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Impacts of 1.5-Year Field Aging on Biochar, Humic Acid, and Water Treatment Residual Amended Soil

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Abstract: While biochar research has progressed, there is relatively little field-scale data over time, which constrains our understandings of biochar's "true" effects on soil quality and our ability to make appropriate recommendations to users, especially in comparison to other amendments. Thus, this study compares 2 successive years' field-scale soil data with biochar and other amendments added to a scalped silty clay loam soil at an application rate of 0.5%. None of the amendments significantly affected any of the measured soil physicochemical properties and greenhouse gas emissions even after 1.5 years of field aging. However, some of the measured soil properties were significantly changed after the second year compared with those of the first year. On temporal scale, soil electrical conductivity and penetration resistance significantly increased under most treated soils, and soil available water capacity significantly increased only under biochar. Although no differences in soil properties were detected, there was a trend toward higher corn dry grain and biomass yields under biochar compared with those of the control. Biochar was able to reduce N_2O emissions from soil, only in the first year, whereas gaseous emissions were not different from control in the rest of the experiment. Thus, the finding of this study suggest that the improvements in soil fertility due to biochar amendment were not because of changes in most of the observed physical properties of the soil, but some other effects (changes in microbial community or nutrient additions) may have controlled the crop yield. In addition, these data demonstrate that selected amendment application rate of 0.5% (wt/wt) was not sufficient to cause significant changes in most observed physical properties beyond 1.5 years of field aging, suggesting additional research using higher rate of application.

Key Words: Biochar, humic acid, water treatment residual, field aging, corn yield, soil physical properties

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Recent studies indicate that humic acid (HA) amendment can improve soil characteristics by buffering pH and chelating micronutrients by increasing acidic ligands (−COOH or Ph-OH) (Kudeyarova, 2007; Mackowiak et al., 2001; Motojima et al., 2012), increasing exchange capacity and available water capacity (AWC) of soil (Senesi and Plaza, 2007; Sharif et al., 2002; Soler-Rovira et al., 2010; Tahir et al., 2011). It was also shown that coal-derived HA substances under laboratory setting can significantly increase field capacity, AWC, and aggregate stability of three degraded arable soils with as low as 100 kg · ha^{-1} rate of application (Piccolo et al., 1996), and similar results were also found elsewhere (Piccolo and Mbagwu, 1989; Piccolo et al., 1997b). In addition, significant reduction in erosion from erosion-susceptible soils with low rates (100–200 kg · ha^{-1}) of coal-derived HA was achieved under constructed rainfall simulator settings (Piccolo et al., 1997a). Simultaneously, various crop yields such as wheat (*Triticum* L.) (Mackowiak et al., 2001; Tahir et al., 2011) and corn (*Zea mays*) (Sharif et al., 2002) were enhanced with HA amendments. The water treatment residuals (WTR) were tested for reduction in (i) contamination of P in sandy and other soils (Ahmad et al., 2012; Ippolito et al., 2011; Miller et al., 2011; O'Connor et al., 2005; O'Rourke et al., 2012; Oladeji et al., 2008; Oladeji et al., 2009; Oliver et al., 2011; Ulen et al., 2012) and (ii) heavy metals (Fan et al., 2011; Mahmoud, 2011). However, except for few occasions (Hsu and Hseu, 2011; Mahdy et al., 2009; Oladeji et al., 2009; Park et al., 2010; Titshall and Hughes, 2009), they were rarely used as soil amendment to test for its ability to alter soil physical properties. Nevertheless, recent WTR application to soils suggested increase in pH, aggregate stability, porosity, water-holding capacity, and saturated hydraulic conductivity and decrease in bulk density (BD) (Hsu and Hseu, 2011; Park et al., 2010), along with significant increase in crop growth (Hsu and Hseu, 2011; Mahdy et al., 2009; Oladeji et al., 2009). However, although some improvements of soil characteristics have been observed under both HA and WTR, almost no data are available on their "temporal" or "aging" effects on soil parameters. In addition, research information on gaseous emissions by these two soil amendments, especially under field settings over time, is scanty.

Considerable progress has been made in understanding biochar properties, sorption ability, and effects on plant growth when applied to soils. Impacts of biochar on soil physical properties have been recently reviewed, and some processes of biochar/soil interactions have been proposed (Mukherjee and Lal, 2013). For example, biochar may experience a variety of interactions in soil environment including (i) surface hydrophobic or hydrophilic interactions (H-bonding, ligand exchange, cation bridging, specific interactions) between organic functional groups and soil mineral phases, (ii) π-π electron donor-acceptor–type interaction between sorbed soil organic matter (OM) and functional groups, and (iii) complexation by multidented organic acids with metal ions in soil (Joseph et al., 2010; Kleber et al., 2007; Lin et al., 2012). Biochar surface oxidation has been identified among the most prominent changes observed over time (Lehmann and Joseph, 2009; Lehmann et al., 2005; Liang et al., 2006), and a 2-phase complexation model was recently proposed on biochar interaction with soil particles, indicating importance of biochar aging in soil (Mukherjee and Lal, 2013). Surface oxidation of biochar can occur by surface chemisorption of oxygen by biochar surficial C during aging either alone or in soil environment in presence of oxygen or humid air or moisture (Adams et al., 1988; Billinge et al., 1984; Cheng et al., 2006). In an artificial laboratory weathering experiment with modified Soxhlet apparatus, Yao et al. (2010) demonstrated similar oxidation by aging as aged sewage sludge biochar produced at 550°C contained higher proportions of carbonyl and carboxylic groups than fresh biochar surface. Biochar chemistry may also be altered by a variety of time-dependent processes that occur in the environment, termed here as *aging*,

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including abiotic and biotic redox reactions, solubilization, and interactions with microbes, OM, minerals, and solutes in the soil environment (Mukherjee et al., 2014c). However, whereas biochar surface and bulk chemical characterization and interaction with soil under temporal scale have been investigated, data are scarce on soil physical properties under biochar treatment over time, especially under field scale.

Crop yield under biochar amendment is also variable on temporal scale, and notable uncertainties exist, depending on feedstock, soil, climate, and management practices (Biederman and Harpole, 2013; Cornelissen et al., 2013; Jeffery et al., 2011; Mukherjee and Lal, 2014a). For example, corn stover biochar produced at 600°C did not significantly increase corn grain yield on fine loamy soils even with a high biochar application rate of 30 Mg · ha^{-1} consistently and varied over 3 consecutive years by 4.0 to 8.6 Mg · ha^{-1} (Guerena et al., 2013). A 2-year field trial with fine loamy sand amended with peanut (*Arachis hypogaea*) hull and pine (*Pinus* L.) chip biochars produced at 400°C slightly increased corn grain yield, but the yields were relatively low compared with the control and decreased in the second year (Gaskin et al., 2010). Similarly, hardwood (*Fraxinus excelsior* L., *Fagus sylvatica* L., and *Quercus robur* L.) derived biochars pyrolyzed at 450°C amended to a sandy clay loam soil did not significantly increase corn and hay grass (*Dactylis glomerata* L.) yield over 3 consecutive years even with biochar application rate of 50 Mg · ha^{-1}. Nevertheless, above-ground biomass of the hay grass significantly increased compared with the control plots by 79% in the third year, implying that biochar aging may have altered some of the key soil properties over time (Jones et al., 2012). This temporal effect of biochar has also been observed in another field trial in the Philippines. While rice (*Oryza sativa*) husk biochar decreased rice yield for the first three seasons on anthraquic Gleysols, yield increased in the fourth year, although the increment was statistically insignificant compared with that of the control (Haefele et al., 2011). Gaskin et al. (2010) observed that yield of corn consistently decreased with application of pine (*Pinus* L.) chip biochar amended with loamy sand in the first year of the study, but corn yield increased with an increase in biochar application rate in the following year. Similarly, coarse loamy soil amended with activated charcoal insignificantly ($P = 0.057$) reduced plant cover and yield of native grass biomass by 17% in the first year, but the plant cover significantly ($P = 0.0041$) increased by 125% compared with control plot in the next growing season (Kulmatiski and Beard, 2006).

Although some recent studies evaluated biochar's temporal effects on metal uptakes (Bian et al., 2014; Cui et al., 2011; Cui et al., 2009) or gaseous emissions (Zhang et al., 2012), those were all carried out under specific paddy cultivation system, which is different than the approach of the current study. Apparently, amended soils undergo changes under natural field conditions over time, but data are scarce on the temporal aging effects of biochar and other selected amendments (HA, WTR) on soil physical properties under field conditions (Mukherjee and Lal, 2013). In addition, biochar effects on soil aging, as well as GHG emissions, have not been directly compared with that of other selected amendment types (Bruun et al., 2012; Jones et al., 2011; Rogovska et al., 2011; Rondon et al., 2005; van Zwieten et al., 2009). Thus, an ongoing field study with HA, WTR, and biochar started in 2012 under soybean (*Glycine max*) has been continued in 2013 under corn and selected soil properties, and gaseous emissions were measured each year of the study. The initial soil quality data measured in 2012 were presented elsewhere (Mukherjee et al., 2014a). The biochar chosen for this study, oak-650 (*Quercus lobata*), has a potential to improve soil properties based on previous experiments (Mukherjee et al., 2014a; Mukherjee et al., 2014b; Mukherjee and Zimmerman, 2013; Mukherjee et al., 2014c; Mukherjee et al., 2011). Specific objectives of the study were to assess the effects of each amendment on soil physical properties and GHG emissions after 1.5 years under field conditions and to compare these with the data from first year of the study.

MATERIALS AND METHODS

Materials and Field Measurements

Most of the materials and methods and initial soil parameter data were published in a previous paper (Mukherjee et al., 2014a). Briefly, the field experiment was started at the Waterman Farm of The Ohio State University, Columbus, Ohio (40°02′00″N, 83°02′30″W) on June 25, 2012, on a Crosby (fine, mixed, mesic, Aeric Ochraqualf) silt loam soil (Abid and Lal, 2009). To simulate an eroded soil, the upper 5 cm of the soil was mechanically scalped. Commercial coal-derived HA was obtained from Sigma-Aldrich, St Louis, Missouri. The aluminum WTR was collected from a water treatment plant in Columbus, Ohio. Biochar was produced from oak wood (5 × 5 × 30-cm pieces), collected in Gainesville, Florida, by combustion for 3 h at 650°C in a container sealed loosely to allow smoke to exit. Detailed information on biochar preparation and physicochemical characteristics of the freshly prepared oak-650 biochar has been presented elsewhere (Kasozi et al., 2010; Mukherjee et al., 2011; Zimmerman, 2010). The coarse size fraction (0.25–2 mm) of amendments was used in the field experiment. All treatments, including control plots in which no amendments were added, were laid out in triplicate with a total of 12 plots, each of 2 × 2 m in area. Amendments were applied at the rate of 3 kg per plot (7.5 Mg · ha^{-1}) and mixed into the upper 10 cm of the scalped soil, which was equivalent to 0.5% by weight. This amendment rate (7.5 Mg · ha^{-1}), while in the lower range of those used in previous research, was chosen because it is most likely to be used by farmers given the manufacturing and transportation costs of the amendments involved. Soil samples were collected after the end of the second growing season in 2013 from 0- to 10-cm depth, air dried, ground, and passed through 2-mm sieve for laboratory analyses. Corn was seeded on each plot on June 22, 2013, at the rate of 56 kg · ha^{-1} by seeder. Corn was planted in 75-cm row spacing, and application rate of (i) preplanting herbicide was 4.7 dm^3 · ha^{-1} atrizine and 2.3 dm^3 · ha^{-1} glyphosate, and (ii) postemergence herbicide was 2.3 dm^3 · ha^{-1} glyphosate. Fertilizer was not applied so as not to confound with biochar/amendment. Upon harvest, all the plant materials were oven dried at 60°C to determine dry biomass and grain yields. Harvest index was calculated by dividing dry grain yield by dry biomass of corn. Previously installed high-density polyvinyl chloride gas chambers (25-cm height and 15-cm diameter) in the middle of each plot at the start of the experiment were used for gaseous sampling taken once a month during the growing season of 2013. Gaseous samples were withdrawn using a 20-cm^3 syringe through a sampling port at 0-, 15-, and 30-min interval (Castaldi et al., 2011; Shrestha et al., 2009). Gas samples were stored in 20-cm^3 airtight previously evacuated glass vials, and concentrations of CO_2, CH_4, and N_2O were determined using a gas chromatograph (GC-2014; Shimadzu Corp., Japan). **AQ1** The flux of each gas (F, in $m^{-2} \cdot d^{-1}$) was computed by Eq. 1 (Shrestha et al., 2009):

$$F = \left(\delta G * 10^{-6}/\delta t\right)\left(V_C/A\right)\left(M/V\right)1440 \text{ min}\, d^{-1} \qquad (1)$$

where G is a gas concentration (in ppm), t is time (in minutes), V_C is the volume of chamber (in m^3), A is the soil surface area within the chamber (in m^2), V is the ideal gas volume at 25°C (24.5 L = 0.0245 m^3), and M is the molecular weight of the gas (in g).

Analytical Methods

The pH and electrical conductivity (EC) of soil and amendments were determined on a 1:2 soil:water ratio slurry using a AQ2 Thermo-scientific Orion Star Series pH/Conductivity Meter. Field BD of soils from the upper 10-cm depth was determined by the core method (Grossman and Reinsch, 2002) but expressed after moisture correction. Concentrations of total C and N in the soil were determined after grinding and passing through a 250-μm AQ3 sieve using an Elemental analyzer (Vario Max; Elemntar Americas, Inc., Germany) by the dry combustion (900°C) method (Nelson and Sommers, 1996). The aggregate size distributions and quantity of water-stable aggregates (WSA) in each soil were determined by the wet sieving method (Yoder, 1936). Soil water retention at matrix potentials of −0.033 and −1.5 MPa was measured using a pressure plate apparatus (Dane and Hopmans, 2002). Undisturbed soil cores were used to determine the water retention at field capacity (−0.033 MPa), whereas loose sieved samples (<2-mm size) were used to determine the permanent wilting point (−1.5 MPa). The AWC of the soil was calculated as the difference in volumetric water content at −0.033 and −1.5 MPa moisture potentials. Three field penetration resistance (PR) measurements were made for the 0- to 10-cm depth from each plot using an Eijkelkamp-type hand penetrometer (Herrick and Jones, 2002). The values of PR were adjusted using the individual moisture content (MC) of each plot.

Statistical Analyses

All values are presented as means ± S.D. of three field or laboratory measurements. Statistical differences between treatments were determined using Tukey's test in PROC GLM in SAS (2012) version 9.2. Treatment differences were declared significant when $P < 0.05$.

RESULTS AND DISCUSSIONS

After both the first and second year of the study, no soil physical properties examined were significantly affected by any of the amendments relative to the control, except the case of BD for biochar in 2012 (Table 1). However, EC and PR of amended soils significantly increased from year 1 to year 2 under most treatments by up to 75% and 87%, respectively (Table 1). On the other hand, while cumulative N_2O emission significantly decreased under biochar amendment in the first year (Mukherjee et al., 2014a), none of the cumulative gaseous emissions were significantly affected by any amendment after the end of the second growing season (Fig. 1).

Soil Physicochemical Properties

After the second year, soil pH insignificantly increased by up to 6% (for WTR), but EC significantly increased by up to 96% (for HA) compared with the antecedent year (Table 1), indicating that observed significantly higher salt content of the amended soils (EC values) had little influence in change in soil pH. In other words, that change in pH was not significant for any of the treatments may be due to the strong buffering capacity of the studied soil. The significance of these observations is that although biochar has been suggested as a liming agent by a number of researchers, the data on the oak-650 biochar used in this study do not support this claim, even after 1.5 years of emplacement in soil. The AWC of amended soil was significant only under biochar as AWC significantly increased by 63% in 2013 compared with that of 2012 (Table 1). The AWC of soil was not significantly affected by even large amounts of biochar incorporation in other similar studies (Hardie et al., 2013), suggesting importance of the specific soil/biochar combination. In addition, in AQ4 cases where AWC of soil increased by biochar addition were all involved sieved and repacked soil columns or greenhouse studies rather than field experiments (Hardie et al., 2013). On the other hand, although BD of biochar-amended soil decreased in many

TABLE 1. Soil Properties Before and After Successive Years of Amendment Field Application

Treatments	Years	Control	Soil + HA	Soil + WTR	Soil + Biochar
pH	2012	6.9aA	7.0aA	7.1aA	7.1aA
	2013	7.1aA	7.2aA	7.5aA	7.3aA
EC ($\mu S \cdot m^{-1}$)	2012	154aB	134aA	147aB	129aB
	2013	225aA	263aA	257aA	231aA
AWC* (%)	2012	41aA	40aA	37aA	32aB
	2013	50aA	48aA	50aA	52aA
BD ($Mg \cdot m^{-3}$)	2012	1.7aA	1.5aA	1.5aA	1.3bA
	2013	1.4aB	1.3aA	1.3aA	1.3aA
Adjusted PR (MPa)	2012	4.0aA	3.9aB	3.1aB	3.8aB
	2013	5.9aA	5.9aA	5.8aA	5.7aA
WSA (%)	2012	70aA	77aA	71aA	60aA
	2013	76aA	74aA	69aA	62aA
Soil C (%)	2012	2.3abA	2.6abA	2.0bA	2.9aA
	2013	2.5aA	2.9aA	2.1aA	2.9aA
Soil N (%)	2012	0.2aA	0.2aA	0.2aA	0.2aA
	2013	0.2aA	0.2aA	0.2aA	0.2aA

All data are based on surface soil (0–10 cm); means followed by lower case letters indicate those treatments that are significantly different within the specific year, and capital letters indicate significant difference between or across the years within a treatment, both at $P < 0.05$.

Data of the year 2012 were reported in Mukherjee et al. (2014b), where the significance level was expressed at $P < 0.1$.

*Assessed by difference in volumetric water content at field capacity (0.033 MPa) and permanent wilting point (1.5 MPa) of the soil.

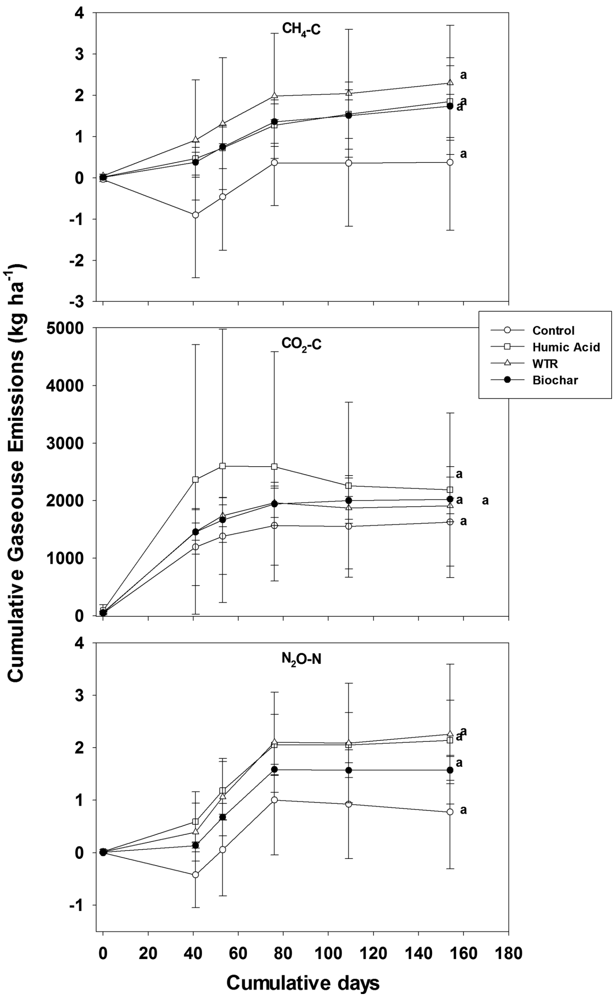

FIG. 1. Cumulative gaseous fluxes after the second growing season of the study; means followed by lower case letters indicate those treatments that are significantly different at $P < 0.05$.

studies (Mukherjee and Lal, 2013), this effect was significant only for the control after the second year (decreased by 13%, Table 1). This observation suggests no temporal effect of any amendment on BD of the scalped silty clay loam soil. In the first year of the study, BD decreased significantly under biochar treatment (Mukherjee et al., 2014a), but the effect was compensated over time (Table 1). No microbial characterization was monitored or image processing software was used in the current experiment to support the underlying cause(s) of this observation of change in BD, but may probably be due to the blockage of the soil pores either by microbial deposition or by OM sorption on to the soil/biochar interface (Quilliam et al., 2013; Suddick and Six, 2013). Similarly, incorporation of 47 $Mg \cdot ha^{-1}$ of acacia green waste biochar in a sandy loam had no effect on soil porosity (Hardie et al., 2013). Thus, despite the perception that a high porosity of biochar would also increase soil porosity, there are limited data to support this hypothesis, at least at temporal level.

Unexpectedly, the PR of all amended soils increased significantly during the second year of amendment emplacement by up to 87% (in case of WTR treatment) compared with that of the first year (Table 1). Factors that influence soil PR include BD, MC, compressibility, structure, texture, and soil OM concentration (Landsberg et al., 2003; Page-Dumroese et al., 2006). Whereas BD and MC were correlated to PR, either inverse or no relationships of these properties with PR have also been reported (Unger and Jones, 1998; Vazquez et al., 1991). For example, Vazquez et al. (1991) observed that traffic on a sandy soil increased PR by greater than 35% in the upper 25 cm of soil, whereas BD increased by less than 3%, indicating that PR can be 10 times more sensitive than BD as an indicator of soil compaction. Similarly, in the present study, PR's weak correlation with BD and MC (data not shown) indicates that PR in a scalped silty clay loam soil was probably influenced more by other soil properties such as soil structure, texture, or compressibility than by BD. In addition, in the current study, farm operations after the first growing season may also have impacted soil physical properties. Furthermore, similar to most other properties, WSA was not significantly increased by any amendments after the second year (Table 1).

Gaseous Emissions

While in the first year, N_2O emission from biochar-amended soil significantly decreased by 92% compared with that of control (Mukherjee et al., 2014a), the same was not affected after the second growing season under any amendments (Fig. 1). A recent meta-analysis including data published from 30 field and laboratory studies indicates that N_2O emission from biochar-amended soil may decrease by 54% compared with control (Cayuela et al., 2013b). The factors that influenced the rate of N_2O flux from biochar-amended soil were identified as biochar feedstock, pyrolysis conditions, C/N ratio, biochar application rate, soil texture, and chemical form of N fertilizer applied with biochar, although no clear mechanism was found for N_2O reduction by biochar treatment (Cayuela et al., 2013b; Mukherjee and Lal, 2013). In addition, soil microbial community structure may change after biochar addition to soil because of availability of labile C and N and increase in pH (Farrell et al., 2013). Liming effect of biochar, which is one important reason for decrease in N_2O emission (Cayuela et al., 2013a), may be lost over time because of biochar's buffering response to soil (Cayuela et al., 2013b; Mukherjee et al., 2011). A field study in Australia with high cattle-manure biochar application rate (10 $Mg \cdot ha^{-1}$) also did not find any significant reduction of any gaseous emissions including N_2O (Scheer et al., 2011). The data of the first year's gaseous emission of the current experiment strongly support the trend of N_2O consumption by biochar-amended soil (Cayuela et al., 2013b); however, the same on temporal scale is scarce. Moreover, the majority of the studies included in the meta-analysis were under laboratory and greenhouse settings, and only 4 studies were conducted under field scale (Cayuela et al., 2013b). In addition, while other factors, such as improvement of aeration or decrease in BD (Rogovska et al., 2011) and increase in pH (Cayuela et al., 2013a) can decrease N_2O emission from biochar-amended soils, the data of the present study could not confirm that conclusion. Soil acidity insignificantly increased and soil BD actually significantly decreased in control over time (Table 1), yet the N_2O emission from any of the treated soil was not affected (Fig. 1) in the current study. In another recent study, biochar derived from walnut (*Juglans regia*) shell when amended to Yolo silt loam soil also could not significantly affect soil N_2O emission and crop yield after 1 year of field emplacement (Suddick and Six, 2013). This information is important as field data of the current study indicate that gaseous emission over the long term may not be decreased by biochar addition, and numerous uncertainties exist regarding gaseous emissions under biochar (Mukherjee and Lal, 2014a).

TABLE 2. Effects of Amendments on Corn Yield During the Second Year of the Study

	Corn Yield Parameters		
	Dry Biomass ($Mg \cdot ha^{-1}$)	Dry Grain Yield ($Mg \cdot ha^{-1}$)	Harvest Index*
Control	3.7a	2.0a	0.52a
HA	5.3a	3.8a	0.36a
WTR	3.7a	2.4a	0.65a
Biochar	6.6a†	5.5a†	0.83a

Means followed by lower case letters indicate those treatments that are significantly different at $P < 0.05$.

*Calculated as ratio of dry grain yield and dry biomass.

†Significantly different from control at $P < 0.1$.

Crop Yield

T2 Corn yield under different treatments is presented in Table 2. Similar to soil properties, corn biomass or grain yields were also not significantly impacted by any amendment at 5% level of probability (Table 2, $P < 0.05$) compared with those of control. Corn grain and biomass yields were low compared with usual yield in this location (Lal et al., 2012), because of no fertilizer use and scalping of the top soil. However, compared with the control, application of biochar increased yield from 2.0 to 5.5 and 3.7 to 6.6 $Mg \cdot ha^{-1}$ (Table 2), for dry grain and biomass, respectively (significantly different at $P < 0.1$), indicating agronomic potential of the selected biochar. However, based on both years' data, it can be stated that higher than 0.5% (wt/wt) application rate may be required to obtain significant ($P < 0.05$) increase in crop yield under selected treatments without fertilization. While soil physical properties were the focus of this study, soil chemical and fertility aspects (cation and anion exchange capacities, micronutrients and micronutrients, and microbial characterization) were not measured, and the trend ($P < 0.1$) of increase in corn yield may be related to either of these aspects. In fact, it has been evaluated that soil quality and corn yield are invariably related to soil fertility parameters, which should be given priority in future research (Mukherjee and Lal, 2014b). Furthermore, both CEC and AEC increased significantly after 1.5 years of field aging of the oak-650 biochar in a separate study (Mukherjee et al., 2014c), suggesting high crop yield potential of the selected biochar.

While the amendments application rate (0.5%, wt/wt) did not cause any significant changes of the measured soil properties even beyond second year of amendments emplacement, one should be careful about reaching a generalized conclusion for a number of reasons. First, a particular soil and biochar types were selected for this experiment, (ii) soil was mechanically scalped before start of the experiment, and (iii) application rate of amendments chosen was relatively low compared with a number of recent biochar studies (Biederman and Harpole, 2013; Cornelissen et al., 2013; Jeffery et al., 2011; Mukherjee and Lal, 2014a; Mukherjee et al., 2014b). In addition, no microbial characterization and fertility aspects were monitored in the current experiment, and thus it cannot be confirmed whether observed gaseous emission was due to the microbial acclimation to the field conditions over time.

SUMMARY

After 1.5 years of amendment emplacement in a scalped soil, the application rate of biochar, HA, and WTR at 0.5% (wt/wt) did not significantly ($P < 0.05$) impact several soil physicochemical properties. The general trends were of increase in EC and PR over 1.5 years of field-aging conditions by all treatments, and AWC significantly increased over time only under biochar amendment. While N_2O emission significantly decreased with biochar treatment after the first growing year, there were no significant differences in gaseous emissions among any treatments after the second year, raising several uncertainty questions over biochar's long-term effects on gaseous emissions. Despite low corn grain and biomass yield, because of no fertilizer use and scalping of the top soil, however, grain and biomass yield increased perceptibly ($P < 0.1$) with biochar application. Additional research is needed with higher application rate and over a longer period before making any further conclusion on the specific soil/biochar combination.

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