Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Acidic sandy soil improvement with biochar — A microcosm study

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HIGHLIGHTS

- Biochar treatment is an innovative option to improve acidic sandy soils worldwide.
- The complex methodology supported selection of the biochar for field application.
- 0.5% grain husk–paper fibre sludge biochar with compost was the most effective.
- 1% grain husk–paper fibre sludge biochar improved physico-chemical soil properties.
- 1% biochar did not pose risk to soil biota.

ARTICLE INFO

Article history:
Received 12 September 2015
Received in revised form 13 January 2016
Accepted 15 January 2016
Available online xxxx

Keywords:
Biochar
Acidic sandy soil
Soil physico-chemical properties
Ecotoxicity
Soil improvement

ABSTRACT

Biochar produced from a wide range of organic materials by pyrolysis has been reported as a means to improve soil physical properties, fertility and crop productivity. However, there is a lack of studies on the complex effects of biochar both on the degraded sandy soil physico-chemical properties and the soil biota as well as on toxicity, particularly in combined application with fertilizer and compost.

A 7-week microcosm experiment was conducted to improve the quality of an acidic sandy soil combining variations in biochar types and amounts, compost and fertilizer application rates. The applied biochars were produced from different feedstocks such as grain husks, paper fibre sludge and wood screenings. The main purpose of the microcosm experiment was to assess the efficiency and applicability of different biochars as soil amendment prior to field trials and to choose the most efficient biochar to improve the fertility, biological activity and physical properties of acidic sandy soils. We complemented the methodology with ecotoxicity assessment to evaluate the possible risks to the soil as habitat for microbes, plants and animals.

There was clear evidence of biochar-soil interactions positively affecting both the physico-chemical properties of the tested acidic sandy soil and the soil biota.

Our results suggest that the grain husk and the paper fibre sludge biochars applied to the tested soil at 1% and 0.5 *w*/*w*% rate mixed with compost, respectively can supply a more liveable habitat for plants and soil living animals than the acidic sandy soil without treatment.

1. Introduction

Biochar has been extensively investigated due to its many potentially advantageous properties which make it suitable for soil amendment, carbon sequestration, contaminant and heavy metal removal, construction and other innovative applications (Lehmann, 2007; Gaunt and Lehmann, 2008).

Biochar amendment in soil may improve soil physical and chemical (Hass et al., 2012; Laird et al., 2010; Liang et al., 2006) and biological properties (Mitchell et al., 2015; Watzinger et al., 2014), nutrient- and water holding capacity, pH buffering capacity as well as soil fertility and plant productivity (Glaser et al., 2002; Lehmann et al., 2003; Major et al., 2010; Yao et al., 2012; Xu et al., 2012). Furthermore biochar may decrease exchangeable acidity and exchangeable aluminium (Al^{3+}) in soil (Novak et al., 2009; Zhao et al., 2015) and control the mobility of environmental pollutants (Lehmann et al., 2006; Verheijen et al., 2010; Inyang et al., 2010; Van Zwieten et al., 2010). Some studies (Case et al., 2015; Gurwick et al., 2013; Woolf et al., 2010) have confirmed that biochar amendment contributes to the efforts to reduce agricultural greenhouse gas emissions and therefore mitigate anthropogenic climate change.

The interactions between biochar and soil and the effects on soil physical properties such as water retention, hydraulic conductivity

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http://dx.doi.org/10.1016/j.scitotenv.2016.01.091

Please cite this article as: Molnár, M., et al., Acidic sandy soil improvement with biochar — A microcosm study, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.01.091

and aggregate stability are dependent on soil texture. The effect of biochar on improvement of sandy soils physical properties and crop yield has been dealt with in several studies (Atkinson et al., 2010; Brockhoff et al., 2010; Jeffery et al., 2011; Uzoma et al., 2011; Basso et al., 2012; Githinji, 2013; Nelissen et al., 2014) since biochar can be a suitable soil amendment.

Jeffery et al. (2011) observed in their meta-analysis positive effects of biochar in acidic and neutral pH soils, and in soils with a coarse or medium texture, suggesting that possibly two of the main mechanisms behind these favourable effects are a liming effect and an improving effect of biochar on soil water holding capacity. Several authors (Atkinson et al., 2010; Brockhoff et al., 2010; Githinji, 2013; Uzoma et al., 2011) reported a decrease in hydraulic conductivity of sandy soil with biochar amendment rate, while Asai et al. (2009) and Bayabil et al. (2015) found an increase for clay and Laird et al. (2010) reported a lack of changes for the loamy sand. According to Basso et al. (2012) biochar increases the water holding capacity of sandy loam soils, and the availability of some nutrients concluding that biochar amendments have the potential to enhance the quality of sandy soils, and therefore should be considered as a management option. Yet, Jeffrey et al. (2015) have recently found no significant effects of biochar application on the water retention and hydraulic conductivity or aggregate stability of a sandy soil in two separate field experiments, at application rates up to 50 t ha^{-1}. Biochar addition to sandy loam soil improved soil physical quality to a certain extent in a field experiment, through reducing soil bulk density, increasing porosity, and improving aggregation but these effects were not sufficient to result in increased crop yield (Nelissen et al., 2014).

Recent studies showed that biochar could be used with organic amendments to increase their stability and reduce organic matter solubility (Ngo et al., 2013, 2014; Doan et al., 2014). Doan et al. (2015) found that biochar alone and the biochar-organic amendment (vermicompost) mixture applied to an acidic sandy soil had positive effects on soil fertility, maize growth and yield, and nutrient retention, while mitigating erosion of a degraded acidic sandy soil.

Soil texture is not the only predictor of likely ameliorating effects of biochar application to soil. The interaction of biochar with the soil biota, in particular earthworms, will also play a role (Jeffrey et al., 2015). Biochar may positively affect soil biota through the increase in soil aggregation and porosity, pH, moisture retention and soil temperature, as well as nutrient retention (McCormack et al., 2013).

The health and diversity of soil microbial populations are critical to soil function and ecosystem services, which, in turn have implications for soil structure and stability, nutrient cycling, aeration, water use efficiency, disease resistance, and C storage capacity (Brussaard, 1997). As reviewed by Lehmann et al. (2011) the impact of biochar on soil microorganisms, fauna and plants shows a wide range of responses, due to variations in the physico-chemical properties of biochar, which contains abundant carbonaceous components, base cations and organic anions (Pereira et al., 2011; Yuan and Xu, 2011). Therefore, the effectiveness of biochar amendment is highly dependent also on the physico-chemical properties of the biochar (Jeffrey et al., 2015; Lehmann et al., 2006; Van Zwieten et al., 2010), and thus, the amendment mechanisms following biochar addition may be different in biochar types and need to be analysed cautiously (Zhao et al., 2015).

The extent of the effects of biochar on soil depends on the biochar production conditions and feedstock which together control the macro- and micro-structure of biochar particles (Downie et al., 2009). In addition, the effects are influenced also by the biochar ageing process (Zhao et al., 2015). The influence of the feedstock and/or the pyrolysis procedure on biochar composition, recalcitrance, or nutrient retention has been dealt with in several studies (Novak et al., 2009; Bruun et al., 2011; Hossain et al., 2011; Singh et al., 2012; Nelissen et al., 2014), while Domene et al. (2015a) tested their influence on its ecotoxicological effects.

In spite of the tendency for demonstration of the environmental benefits of biochar while avoiding detrimental effects on soil (Verheijen et al., 2010) increasing attention is paid to biochar contamination with polycyclic aromatic hydrocarbons (PAHs) (Hale et al., 2012) and trace metals (Freddo et al., 2012), enhanced retention of ammonium and pesticides (Ennis et al., 2012; McCormack et al., 2013) or reductions in yields and increased greenhouse gas emissions (Mukherjee and Lal, 2014). Some biochars might pose a direct risk to soil biota and their functions (Liesch et al., 2010; Weyers and Spokas, 2011).

Domene et al. (2015a) pointed out the need to consider ecotoxicological criteria in biochar characterization schemes or in management recommendations, so that it complements the traditional physico-chemical characterization for the quality assessment of biochars, similar to what has been proposed for the characterization of wastes in the EU (Moser and Römbke, 2009). Major (2009) proposed earthworm and enchytraeid avoidance tests, together with plant germination tests as suitable for the ecotoxicological characterization of biochars before their application in biochar trials. Bioassays are not included in all of the currently available biochar quality standards, with the exception of the germination assay which is mandatory in the IBI standard (IBI, 2013). In addition a variety of OECD and ISO standardized ecotoxicological tests exist for soil organisms that could be easily adapted for biochar testing (Domene et al., 2015a).

According to Jeffrey et al. (2015) biochars and their ecological and physical effects should be investigated on a "char by char" basis to gain an understanding as to why a given biochar produces its associated effects (or lack of effects) when applied to a soil. To assess the environmental risks of biochar utilization in soil the traditional chemical characterization has to be complemented with the use of bioassays (Domene et al., 2015a).

There are contradictory results in the scientific literature about the effects of biochar on sandy soils therefore new studies are needed to fill the knowledge gaps and to contribute to the understanding of the effects of biochar on various soil types on a char by char basis. Studies focusing on the complex, integrated assessment of the effects of biochars on sandy soils are scarce, although several authors focused on evaluating the impact of biochars on soil properties, crop yield, soil biota etc. (Atkinson et al., 2010; Doan et al., 2015; Jeffrey et al., 2015, Nelissen et al., 2014; Uzoma et al., 2011). The aim of our work was to assess and evaluate in microcosms the physico-chemical, biological and ecotoxicological characteristics of biochars from various feedstocks, added at various rates to typical acidic sandy soils in Hungary as a preliminary step of the field experiments.

The target of the work was to contribute to the international investigation efforts in understanding the effects of various biochar types on the characteristics and functions of sandy soils. The significance of this work relies in studying the effect of individual and specific biochar treatments of combined biochar and organic amendments and combinations with non-treated and post-treated biochars not only on the physico-chemical characteristics of an acidic sandy soil but also in terms of the risks posed to the soil as habitat for microbes, plants and animals.

2. Materials and methods

The microcosm experiment described in this paper is part of a tiered experimental plan (Gruiz et al., 2015) targeting the evaluation of the studied biochars prior to field application. A number of thirteen biochars from different organic waste feedstocks have been pre-screened (Feigl et al., 2015) and three biochars were selected for the laboratory microcosm experiment. The soil microcosms were monitored by an integrated methodology including physico-chemical methods, biological analysis and ecotoxicity testing.

2.1. Soil properties

The studied soil originates from an agricultural field near Nyírlugos, Eastern Hungary. The soil is characteristically of light, sandy texture and

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