ARTICLE IN PRESS

Journal of Environmental Management xxx (2016) 1–9

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Effects of three different biochars on aggregate stability, organic carbon mobility and micronutrient bioavailability

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ARTICLE INFO

Article history:
Received 1 February 2016
Received in revised form
20 April 2016
Accepted 10 July 2016
Available online xxx

Keywords:
Biochar
Organic carbon
Aggregate stability
Microbial activity
Micronutrients

ABSTRACT

Previous studies have demonstrated both beneficial and detrimental effects on soil properties from biochar incorporation. Several biochars, with different feedstock origins, were evaluated for their effectiveness at improving soil quality of a sandy agricultural soil. A pot trial was used to investigate aggregate stability and microbial activity, pore water trace element mobility and micronutrient concentrations in grain of spring wheat after incorporation of three biochars. The feedstocks for biochar production were selected because they were established UK waste products, namely oversize woody material from green waste composting facilities, and rhododendron and soft wood material from forest clearance operations. Biochars were incorporated into the soil at a rate of 5% v/v. Aggregate stability was improved following addition of oversize biochar whilst microbial activity increased in all treatments. Dissolved organic carbon (DOC) concentrations in soil pore water from biochar-treated soils were raised, whilst micronutrient concentrations in wheat grain grown in the treated soils were significantly reduced. It was concluded that incorporation of biochar to temperate agricultural soils requires caution as it may result in reductions of essential grain micronutrients required for human health, whilst the effect on aggregate stability may be linked to organic carbon functional groups on biochar surfaces and labile carbon released from the char into the soil system.

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1. Introduction

The incorporation of biochar to improve impoverished agricultural soils is not a new phenomenon, indeed its historical use dates back at least 2000 years (O'Neill et al., 2009). Biochars' potential to sequester carbon in the soil, and prevent it from being released to the atmosphere, has attracted the greatest attention (Liang et al., 2008; Woolf et al., 2010). Still, incorporation of biochar to improve soil quality and plant growth are also of importance, as biochar has been shown to have a significant influence on soil properties such as microbial activity and soil structural stability (Lehmann and Joseph, 2009).

Aggregate stability and associated microbial activity are important factors in assessing soil sustainability. Aggregate stability is a measure of a soils structural resilience and its potential to maintain long-term crop productivity by encouraging root penetration, maintaining soil temperature and gas diffusion, improving water transport and enhancing seedling emergence. Ouyang et al. (2013) observed enhanced macroaggregate formation in a sandy loam soil amended with biochar produced from dairy manure. It was suggested that the relatively higher C/N ratio of the biochar favoured fungal growth, enhancing aggregate stability (Bossuyt et al., 2001). Nevertheless, data are scarce on the development of aggregate stability in biochar-amended soils (Mukherjee and Lal, 2013) and as a relatively new soil amendment, its effect on soil physical properties still requires further research (Atkinson et al., 2010).

Clearly, the physicochemical nature of biochar will depend upon the type of organic feedstock and the process by which it is produced. There are many possible combinations of feedstocks, conversion technologies, and application systems, yet much of what has been reported in the literature is theoretical (Brick, 2010). Production temperature will have an effect on the surface area and pore volume of the biochar. The porous nature and surface chemical properties are important factors that will govern the adsorptive capabilities of biochar once it is applied to soil (Mukherjee and Lal, 2013). This is a significant feature that will ultimately dictate its

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http://dx.doi.org/10.1016/j.jenvman.2016.07.023
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Please cite this article in press as: Hartley, W., et al., Effects of three different biochars on aggregate stability, organic carbon mobility and micronutrient bioavailability, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.07.023

quality and ability to improve temperate agricultural soils. There are also many potential feedstocks ranging from straw, sludge and woodchip (Sun and Lu, 2014) to those derived from waste products such as sawdust (Liu et al., 2012).

Waste products are an attractive option for biochar feedstocks. In this respect, an important consideration is the current European Union requirement to divert biodegradable wastes from landfill, limiting decomposition and reducing methane production. In the UK, legislation has given considerable impetus to the production of soil-improvement composts derived from domestic green waste. Nevertheless, as a result of the garden waste composting process, a woody 'oversize' fraction is generated which causes problems for site operators due to space constraints and odour problems; this material is either chipped or in most cases sent to landfill. Other surplus woody materials that may also have the potential to become important feedstocks are those generated from Rhododendron (*Rhododendron ponticum*), Larch (*Larix kaempferi*) and Sitka Spruce (*Picea sitchensis*) clearance. For example *Rhododendron ponticum* is a widely-established invasive species, and is a nuisance particularly in north and west UK, and therefore is frequently targeted for control or removal on environmentally significant sites. In all cases the resulting woody material is typically disposed of by mechanical mulching or by controlled burning on site.

Considerable work is necessary to evaluate soil-quality indicators following biochar application, but more importantly, different feedstocks must be sufficiently investigated as they may respond differently in temperate soils (Novak and Busscher, 2012; Sun and Lu, 2014). Furthermore, there are conflicting results in the literature regarding the effect of biochar on sandy soils and there is a need to understand the effects of this product on different soil types on a char by char basis (Molnár et al., 2016). Molnár et al. (2016) also noted that investigations focusing on the complex effects of different biochars on sandy soils are scarce. Biochars are inherently variable due to differences in production technologies and feedstock and caution must be used when applying them to agricultural soils. Not all biochars have been shown to enhance agricultural productivity (Van Zwieten et al., 2010), with limited information existing about soil-biochar interactions. Thus far, this product has little use in commercial agriculture (Liang et al., 2015). Due to the irreversibility of biochar application to soil, comprehensive studies must be performed to achieve confidence that its incorporation does not negatively affect soil health and productivity (De la Rosa et al., 2014). As a consequence of this uncertainty, pot investigations are required as proof-of-principle studies, prior to field application.

Therefore the objectives of the present work were to evaluate the effects of three biochars (pyrolysed 'oversize' woody material, rhododendron and softwood) incorporated into a sandy soil on (i) aggregate stability and microbial activity (ii) mobilisation of carbon and trace elements in pore waters and (iii) micronutrient (Zn, Cu, Mn and Fe) bioavailability to wheat.

2. Materials and methods

2.1. Feedstocks and biochar production

All feedstocks were identified and characterised as widely available at the UK level and as being co-products or residues, rather than mainstream wood supply chain materials. The three feedstocks used were as follows:

1) The 'oversize' woody biomass (cited as 'OS' from here on) screened-out during the composting of municipal and domestic green waste. This material causes many operational issues for compost site operators taking up valuable storage space and creating odours if not removed regularly from the site.
2) Rhododendron (*Rhododendron poniticum*) is an invasive shrub of woodlands and commercially managed forests (cited as 'RD' from here on). The biomass generated from clearing operations results in the production of excess carbon to the atmosphere as a result of burning the waste material.
3) Soft wood biomass (cited as 'SW' from here on) mainly consisting of Japanese Larch (*Larix kaempferi*) and Sitka Spruce (*Picea sitchensis*) wood residues from large-scale commercial forestry harvesting operations, present in approximately equal proportions.

Conversion of the three feedstocks into biochar was carried out in an Exeter Biochar Retort. The retort chamber was 1.7 m^3 and fully insulated with a ceramic blanket. Steam production decreased at 375 °C and the gases which subsequently formed were diverted into the firebox and ignited. This is referred to as the exothermic or retorting stage (which is kept below 500 °C) and completes the pyrolysis process. For additional operational details of the retort device see: http://biocharretort.com/index.html. Each feedstock was converted into biochar separately in individual batches, with a retort temperature of 430–440 °C which was maintained throughout the conversion process (~4 h). Biochar was subsequently milled in separate batches using a proprietary feed mill (Novital Nuovo Ercolino 1500 W electric mill) to provide a consistent size fraction (4.0 mm).

2.2. Soil collection and preparation

The soil used in this investigation was a Typic Arenic Endoleptic Regosol, Bridgnorth series. Bulk surface soil samples (0–10 cm) where obtained from Harper Adams University, Shropshire, (52° 46′19.9″ N 2° 25′31.1″ W), using an excavator. The soil was subsequently air-dried and then sieved (<4 mm). Table 1 provides the main characteristics of the untreated soil. A sub-sample was taken

Table 1
Physicochemical characteristics of the untreated soil ($n = 3$).

Property	
Soil series	Bridgnorth
Sand (%)	91
Silt (%)	7.8
Clay (%)	1.2
Texture	Sand
Loss-on-ignition (%)	2.05
Total carbon (%)	1.04
Total organic carbon (%)	1.02
Total inorganic carbon (%)	0.02
Total nitrogen (%)	0.2
Total sulphur (mg/kg^{-1})	124.2
pH (H_2O)	6.56
Electrical conductivity (μs)	74.2
P (%)	0.25*
Zn (%)	0.013*
Cu (%)	0.003*
Fe (%)	1.73*
Mn (%)	0.071*
K (%)	2.89*
Ca (%)	1.67*
Mg (%)	2.53*
Na (%)	0.99*
K (meq 100g^{-1})	1.31**
Ca (meq 100g^{-1})	0.20**
Mg (meq 100g^{-1})	0.33**
C:N	5.2

* Determined using XRF analysis.
** Determined using AAS analysis.

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