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Research paper

Impact of biochar on soil characteristics and temporal greenhouse gas emissions: A field study from southern Canada

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ABSTRACT

Biochar affects soil properties and greenhouse gas (GHG) emissions when used as an agricultural amendment. Using a field study, we quantified the effects of two different biochar treatments [3 t/ha poultry manure + 3 t ha^{-1} biochar (MB); and 3 t ha^{-1} poultry manure, 3 t ha^{-1} biochar + 135 kg N ha^{-1} (MNB)] compared to a non-biochar amended soil [6 t ha^{-1} poultry manure + 135 kg N ha^{-1} (MN)] on soil characteristics [organic carbon (SOC), nitrogen (N), C/N, pH, moisture and temperature], crop metrics and temporal variations in NH_4^+—N, NO_3^--N and GHG over 2 years. MNB and MB treatments had a significantly lower ($p < 0.05$) soil moisture (16–22%), temperature (1–4%) and NO_3^--N (24–39%) concentration compared to MN. The C/N ratio was 12% greater ($p < 0.05$) in biochar amended soil compared to MN. Crop metrics were not significantly different ($p < 0.05$). In both years, CO_2 missions were significantly different ($p < 0.05$) among seasons (spring, summer, autumn) within and between treatments. N_2O emissions were significantly different ($p < 0.05$) among seasons, and was 20% greater in the MNB treatment, in year 2 only. GHG emissions significantly ($p < 0.05$) correlated to soil moisture, temperature and NH_4^+. Our results demonstrated that biochar combined with poultry manure and/or N fertilizer caused no negative effects on soil and crops relative to commercial farming practices (poultry manure + mineral N fertilizer). We found that biochar influenced carbon (C) and N transformations in the soil-plant-atmosphere system and caused seasonal changes in GHG emissions.

1. Introduction

Biochar is a carbon (C)-rich residue produced during the pyrolysis of organic material in an oxygen-limited environment [1]. As such, biochar is chemically the same as charcoal but it is distinguished from charcoal by its intended use as a soil amendment and as a mechanism for C sequestration [2]. Biochar has been used in tropical agricultural soils for millennia, where it has remained stable due to its highly conjugated and aromatic carbon structure [3]. In tropical soils, biochar improved soil chemical, biological and physical characteristics [1,3–6]. Adding biochar to nutrient-impoverished tropical soils increases soil pH and reduces aluminum toxicity [4]. However, temperate soils have greater pH, greater soil organic matter (SOM) and plant nutrient content, high-activity clays and lower iron and aluminum oxide contents and therefore will respond differently to biochar than tropical soils [7]. Amending intensively managed temperate soils with biochar is a more recent approach to agriculture [8], with research still in its infancy and comprehensive long-term studies remain limited [9].

Despite these differences, Hammond et al. [10] and Borchard et al. [11] proposed that biochar is a C-negative soil amendment that can be used as a climate change mitigation strategy in temperate agroecosystems. Currently, 11% of the total global anthropogenic GHG emissions, not including land-use change, are derived from agricultural activities [12]. Heavy reliance on nitrogen (N)-based fertilizers and/or manure, to maintain crop productivity, causes agricultural soil to contribute 60% of total global N_2O emissions; a GHG with 296 times the global warming potential of CO_2 [13]. Carbon and N are transformed through processes such as mineralization and nitrification/denitrification, which are also dependent on soil moisture and temperature and in turn influence temporal GHG emissions (14). However, the mechanisms of interaction that drive these processes will be influenced differently when biochar is added to soil [6,15]. The extent that soil physical characteristics (pore space, water holding capacity), chemical characteristics (pH, available nutrients) and edaphic processes (mineralization, nitrification/denitrification) are altered by biochar, and how this influences GHG emissions, remains unclear [6,15]. It was suggested that former atmospheric C sequestered in the pyrolyzed biomass becomes trapped and stable for thousands of years in the soil contributing

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to C sequestration [16]. Additionally, biochar alters soil microbial activity and therefore the availability of nutrients to the microbiome, resulting in lower GHG emissions [15,17]. These processes will be further influenced depending on biochar quality (feedstock type, pyrolysis temperature), rate of biochar addition, and edaphic [2] and climatic conditions [1,18–20]. For example, previous studies found that biochar altered soil moisture and therefore influenced CO_2 and N_2O emissions [3,10]. Spokas and Reicosky [21] observed that out of the 16 different biochars they investigated, 33% of these increased CO_2 emissions, 33% decreased CO_2 emissions and the remainder caused no change. This is due to a variation in the rate of mineralization among the different characteristics of biochar based on feedstock type and pyrolytic conditions [19].

The addition of biochar to temperate soil is a relatively new concept [22], and to date, the majority of studies took place over the short-term and conducted under laboratory conditions which do not capture temporal variations in GHG emissions [23]. Sohi et al. [5] and Clough and Condron [23] identified no existing peer-reviewed field-level studies investigating GHG emissions prior to 2010. However, since then, multiple field-level studies in temperate environments have emerged [3], although only a few are representative of Canadian agroecosystem management practices. It is essential however, to understand the response of temperate soil to biochar addition, using agronomic fertilizer and/or manure types and quantities that are representative of regional practices, and how this impacts GHG emissions [24]. Therefore, the objective of this study was to quantify differences in soil characteristics [organic carbon (SOC), total nitrogen (TN), pH, moisture and temperature], crop metrics and temporal variations in NH_4^+—N, NO_3^--N and GHG emissions measured in 2016 and 2017 in soil amended with and without biochar. This study provided new knowledge on the impact of biochar on soil, crop productivity and seasonal variation of GHG emissions on a calcareous soil in southern Canada.

2. Material and methods

2.1. Study site and experimental design

The study site was located in Bayfield (43°34′45.8′N, 81°39′52.2″W), Ontario, Canada on a commercial poultry-cash crop farm. The site was located 183 m above sea level with a slope of 1.5%. The soil was classified as a uniform grey-brown Luvisol with a loam texture. The 30 year mean weather data was obtained from a nearby weather station located in Goderich (43°74′28′N, 81°71′39″W), Ontario, Canada (Fig. 1), which recorded a mean annual temperature of 8 °C and an annual precipitation of 991 mm [25]. Commercial farming practices included the production of maize (*Zea mays* L.) in rotation with soybean (*Glycine* max *(L.) Merr.*). Poultry manure, based on switchgrass (*Panicum virgatum* L.) bedding, was added on a 3-year rotation at a rate of 6 t ha^{-1} and was topped-off with urea N fertilizer at 135 kg N ha^{-1} only in the years maize was produced. The site was tilled using a disc harrow and weeds were controlled by N-phosphonomethyl glycine (Glyphosate).

The experimental design was a randomized complete block design (RCBD) with three replications. The treatments were: 6 t ha^{-1} poultry manure plus 135 kg N ha^{-1} fertilizer [control (MN)]; 3 t ha^{-1} poultry manure plus 3 t ha^{-1} biochar (MB); and 3 t ha^{-1} poultry manure, 135 kg ha^{-1} nitrogen (N) fertilizer and 3 t ha^{-1} biochar (MNB). The plot size for each treatment replicate was 10 m × 10 m, with a 3 m border between plots. Biochar in MB and MNB treatments was added using a drop spreader and worked into the soil using a Salford RTS vertical tillage unit to ensure uniform distribution. Commercial farm management operations including herbicide additions and N fertilizer application rates were standard agronomic practices for this region of southern Canada.

The study was conducted over two years, beginning in May 2016 with a maize crop and addition of biochar, and a soybean crop in 2017. The biochar was added to the respective treatment replicates only once over the duration of this study. Sample collection began in May and terminated in November of each year. The biochar was provided by Titan Carbon Smart Technologies (Saskatoon, Saskatchewan, Canada). The feedstock of the biochar was a 50/50 mix of pine (*Pinus* spp.) and spruce (*Picea* spp.), and the resultant biochar was produced using slow pyrolysis (550 °C, 15 min). Granulometry of the biochar was maintained as the same as its particle size distribution (Table 1). Basic chemical properties of the poultry manure included a pH of 8.7, a dry matter content of 72%, a C content of 31%, total N content of 3% and a C/N ratio of 10.

2.2. Soil characteristics and crop metrics

Prior to crop harvest in 2016 and 2017, five soil samples were collected randomly from each treatment replicate to a 10 cm depth. The collected soil was air dried and sieved to 2 mm before removing carbonates through acid washing [26]. Carbonates were removed by washing 2 g of soil with 50 mL of 0.5 M HCl. The soil-acid solution was shaken 3 times over 24 h on a reciprocating shaker at 200 rpm (Heidolpj Unimax 1010 DT, Schwabach, Germany). Following a settling period of 30 min, the acid was removed using a pipette after. The soil was washed by adding 50 mL ultrapure water and shaking the soils at 200 rpm for 15 min, after which the water was removed with a pipette. The washing procedure was repeated daily for 4 days after which the soil was dried at 40 °C for 2 days and ground in a ball mill (Retsch® ZM1, Haan, Germany) prior to analysis for soil organic C (SOC) and N using a Costech 4010 (Valencia, USA) elemental analyzer. Prior to soil

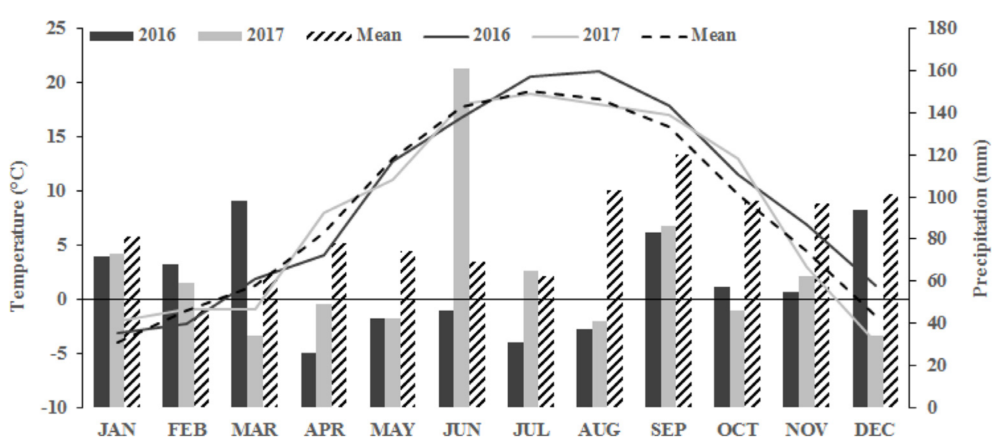

Fig. 1. Mean monthly ambient air temperature [°C (line graph)] and total precipitation [mm (bar graph)] in 2016 and 2017 compared to the 30 year mean in Goderich (retrieved on February 5th, 2017 from: http://climate.weather.gc.ca/historical_data).