Science of the Total Environment 607–608 (2017) 715–724

Contents lists available at ScienceDirect

Science of the Total Environment

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

Improvements in wheat productivity and soil quality can accomplish by co-application of biochars and chemical fertilizers

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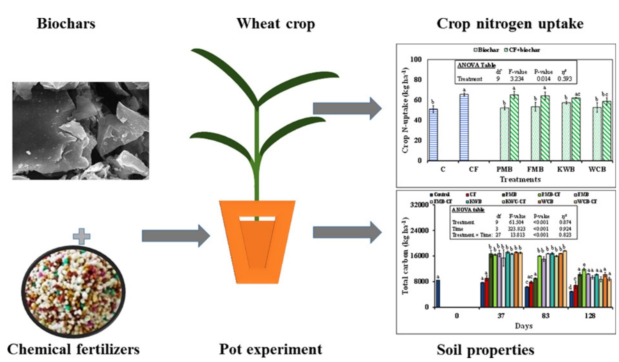
HIGHLIGHTS

- *Nutrient*, *structure* biochars and chemical fertilizer (CF) tested on wheat growth
- CF increased the wheat yield but decreased soil carbon content.
- Grain yield was higher in *nutrient (manure)* than *structure* biochars.
- *Structure* biochar from wood chips negatively affected grain yield.
- High wheat yield in co-applied *nutrient* biochars and CF than structure biochars

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 March 2017
Received in revised form 12 May 2017
Accepted 22 June 2017
Available online xxxx

Editor: Ajit Sarmah

Keywords:
Animal waste
Biochar
Carbon storage
Crop performance
Kitchen waste
Mineral N

ABSTRACT

The beneficial role of biochar is evident in most of infertile soils, however this is argued that increment in crop yield owing to biochar application does not always achieve in cultivated/fertile soils. The *nutrient* biochar believed to enhance crop yield and soil fertility than *structural biochar* that may offset the positive effect of chemical fertilizer on crop performance but improves soil structural properties. Therefore, we investigated the effect of biochars [produced from nutrient rich feedstocks like poultry manure (PMB) and farmyard manure (FMB) and structural feedstocks such as wood chips (WCB) and kitchen waste (KWB)], and chemical fertilizers (CF) when applied alone or in combination on soil chemical properties, wheat growth, yield and nitrogen uptake in a cultivated clay loam soil. Sole biochar treatments increased the total carbon and mineral nitrogen content that were 21 and 106% higher, respectively compared to control after 128 days ($P < 0.001$). Contrarily, sole biochars application did not increase wheat biological yield and N uptake compared to control ($P > 0.05$) except PMB, the *nutrient* biochar ($P < 0.05$). Compared to control, grain yield was 6 and 12% lower in WCB and FMB, respectively but not differed from KWB, PMB or WCB-CF. Conversely, co-application of biochars and CF treatments increased crop biological yield but the increment was the highest in *nutrient biochars* FMB or PMB (29 or 26%), than *structural biochars* WCB and KWB (15 and 13%), respectively ($P < 0.05$). For N uptake, this increment varies between 16 and 27% and again *nutrient biochar* has significantly higher N uptake than *structural biochars*. Hence, *nutrient biochars* (i.e. PMB) benefited the soil fertility and crop productivity more *than structural biochars*. Therefore, for

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http://dx.doi.org/10.1016/j.scitotenv.2017.06.178

immediate crop benefits, it is recommended to use *nutrient biochar* alone or in combination with chemical fertilizer. Such practice will improve crop performance and the quality of cultivated soil.

1. Introduction

Land degradation will become a global peril to crop production and food security in the coming decades. It is estimated that 30% of the world agricultural soil will be converted into degraded land in the next few decades (Oldeman et al., 1990; Rashid et al., 2016). The situation is even worse in Pakistan where 61% of cultivated soils were under serious threat of degradation in 2006 (Anonymous, 2006). Only in Punjab province, 1.58 million hectares of sandy and loamy soils were strongly deficient in nutrients thus termed as nutrients depleted soils (Alim and Javed, 1993; Hassan and Arshad, 2006). This could be the results of growing exhaustive crops, inappropriate agriculture practices, like tillage (Wu et al., 2017), use of high dosage of chemical fertilizers especially nitrogen enhanced light fraction of soil carbon decomposition (Neff et al., 2002) and low carbon inputs resulted in serious decline of soil organic matter (Lu et al., 2011), which is on average 0.5% at current in Pakistani soils (Hassan and Arshad, 2006). Such causative factors could be among the main roots of decrease in crop yield in the country. For instance, reduction in wheat (*Triticum aestivum* L.) yield, the main staple crop of the region, was approximately 5% from year 2008 to 2013 (FAO, 2013) and further declining trend in yield was observed up to last year (Alam, 2016). The decrement in the yield could be attributed to inefficient use of chemical fertilizers especially nitrogen. Since, this nutrient is applied at the time of sowing mostly in the form of urea therefore, significant amount of applied nitrogen is lost through volatilization, leaching, nitrification and denitrification processes, ultimately less ends up in plant. The problem could be solved by supplying adequate N levels in the soil and its subsequent uptake by the crop (Malhi et al., 2006; Rashid et al., 2013) as well as by increasing soil fertility especially organic matter or carbon content in the soil (Kaneez-e-Batool et al., 2016; Rashid et al., 2014a; Rashid et al., 2014b; Rashid et al., 2017; Rashid et al., 2016; Shah et al., 2012) or co-applied biochar with chemical fertilizers that may synchronize the soil nutrient availability with crop N demand (Agegnehu et al., 2016). According to an estimate, irrigated agricultural soil of Pakistan has a potential to sequester 1.04–2.08 Tg carbon year^{-1} (Khan and Lal, 2007). Such huge potential would urge scientists to find suitable approaches or management strategies for carbon sequestration and would be able to increase the organic matter content up to 2% (Lal, 2004). By doing so the soil nutrient deficiency problem might be solved (Khan and Lal, 2007) and would be helpful in improving the crop yields.

Animal manures and poultry litters are among the largest waste streams in Pakistan. It is estimated that annual waste production from animals was approximately 2.5 million tons (Mangalwala, 2014). This huge amount of waste was two times higher than municipal solid waste production in the country which is mainly dominated by food waste (about 60%) (Kamran et al., 2015). Improper management of these wastes, such as open dumping of kitchen waste, poultry litter or animal dung and the later waste also used as an energy source for burning stoves in the houses resulted in an increased greenhouse gaseous emission to the atmosphere that are prone to global warming in the region (Gustafsson et al., 2009; Irwin, 2015). Therefore, sustainable and smart management practices are required to reuse this waste in crop management strategy.

Biochar is a carbonaceous material obtained through pyrolysis of plant biomass or animal wastes (López-Cano et al., 2016) in absence of oxygen. The most recent technology developed to prepare charred material from waste with the intent to mitigate climate change by sequestering carbon when applied to the soil (Lehmann and Joseph, 2015). Likewise, biochar also enhanced other important fertility indicators when applied to the soil including carbon content, reduced nitrate mineralization (Marks et al., 2016) and therefore decreased the leaching losses of C and N from soil (Bass et al., 2016; Haider et al., 2017). Biochar application to soil proved to be beneficial for improving soil fertility and carbon sequestration of degraded soil (Yeboah et al., 2009). Due to a highly basic product, biochar changes the soil pH through its interaction with H^{+} ions (Barrow, 2012; Liu and Zhang, 2012). The high porosity and recalcitrant nature of biochar decreases the mineralization rate thus helps in slow release of plant available nutrients.

Depending on the feedstock and temperature used to produce biochar, many studies ended up into conflicting results for crop yield and plant nutrient availability (Bass et al., 2016; Haider et al., 2017; Hussain et al., 2016; Sun et al., 2014). The variations in crop yield and soil properties indexes due to biochar soil application were ranged between −36 to 31% and −21 to 101%, respectively (Hussain et al., 2016). These differences could be linked to the nature of the feedstock used to prepare various biochars, i.e. the *nutrient* or *structure* biochars produced from animal manure or plant waste, respectively (Jeffery et al., 2017). On the other hand, a recent meta-analysis study indicated no significant mean response of biochar application to soil, mineral nitrogen, aboveground plant productivity and crop nitrogen uptake (Biederman and Harpole, 2013). Hussain et al. (2016) concluded from the literature review that biochar application enhanced the crop yield in highly degraded or infertile soil but this parameter was not enhanced when biochar was applied to cultivated, fertile and/or healthy soils. This means that biochar does not always enhance crop yield when applied on cultivated soil. Consequently, integrated application of biochar and chemical fertilizer could be suitable management strategy for improving crop yield in such soils (Agegnehu et al., 2016; Ali et al., 2015; Fageria and Baligar, 2005). However, only few studies have been carried out to evaluate the integrated effect of biochar as soil amendment to improve the efficiency of chemical fertilizers (Agegnehu et al., 2016; Ali et al., 2015; Brantley et al., 2016; Gul and Whalen, 2016; Tammeorg et al., 2014b). Hitherto, Tammeorg et al. (2014b) did not find any increase in wheat yield after combined application of meat-bone meal biochar and chemical fertilizer. Therefore, for integrated application of biochars and/or chemical fertilizer, appropriate fractions of chemical fertilizer with biochar or different biochars in a blend are required (Sigua et al., 2016; Tammeorg et al., 2014b). To elucidate the former blending, a study was conducted in pots under semi-field conditions to investigate the influence of different biochars produced from various organic wastes and chemical fertilizer in enhancing wheat yield and crop nitrogen utilization when applied alone or in combination in a clay loam soil. We hypothesized that i) sole application of biochar will enhance soil carbon content ii) biochar produced from nutrient rich feedstock when applied in cultivated soil will enhance the wheat yield compared to structural biochar that will only improve soil structural properties, iii) co-application of both *structural* and *nutrient* biochar with chemical fertilizer will increase the soil fertility status, wheat yield and nitrogen uptake, iv) the increment in wheat yield would be variable among various biochars (*nutrient* or *structure*) and chemical fertilizer blending since differences in the feedstocks of biochars will influence their end-product quality.

2. Materials and methods

2.1. Biochar production

Biochar were produced from farmyard manure (FYM), poultry manure (PM), wood chips (WC) and kitchen waste (KW) in a laboratory-scale pyrolysis unit. *Dalbergia sissoo* wood chips were collected from