dairy manure effluent and absorbed 5,3 mg g^{-1} NH_4 and 0,24 g g^{-1} PO_4 from the solution with biochar. Therefore, an enrichment of various nutrients on the biochar is expected. When the enriched biochar would be applied to soil, a release of the nutrients to crops is expected. Kammann et al. (2015) showed the slow fertilizer behavior and plant growth improvement through nutrients captured in biochar pores during composting.

We hypothesized, a simple biochar filtration system could work as an on-site water treatment system to remove harmful microorganism and thus produce safer water for crop irrigation. Furthermore, we expected that a nutrient enriched biochar for soil fertility improvement is produced in the filter. Therefore, the objectives of this study were to i) test the retention of pathogens with a slow through flow biochar filter; ii) measure the alteration of biochar properties during filtration and iii) evaluate the agronomic benefits of applied filterchar on crop yield and nutrient supply in a greenhouse pot trail.

2. Materials and methods

2.1. Biochar production and waste water filtration

Biochar was produced from rice husks in a batch type custom made kiln at Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana. We chose this feedstock since it is a waste material in Ghana and unlike wood there is no risk of fostering deforestation. The feedstock was heated to a temperature of approximately 450 °C under oxygen limited conditions. After pyrolysis, the biochar was quenched with water to avoid burning after removal from the kiln and subsequently air dried.

The detailed experimental setup of the slow filters was identical to our previous experiment (Kätzl et al., 2014). Biochar was compared with sand as a commonly used filter material. As a water source we used pre-treated effluents of the grit chamber of a municipal waste water treatment plant (Ölbachtal, Bochum, Germany). The water was pre-treated with an anaerobic roughing filter to remove suspended solids and turbidity. The beds of the biochar and sand filters were established in triplicates, had a depth of 55 cm and were covered by a 5 cm quartz sand layer, to prevent floating of the light biochar. The hydraulic loading rate of the slow biochar filters was adjusted to 50 mm h^{-1} and the run time of the filters was three months.

Samples for microbiological analysis of the fecal indicator bacteria (FIB) *E. coli* and intestinal enterococci were collected once per week and analyzed within 24 h, using standardized microplates (Bio-Rad Laboratories GmbH, Munich, Germany) for determination of the most probable number (MPN) of bacteria (DIN EN ISO 7899-1, 2000, DIN EN ISO 9308-3, 1999). Additionally, samples for physico-chemical analyses were taken and stored at −20 °C for determination of chemical oxygen demand (COD), total nitrogen (N_{tot}) and total phosphorous (P_{tot}). At each sampling interval ancillary data of pH, electrical conductivity (EC), redox potential and turbidity were also collected. Average characteristics of pre-treated wastewater used as the influent of the biofilters are given in Table 1.

2.2. Experimental design of the pot experiment

A pot experiment was carried out in the greenhouse (Witzenhausen, Germany) to assess biochar and filterchar effects on plant growth and soil properties. The surface soil (0–20 cm) was taken from a Psammentic Paleustalf (Arenosol; FAO-WRB) in Sadoré, Republic of Niger (13° 14′ N, 2° 17′ E). Texture was a sandy loam (FAO, 2006) with 7% clay, 22% silt and 68% sand. The soil had 0.2% C_{org}, 0.03% nitrogen (N), P Bray 1 of 2,51 mg kg^{-1} and a pH of 5.5. The soil was mixed with biochar or filterchar at a rate of 20 Mg ha^{-1} (7.14 g kg^{-1} soil) assuming an incorporation depth of 20 cm and a mean bulk density of 1.4 g cm^{-3}. Unamended soil was used as a control. The pots had a size of 9 × 9 × 9.5 cm (length x width x height) and were filled with two kg of soil or soil-biochar mixture.

Five seeds of spring wheat (*Triticum* L. *Spp.*) were planted in each pot. Both amended soils and the unamended control were tested with and without fertilizer addition of 85 mL from a 1.5% fertilizer solution (8% N, 8% P_2O_5, 6% K_2O; Wuxal Universaldünger, Manna GmbH, Düsseldorf, Germany). All treatments were replicated five times and their locations on the greenhouse table were completely randomized. The plants were harvested after eight weeks and their fresh weight was recorded. Subsequently, the samples were dried at 60 °C to constant weight for determination of dry weight and further analysis.

2.3. Analysis of biochar, plant and soil samples

The pH and electrical conductivity (EC) of bio- and filterchar were determined according to Rajkovich et al. (2011). Briefly, 1 g of the materials was mixed with 20 mL deionized water and shaken on a horizontal shaker for 1.5 h. Readings were taken in supernatant with a gel electrode and a conductivity cell (Sentix 41 and TetraCon 325, Wissenschaftlich-Technische Werkstätten (WTW) GmbH, Weilheim, Germany), respectively. The pH of soil was

Table 1
Mean characteristics of the waste water used as influent in the filtration experiment ± one standard deviation, n = 9. The analyzed water samples were collected throughout the whole experimental period of 3 months. COD = Chemical oxygen demand; MPN = Most probable number; NTU = Nephelometric turbidity unit.

Parameter	Unit	Mean ± *SD*
pH	[−]	8.2 ± *0.24*
EC	[µS cm^{-1}]	1005 ± *124*
E. coli	[log MPN 100 ml^{-1}]	4.87 ± *0.89*
Enterococci		4.62 ± *0.98*
COD	[mg l^{-1}]	55 ± *41.7*
N_{tot}		57 ± *10.5*
P_{tot}		2.24 ± *0.3*
Turbidity	[NTU]	11 ± *7.2*