SOIL CARBON ADDITIONS IMPROVE SOIL NUTRIENT CYCLING AND YIELD OF CORN

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ABSTRACT

Increasing soil organic matter and the associated soil carbon is known to positively influence nutrient cycling, and agronomic practices such as conservation tillage and cover crops can facilitate soil carbon increases in the long term. Alternatively, the direct addition of carbon amendments to the soil may serve as an alternative solution for enhancing nutrient cycling in the short-term, which was the basis for this research. Our objective was to assess the potential of granular carbon amendments to increase corn (*Zea mays*) yield by either enhancing nutrient cycling and the release of soil nutrients or by improving the efficiency of fertilizer use. Field experiments were conducted in 2022 and 2023 at Champaign, IL and included two carbon amendments (biochar or humic acid) applied at three rates of carbon (90, 180, or 360 lbs carbon/acre), either with or without phosphorous (P) plus potassium (K) fertilization. The fertilizer treatment included MAP (11-52-0) and MOP (0-0-60) at rates of 60 lbs of P_2O_5/acre and 60 lbs of K_2O/acre, respectively. All treatment applications were broadcast-applied just prior to planting and lightly incorporated, with soybean [*Glycine max* (L.) Merr.] as the previous crop and with all plots receiving 180 lbs N/acre. Without the carbon amendments, fertilization with P and K significantly increased grain yield by 12.4 bushels/acre. Averaged over the carbon rates, both carbon amendments increased yield when applied without fertilizer (7.3 and 3.3 bushels/acre for biochar and humic acid, respectively), but not when applied with fertilizer. Although somewhat variable depending on the carbon source and the fertilization level, the lowest carbon rate (90 lbs carbon/acre) generally resulted in the highest yield. These data indicate that granular carbon additions can improve corn yield by enhancing soil nutrient cycling, without negatively affecting the availability of P or K from fertilization.

INTRODUCTION

As atmospheric carbon (C) levels continue to rise, new avenues for C sequestration are being explored in an attempt to mitigate the greenhouse gas effects of these elevated C levels. Carbon dioxide (CO_2) has recently become a gas of interest in the agricultural sector due to the annual C cycling that occurs in farmland soils, and increasing sequestration or reducing emission processes have been proposed as greenhouse gas mitigation strategies. The challenge proposed to farmers is to implement management practices that maintain or increase yields and simultaneously capture CO_2 via plant biomass production while sequestering that C in their soils for a net positive C balance to help offset emissions from the agricultural sector and reduce agriculture's contribution to climate change.

Replacing current agricultural management practices with ones that increase soil C sequestration, or that reduce C losses is considered a cost-effective mitigation strategy and is possible due to the active management of agricultural soils (Lal, 2013). Practices such as reducing tillage, switching to no-till, or implementing cover crops have been shown to increase soil C sequestration (Lal, 2013; Marks, 2020; Oldfield et al., 2021; Paustian et al., 2016; Smith et al., 2008). However, farmers can be resistant to changing their management practices as it can involve risk, have applicability limitations, and require the purchase of costly new equipment. Therefore, adding organic amendments that contain high levels of C may be a more feasible and immediately-implementable way to tandemly-increase nutrient availability, soil organic carbon levels, and soil health in a cost-effective manner. Additionally, combining carbon sources such as humic acids with fertilizers may potentially increase fertilizer use efficiency and crop yield.

Simultaneously enhancing fertilizer use efficiency, increasing plant productivity, sequestering C, and improving soil health would help to alleviate global concerns of environmental health and food insecurity. The question this research seeks to answer is if there is potential to simultaneously enhance the efficiency of fertilization and increase corn crop yields with application of organic amendments with or without phosphorus (P) and potassium (K) fertilizers. Previous studies have evaluated the effect of organic amendments on C fluxes and grain yield; however, their results have varied (Allohverdi et al., 2021; Yeboah et al., 2018), and little research has been conducted regarding the effect of these additions when paired with traditional fertilizers. The objective of this research project was to assess the effect of the application of two carbon amendments, biochar and humic acid, on nutrient use efficiency and corn grain yield.

MATERIALS AND METHODS

Site Description

Field experiments were conducted in 2022 and 2023 at two different fields at the Crop Sciences Research and Education Center at Champaign, IL. The soil in both fields were classified as Flanagan silt loam, (Fine, smectitic, mesic Aquic Argiudolls). In 2022, the site had a soil organic matter (SOM) content of 3%, pH of 6.7, a CEC of 15.7 meq/100g, and Mehlich III extractable P and K levels of 29 and 103 ppm, respectively. In 2023, the site had 3.2% SOM, 6.4 pH, a CEC of 20.6, and Mehlich III-extractable P and K levels of 24 and 114 ppm, respectively. Both sites followed a traditional corn-soybean rotation with soybean as the previous crop.

Experimental Design and Agronomic Management

For both years, six replications of treatments were arranged in a randomized complete block design. Each experimental unit (plot) comprised of four rows, each measuring 37.5 feet in length and spaced 30 inches apart, with a 30-inch walkway separating adjacent ranges of plots. Rows one and four of each plot served as border rows while rows two and three were considered yield rows. Corn hybrid DKC65-84 (Bayer Crop Science, Research Triangle Park, NC) was planted at a population of 36,000 plants/acre on 11 May 2022 in the first year of the study, and 26 April 2023 on the second year of the study using a SeedPro 360 research plot planter (ALMACO, Nevada, IA). To ensure optimal seedling-insect pest control, an in-furrow application of Force 6.5G [Tefluthrin: (2,3,5,6-tetrafluoro-4-methylphenyl)methyl-(1α,3α)-(Z)-(±)-3-(2-chloro-3,3,3-tri-fluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate; Syngenta Crop Protection LLC., Greensboro, NC] was applied at a rate of 2.3 oz/1000 ft at planting. In-season foliar protection was achieved using Miravis Neo fungicide (7.0% Pydiflumetofen + 9.3% Azoxystrobin + 11.6% Propiconazole; 13.7 fl oz/acre; Syngenta Crop Protection, LLC.) and Warrior II insecticide [22.8% Lambda-cyhalothrin (synthetic pyrethroid); 1.6 fl oz/acre; Syngenta Crop Protection, LLC.), which was applied at the VT/R1 (tasseling-to-silking) growth stage using a pressurized-CO_2 back-pack sprayer at a total volume of 20 gal/acre.

Treatment Applications

All treatments were broadcast-applied at pre-plant and lightly incorporated (2 inches deep) with a harrow. Each plot, including the untreated control (UTC), received an application of 180 lbs N/acre as urea ammonium nitrate (UAN-32) at preplant. Carbon amendments biochar or humic acid (Novihum; 78% organic matter sourced from lignite + 21% Bentonite clay), were applied at three rates (90, 180, or 360 lbs of C/acre) with or without P plus K fertilizer. Consequently, the C rate of 90 lb/acre corresponded to an applied carbon-to-nitrogen ratio of 1:2 (90C:180N), the 180 lb/acre rate corresponded to a ratio of 1:1, and the 360 lb/acre rate corresponded to a ratio of 2:1. Due to differences in carbon concentration between the two products (Biochar 90% C; Humic acid 42% C), the product application rate was balanced for the C concentration in each product, which resulted in product rates of 100, 200 or 300 lbs of biochar/acre and 210, 420, or 840 lbs of humic acid/acre, respective to the C rates of 90, 180, and 360 lbs/acre. Fertilization treatments of P plus K (P + K) were broadcast-applied as monoammonium phosphate (MAP; 11-52-0) and muriate of potash (MOP; 0-0-60) at rates of 60 lbs P_2O_5/acre and 60 lbs K_2O/acre.

Measured Parameters

Corn biomass nutrient concentrations were measured by collecting the entire above-ground portion of four plants from the center two plot rows (two plants from each row) of each plot at the VT growth stage. Samples were then dried to 0% moisture in a forced air oven at 75°C and weighed to determine shoot biomass per plant. Once weighed, samples were ground to pass through a 2 mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and analyzed for nutrient concentrations of K, calcium (Ca), and magnesium (Mg) by A & L Great Lakes Laboratories (Fort Wayne, IN).

Following crop dry down, the two center rows of each plot were mechanically harvested for determination of crop grain weight and moisture using an R1 rotary combine (ALMACO, Nevada, IA). Grain yield data was standardized to 15.5% moisture. Statistical analysis was performed using a linear mixed model approach in PROC MIXED of SAS

(SAS 9.4) (SAS Institute Inc., Cary, NC), and means were separated using Fisher's protected LSD test. Assessment of normality of residuals and detection of potential outliers was conducted with PROC UNIVARIATE. Additionally, the Brown-Forsythe modification of the Levene test was performed using PROC GLM to ensure homogeneity of variance. The assumptions of homogeneity of variance and normality were confirmed, and the data from two years were combined and analyzed as a single dataset.

RESULTS AND DISCUSSION

All treatments containing carbon amendments significantly decreased Mg concentration in corn biomass at the VT growth stage (Table 1). However, plant K concentration significantly increased with biochar at 90 and 180 lbs C/acre with fertility, and humic acid at 90 lbs C/acre without fertility, and 180 and 360 lbs C/acre with fertility. All treatments containing carbon amendments numerically increased K concentration in corn biomass at the VT growth stage, while Ca and Mg concentrations tended to decrease (Table 1).

Even without additional P and K fertility, there tended to be more grain yield as a result of carbon amendment applications (Table 2). Notably, none of the carbon amendment treatments in the study decreased yield compared to the UTC. The application of biochar at 90, 180, and 360 lbs C/acre without fertility significantly increased yield over the UTC by 9.5, 6.8, and 5.8 bushels/acre, respectively, averaging a 7.3 bushel/acre yield increase (Table 2). Conversely, humic acid applications without fertility increased yield numerically, but not significantly, regardless of the rate applied. (Table 2).

Fertilization with P + K alone increased yield by 12.4 bushels/acre over the UTC, indicating that the research sites were deficient in P and K, limiting yield potential. Although non-significant, adding carbon amendments to P + K fertilizer numerically increased grain yield at the biochar rates of 90 and 180 lbs C/acre, and at the humic acid rate of 90 lbs C/acre, while the 360 lbs C/acre rate tended to decrease grain yield compared to P + K only, regardless of the carbon source. When averaged across fertility and carbon sources, as the rate of applied carbon increased, corn grain yield tended to decrease (Table 3).

When averaged across carbon rates and fertility, application of biochar resulted in greater corn grain yield than when humic acid was applied (Table 4). Due to the higher product application rate of humic acid when compared to biochar to achieve the same carbon application rate (100, 200, and 300 lbs biochar/acre vs. 210, 420, and 840 lbs humic acid/acre), biochar applications are potentially a more economical and feasible approach to adding carbon to soils than humic acid applications.

The results of this study demonstrate the potential of granular carbon amendments, with or without P and K fertilization, to increase corn grain yield, which may be related to the effect of carbon amendments on corn cation uptake. Therefore, granular carbon amendments may positively influence soil functions and soil carbon levels, while maintaining or increasing corn grain yield.

Table 1. Nutrient concentrations in corn plant tissue at the VT growth stage as affected by carbon amendment, rate, and fertilizer treatments at Champaign, IL in 2022. Data from 2023 was not available at the time of this publication.

Carbon Amendment	Rate	K		Ca		Mg	
		Fertility†					
		-	+	-	+	-	+
	lbs C/acre			%			
None		1.07	1.16	0.52	0.55	0.55	0.54
Biochar	90	1.16	1.22	0.52	0.50	0.50	0.48
	180	1.14	1.33	0.52	0.48	0.50	0.46
	360	1.12	1.19	0.49	0.52	0.48	0.49
Humic Acid	90	1.21	1.17	0.48	0.49	0.47	0.50
	180	1.09	1.28	0.48	0.49	0.46	0.48
	360	1.19	1.25	0.45	0.47	0.46	0.48
LSD(0.10)		0.13		0.04		0.05	

†Fertility applied as MAP at 60 lbs of P_2O_5/acre plus MOP at 60 lbs of K_2O/acre.

Table 2. Corn grain yield as influenced by fertility and biochar or humic acid treatments applied at three different rates at Champaign, IL.

Carbon Amendment	Rate	Fertility† -	Fertility† +
	lbs C/acre	bushels/acre	
None		238.9	251.3
Biochar	90	248.4	251.8
	180	245.7	253.5
	360	244.7	249.4
Humic Acid	90	242.3	254.4
	180	241.2	250.7
	360	243.3	247.8
LSD(0.05)		5.1	

†Fertility applied as MAP at 60 lbs of P_2O_5/acre plus MOP at 60 lbs of K_2O/acre. Grain yield data is averaged across two years and is presented at 15.5% moisture.

Table 3. Effect of carbon rate on corn grain yield at Champaign, IL.

Carbon Rate	Grain Yield
lbs C/acre	bushels/acre
90	249.0
180	247.8
360	246.3
LSD(0.05)	NS

Data was averaged across carbon source and fertility over two years.

Table 4. Effect of carbon source on corn grain yield at Champaign, IL.

Carbon Source	Grain Yield
	bushels/acre
Biochar	248.9
Humic Acid	246.5
LSD(0.05)	2.0

Data was averaged across years, carbon rates, and fertility.

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