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CL:AIRE's INSPIRATION bulletins describe practical aspects of research which have direct application to the management of contaminated soil or groundwater in an agricultural context. This bulletin describes a field-scale experiment to determine the effects of biochar and brown coal waste on maize productivity.

Investigating the effects of biochar and brown coal waste on productivity of maize

1. Introduction

Current crop production systems in the West are highly intensive and mechanised, characterised by the extensive use of powered machinery and agrochemicals. While this has led to large-scale production increases over the years, it has also resulted in various forms of land degradation, which have considerable implications on soil resources (Lal, 2009). The application of organic amendments especially to marginal or degraded soils almost immediately leads to concomitant improvements in important soil properties (Mondini *et al.*, 2018). This consequently enhances soil functionality and agricultural productivity.

2. Background

Soil organic matter (SOM) affects multiple soil properties, such as fertility and water retention, and consequently is the focus of many soil restoration programmes. Organic materials such as manures, sewage sludges and composts are rich sources of SOM, therefore useful for ameliorating soil structure, augmenting soil fertility and improving crop productivity (McGeehan, 2012). Biochar and brown coal waste (BCW), also with high SOM contents, are currently being investigated as options for soil amendment (Asai *et al.*, 2009; Tran *et al.*, 2015).

Biochar is a carbon-rich material produced by pyrolysis of organic materials, including woodchips, straw, manures, bagasse from sugarcane and other agricultural wastes, under oxygen-limited and varying thermal conditions (Denyes *et al.*, 2014). Biochar is resistant to microbial breakdown, hence, has a long residence time that can account for sequestration of significant quantities of organic carbon in soil (Kuzyakov *et al.*, 2009). This has sparked high interest in biochar applications, especially in restoration of marginal and contaminated soils, and as a soil enhancer (Asai *et al.*, 2009). The beneficial effects of biochar are stronger in tropical soils, which are often acidic and degraded (Asai *et al.*, 2009), with a 20% median increase in crop yield found from meta-analysis of biochar-amended tropical soils (Jeffery *et al.*, 2017). These effects, however, are less pronounced in temperate soils, which tend to be more fertile (Jeffery *et al.*, 2017).

BCW, formed during the early stages of coalification, where plant residues are chemically transformed under heat and pressure into a highly-carbonised material, has emerged as a useful soil conditioner (Tran *et al.*, 2015). BCW has multiple ion exchange sites that enhance complexation with metals and other cations in soil (Kwiatkowska *et al.*, 2008), making it effective for immobilising heavy metals and reducing their availability to plants (Skłodowski *et al.*, 2006). Tran *et al.* (2015) only found a minor and temporary impact of BCW on soil microbial community and activity. However, BCW has also been found to negatively impact soil, by inhibiting potworm reproduction (Frouz *et al.*, 2005) and impeding ryegrass growth at application rates higher than 7.1% (w/w) (Simmler *et al.*, 2013). Beyond these reported applications, documented evidence of the effects of BCW on crop productivity is scarce.

The benefit of improved soil conditions from biochar and BCW amendments could act as a precursor for increased crop productivity. The aim of this study, therefore, was to determine the effects of soil applications of biochar and BCW on the productivity of maize in a field-scale experiment.

3. Site Description

The research was carried out in a long-term field experiment at the Skierniewice Experimental Station in central Poland (Fig. 1). The station, established in 1923 has continuously carried out long-term static fertiliser experiments for over 90 years, and is the oldest experimental facility of this type in Poland. Soils found in the region originated from Haplic Luvisols, according the World Reference Base for Soil Resources (WRB), formed from loamy sand on light clay (7% clay, 6% silt, 87% sand).

The experiments at the Skierniewice Experimental Station were set up to evaluate the impact of long-term fertilisation (with farmyard manure (FYM) and mineral fertiliser, NPK) and crop cultivation on soil properties and yields in different crop rotation systems (rye, potato and triticale). The station is currently being maintained by The Warsaw University of Life Sciences.

4. Experimental Design

The field experiment was set up in spring 2017 (Fig. 1). It consisted of triplicates of 8 fertiliser treatments spread on the topsoil of 12.5 m^2 sized plots. Plots were structured into two groups, one with organic amendments only and the other with organic amendments plus NPK. Each group had four treatments: (i) No amendment, (ii) FYM, (iii) BCW, and (iv) biochar (BIO). The doses of each organic

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Figure 1: Map of Poland showing the location of the Skierniewice Experimental Station, the plot layout at the station and the experimental block of the current study .

amendment used were calculated as the amount of total C in 30 t/ha of amendment. The biochar used was produced from wood chips, while FYM was a mixture of straw and cow dung. NPK was applied at standard dosages as the ongoing static experiments at the Skierniewice Experimental Station – 90 kg N/ha, 26 kg P/ha and 91 kg K/ha.

Maize was cultivated on the plots in spring 2017. Soils were sampled from each plot after the harvesting season in autumn 2017, and in addition to the pure organic amendments, analysed for basic chemical properties, which included pH_{KCl}, cation exchange capacity (CEC) and total Nitrogen (N_t). Crop yields (wet mass) were estimated per plot for maize.

5. Findings

Application of biochar, BCW and FYM increases SOM which can increase pH, nutrient availability and biomass production. FYM is a classic organic amendment used in conventional farming and therefore was used as a reference treatment (Table 1).

The receiving soil is acidic (pH5.6) and therefore expected to respond to liming from soil amendments by increasing the pH. Liming efficiency is even higher in highly acidic soils (pH < 5). High concentrations of carbonates and oxides of Ca, Na, K and Mg are formed on the surface of biochar during pyrolysis (Yu *et al.*, 2019)

Table 1: Characteristics of selected biochars.

Sample	pH_{KCl}	CEC (meq/100g)	N_t (mg/g)
FYM	8.75	47.3	26.5
BCW	5.40	20.6	4.45
BIO	9.49	31.4	4.13
Soil (control)	5.57	0.93	0.63

giving rise to an alkaline product (pH = 9.49) which is typically produced by high pyrolytic temperatures (> 400 °C) (Chintala *et al.*, 2014). These surface compounds contribute significantly to raising soil pH, especially given the high CEC of biochar (313.86 meq/100g) compared with the receiving soil (9.26 meq/100g). However, biochar, as well as the other organic amendments with or without NPK failed to significantly influence soil pH ($p<0.05$), even though the CEC of the other amendments FYM (472.54 meq/100g), BCW (206.31 meq/100g)) were also markedly higher than that of the soil.

Though the soil pH changes following amendments were generally not significantly different, the instances of pH reduction, even if minor, could be due to loss of soluble salts through leaching during the cultivation period (Joseph *et al.*, 2010). Perhaps, this can effectively nullify the initial liming effects of amendments on soil. The pH of soils amended with a combination of NPK and organic amendments were not significantly different from that of corresponding soil treatments without NPK range. However marginal reductions (pH units of 0.2-1.2) possibly attributed to N nitrification after NPK addition could be observed, as were also reported by Syuhada *et al.* (2016).

Both biochar and BCW are reported to reduce ammonia volatilisation, hence improving the availability and utilisation of N in soil (Ding *et al*, 2010; Saha *et al.*, 2016). These organic amendments are also a rich source of plant nutrients, including N, while also contributing to the regulation of their cycles.

The test soils showed marginal increases in N_t (8-25%) from organic amendments. There were minor variations across the different types of amendments and also between treatments with and without NPK (Table 2). For soils treatments both with and without NPK, N_t content in soils amended with BCW and biochar were respectively higher and lower than FYM-amended soils. It has also been shown elsewhere that the acidic nature of BCW is useful for retention of soil N, especially when it is blended with urea (Saha *et al.*, 2016).

Table 2. Chemical properties of soils after cultivation of maize.

Treatment	Sample	pH_{KCl}	N_t (mg/g)
Mineral fertiliser + Organic amendment	NPK only	5.50	0.73
	NPK + FYM	5.54	0.70
	NPK + BCW	5.52	0.74
	NPK + BIO	5.57	0.72
Organic amendment only	No amendment	5.60	0.71
	FYM only	5.56	0.68
	BCW only	5.64	0.79
	BIO only	5.67	0.70

Fertilisation with organic amendments (only) resulted in improved maize yields (Fig. 2). Overall, when compared with the unamended soil, the application of biochar increased maize yield by 52.6%, and 98.7% when combined with NPK. Compared with a similar study with straw biochar elsewhere, amendment (20 t/ha and 40 t/ha) increased maize yield by 15.8% and 7.3% without N fertilisation, and by 8.8% and 12.1% with N fertilisation, respectively (Zhang *et al.*, 2012). Also, 125% and 68% increases in maize yield were recorded for the application of BCW, with and without NPK, respectively. Maize yield realised from NPK (only) treatment was higher than yields from the single use of any organic amendment, and even 11.7% higher than from a combination of NPK + biochar.

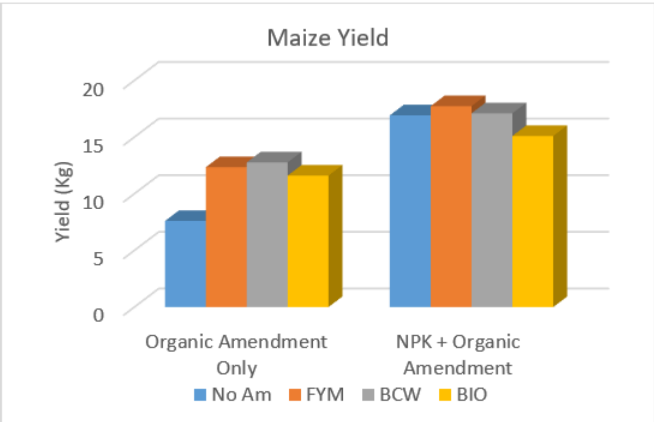

Figure 2: Yield of maize (wet biomass). FYM – farmyard manure; BCW – brown coal waste; BIO – biochar; No Am – no organic.

With no substantial increases in N_t and pH observed, soil may have profited from other well-documented benefits of organic amendments use (e.g. aggregate stability, bulk density, C sequestration, water retention and increased microbial diversity) leading to increased crop yield. Organic amendments may facilitate the efficient use of fertilisers by improving sorption and retention, thus reducing their leaching from soil. This increases their availability to plants for absorption, and may explain the substantial increase in maize yield for treatments with both NPK and organic amendments. Biochar has been shown to have great sorption potential, but also known to slowly release sorbed plant nutrients (Ding *et al.*, 2010). This may be partly be responsible for maize yield being substantially lower in soil treated with a combination of biochar with NPK than in all corresponding NPK treatments.

6. Concluding Remarks

Biochar and BCW, aside from their use as conditioners for the restoration of degraded and contaminated soils, may also be suitable for improving the productivity of arable crops. The observed increases in maize yield across all treatments could not be attributed to changes in soil pH or N_t, indicating other collateral benefits of organic amendments, including enhanced water retention, carbon sequestration and soil bulk density may account for these observations. Extending studies to include different crops for both long- and short-term field trials, and integrating other soil processes or properties will improve understanding of the effects of biochar and BCW amendments on crop productivity.

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