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Biochar and manure effluent effects on soil biochemical properties under corn production

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ABSTRACT

Biochar (BC), an aromatic carbon (C) rich compound has been used to sequester C in terrestrial ecosystems. Biochar has also been shown to improve soil fertility and crop productivity when applied to soil. Biochemical properties of soil are sensitive parameters that indicate the change in soil processes that result from soil management practices. Major knowledge gaps exist on the long term effects of biochar addition in cropped field soils. Therefore, a field experiment (3 yrs) was conducted on a Warden silt loam soil to investigate the changes in soil biochemical properties following three years of corn (*Zea mays* L.) production with applications of biochar (BC), fertilizer (NPK) or dairy manure (DE). The NPK or DE treatments were applied annually, while BC was applied only the first year. Organic carbon (TOC), total organic nitrogen (TON), TOC to TON ratio (CNR), soil microbial biomass carbon (MBC), Metabolic quotient (MQ), potential mineralizable nitrogen (PMN), fluorescein diacetate hydrolysis activity (FDA), acid phophatase activity (ACP), alkaline phosphatase activity (ALP), β-glucosidase activity, urease activity (URA), and soil pH were evaluated at 0–15 and 15–30 cm depths after the 3rd year of corn production. A soil quality index equation was also developed with linear scoring functions. NPK or DE with BC application increased soil pH, TOC, MBC, FDA, CN ratio, ALP and URA while decreased MQ and ACP activity. Biochar had little effect on N dynamics in the soil. Application of biochar to both NPK and DE treatments improved the soil quality index as compared to that without biochar.

1. Introduction

Biochar is a carbon rich byproduct of energy production from thermal decomposition of biomass feedstock under oxygen starvation termed pyrolysis (Lehmann and Joseph, 2009). Due to high aromatic carbon content of biochar (Cheng et al., 2008), it is recalcitrant in terms of biochemical degradation and C-mineralization when applied to soil (Streubel et al., 2011). It can be used as a soil amendment to sequester carbon in terrestrial ecosystems and can contribute to mitigate global climate change. Mean residence time of biochar carbon in soil ranges between 1000 and 10000 years (Warnock et al., 2010). Besides sequestering carbon, biochar is also reported to increase soil quality and crop productivity in temperate and tropical cropping systems (Güereña et al., 2013). Soil response to biochar amendment is a function of the biochar properties resulting from the pyrolysis process conditions and feedstock type. The major properties of biochar are alkaline pH, a high aromatic carbon content, total organic C to total N ratio (CNR), ash content, porosity, and CEC, with low bulk density (Cheng et al., 2008; Amonette and Joseph, 2009; Chan and Xu 2009; Atkinson et al., 2010; Rajkovich et al., 2011; Novak et al., 2013). Biochar amendments can increase soil pH (Chan et al., 2008; Gaskin et al., 2010; Laird et al., 2010; Streubel et al., 2011), decrease bulk density (Laird et al., 2010; Chen et al., 2011), and change the hydrologic regimes (Uzoma et al., 2011; Herath et al., 2013). Soil fertility status is also enhanced by biochar addition through changing soil available nutrient status (Lehmann et al., 2003) and biochemical properties (Paz-Ferreiro et al., 2012).

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Soil processes, i.e. nutrient cycling, organic matter decomposition, filtering and buffering are driven by soil biochemical properties. Therefore soil biochemical properties are important indicators to monitor changing soil processes as they are more sensitive to changes in management than soil physical and chemical properties (Paz-Ferreiro et al., 2009), and are easily measured in the laboratory (Nannipieri et al., 2002). Most important soil biochemical properties as indicators of soil health are: microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soil respiration, nitrogen mineralization and activities of extracellular enzymes such as β-glucosidase, acid phosphatase, alkaline phosphatase and urease (Nannipieri et al., 1995).

There are few investigations on the effects of biochar on soil biochemical properties. Bailey et al. (2011) found increased β-glucosidase activity in Warden Soil (coarse-silty, mixed, mesic Xeric Haplocambids) following seven days laboratory incubation with 2% biochar, while the effect of biochar was insignificant for Palouse silt loam (fine-silty, mixed, mesic Pachic Ultic Haploxerolls) and Quincy sand (sandy, mixed, mesic Xeric Torripsamments) soil series. Lammirato et al. (2011) observed a 30% decrease in β-glucosidase in degrading cellobiose in presence of chestnut wood biochar. This decrease in reaction was a consequence of adsorpotion of cellobiose on the chestnut wood char rather than a decrease in activity of β-glucosidase. In another study, Paz-Ferreiro et al. (2012) showed a decrease in β-glucosidase activity and basal respiration with an increase in soil microbial biomass after addition of 4% and 8% sewage sludge biochar. Microbial biomass also increased by 66% with a single addition of 12 Mg ha^{-1} corn (*Zea mays* L.) biochar amended with fertilizer annually in 4 year study on a Kendaia silt loam (fine-loamy, mixed, mesic Aeric Endoaquepts) soil (Güereña et al., 2013). In a greenhouse experiment Lu et al. (2015) found eucalyptus (*Eucalyptus urophylla*) and poultry litter biochar (1.5% w/w) increased invertase, β-glucosidase and phosphomoesterase enzyme activities in a heavy metal contaminated soil with or without amaranthus (*Amaranth tricolor* L.) plant as a phyto-remediator. Chen et al. (2013) found 1.7 fold increase in alkaline phosphatase activity (ALP) in an acid Aquept paddy soil when 20 and 40 Mg of biochar ha^{-1} was applied. Soil ALP activity was also increased in a Typic Haplustept amended with 20 Mg ha^{-1} wheat (*Triticum aestivum* L.), corn and pearl millet (*Pennisetum glaucum* L.) residue biochar during a 67 day laboratory incubation (Purakayastha et al., 2015). Demisie et al. (2014) reported an increase in carbon management index, i.e. increase in total organic carbon and labile carbon one year after application of bamboo (*Phyllostachy edulis*) and oak (*Quercus phillyraeoides*) biochar but failed to obtain a clear conclusion on the effect of these biochar on dehydrogenase, β-glucosidase and urease activity (URA).

In summary most published literature on biochar effects on biochemical properties are based on short term incubation studies. Major knowledge gaps exist on the long term effects of biochar addition in cropped field soils. The goal of this study was to investigate the changes in soil biochemical properties following three years of corn (*Zea mays* L.) production with combined application of biochar, fertilizer or manure.

2. Materials and methods

2.1. Site description

A field experiment was conducted in Benton county, WA (46°15′22.07N, 119°44′21.65W), during 2009–2011 to evaluate the effects of biochar application to corn grown on a Warden Silt loam soil (a coarse-silty, mixed, superactive, mesic Xeric Haplocambid). Annual precipitation of the site was 178 mm, primarily during the winter season. The mean annual temperature was 11.2 °C with an average low of −13.6 °C and high of 38.7 °C.

2.2. Experimental design

Corn was grown under solid set irrigation for three consecutive years on a Warden Silt loam soil. Treatments included: (i) annual application of 336, 50, and 140 kg ha^{-1} N, P, and K, respectively (NPK); (ii) annual application of 168,000 l ha^{-1} digested dairy manure effluent equivalent to supply 336 and 64 kg ha^{-1} N, and P, respectively (DE) (iii) NPK + 22 Mg ha^{-1} biochar once at the beginning of the experiment (NPK + BC); (iv) DE annually + 22 Mg ha^{-1} biochar once at the beginning of the experiment (DE + BC). The study was conducted using a randomized block design with three replications of 7.6 m × 4.6 m plots of each treatment. The sources of N and P in treatments (i) and (iii) were urea (46% N) and mono-ammonium phosphate (MAP) (22% P). The dairy effluent contained an average of 2.2 g N L^{-1} and 0.41 g P L^{-1} and 3.03% solids. Potassium was applied through muriate of potash (MOP) (50% K) in all four treatments. The hardwood biochar, mix of white ash (*Fraxinus Americana* L.), oak (*Quercus* spp.), maple (*Acer saccharum*) and beech (*Fagus grandifolia*) was produced using fast pyrolysis (500–600 °C) by Dynamotive Technologies Corp. (West Lorne, Ontario, Canada). Selected properties of the BC is presented in Table 1. DE was collected from a dairy located near Outlook, WA, from a GHD Plug Flow anaerobic digester (GHD Inc., Chilton, WI), built by Andgar Corp., Ferndale, WA. All the amendments were applied before crop planting and incorporated into the soil.

2.3. Soil sampling and analysis

After harvesting the third year corn (September, 2012), approximately 300 g soil sample was collected at 0–15 and 15–30 cm depths from two locations from each plot, mixed and divided into two subsamples. One subsample was air dried and sieved through 2 mm sieve and stored for further analysis. The second subsample was sieved through 2 mm sieve in field moist condition and stored at 4 °C for enzyme analysis. Moisture content of the field moist soil was determined gravimetrically after oven drying at 105 °C for 24 h. Moisture content of the moist samples ranged between 14 and 16% (w/w basis) at the time of sampling. The soil pH was measured in 1:2 ratio of soil:deionized water using Corning 445 pH meter (Corning Inc., Corning, NY). Concentrations of NH_4^+-N and NO_3^--N were measured by extracting 10-g moist soil with 50 ml of 2 mol L^{-1} KCl and determined on a flow-injection analyzer (QuikChem AE, Lachat Zellweger, Loveland, CO). Total organic C and total N concentrations were measured in air dried soil by dry combustion method using Leco CNS-2000 elemental analyzer.

Table 1
Properties of biochar used in the experiment.

Volatile Content (% wt.)	18–30
Bulk Density (kg m^{-3})	250–350
Surface Area (m^2 g^{-1})	1.6
Pore volume (cm^3 g^{-1})	0.001
Proximate Analysis (% wt.)	
Moisture Content	5.07
Ash Content	8.47
Carbon Content	68.87
Hydrogen	2.69
Nitrogen	0.32
Sulfur	0.02
Oxygen	14.56