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FLUID FERTILIZER'S ROLE IN SUSTAINING SOILS USED FOR BIO-ENERGY FEEDSTOCK PRODUCTION

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ABSTRACT

The use of corn (*Zea mays* L.) as a bio-energy feedstock has attracted the attention of many producers. Recently, the focus has shifted from grain-based to cellulose-based ethanol production. In addition to biological conversion of corn stover to ethanol, thermal conversion (pyrolysis) of stover is being explored. Regardless of post-harvest processing, the short- and long-term effects of both increasing grain yields and removing stover on soil nutrient cycling, physical properties, and biological activity must be understood to ensure that soil productivity and ecosystem services are maintained. Our objectives for 2010 were to evaluate: (i) the use of surface or subsurface bands of N-P-K-S fluid fertilizers to optimize positional and temporal availability of nutrients; and (ii) the effect of biochar application on P availability and cycling in Clarion-Nicollet-Webster soils. Corn was grown in a field trial under a variety of management systems including 30-inch row spacing with standard fertility management and a twin-row, high-population treatment with increased nutrient additions applied in split-applications. Analysis of whole plants at V6 and ear leaves at mid-silk indicated that management scenario, tillage, and the amount of stover removed from the field with the 2009 harvest did not affect uptake of most nutrients. Nitrogen concentrations in ear-leaf tissue, however, were below the critical value for all treatments. Management scenario and tillage and did not affect corn grain yields, but plots from which corn stover was not removed always yielded less than plots from which ~50% (harvested just below the ear shank) or ~90% (harvested at a stubble height of approximately 4 inches) of the stover was removed. We suspect that this is a short-term effect. The wet growing conditions in central Iowa during June and early July may have caused significant nitrate leaching and denitrification, thus limiting N availability and decreasing yields of all treatments. If wet weather patterns continue, mid-season N applications may become necessary. In a separate controlled-climate chamber study, 20-day-old plants grown in soil with only 100 lb. P_2O_5/A had the highest shoot and root dry matter values, while those grown in soil amended with biochar in 2007 without P fertilizer had the lowest values. Addition of 100 lb. P_2O_5/A numerically increased shoot and root dry matter values regardless of legacy or fresh biochar amendment. Continued generation of plant growth and nutrient uptake data should provide a clearer picture of the value of the biochar, any biochar-fertilizer interactions, and whether legacy or fresh biochar affects the nutrition of juvenile corn in different ways.

INTRODUCTION

The use of corn as a bio-energy feedstock has attracted the attention of many producers, especially in the Cornbelt states. Recently, the focus has shifted from grain-based to cellulose-based ethanol production, with corn stover (stalks and cobs) being an important feedstock material (Bridgwater, 2006). In addition to biological conversion of corn stover to ethanol, thermal conversion (pyrolysis) of stover to bio-oil, syngas, and biochar is being explored as an alternative platform (Laird, 2008). Regardless of post-harvest processing, the short- and long-term effects of both increasing grain yields and removing stover on soil nutrient cycling, physical properties, and biological activity must be understood to ensure that soil productivity and ecosystem services are maintained. Up to this point, the bio-energy industry has been forced to use estimates, such as those offered by Johnson et al. (2006), to determine the amount of crop residues that must remain in the field. Research has shown that the use of no-tillage production can reduce the rate of residue decomposition, thus offering a mechanism to maintain soil organic carbon after removing some portion of the stover (Perlack et al., 2005). A significant amount of research has addressed fertility requirements and nutrient cycling in conventional grain production systems, but only recently has information on bio-energy feedstock systems become available (Heggenstaller et al., 2008; Blanco-Canqui and Lal, 2009). To provide more quantitative fertility guidelines, soil management studies focusing on cropping systems, tillage, fertilizer rates and placement, use of cover crops, and controlled wheel traffic are needed. Because it would be difficult to address all of these variables in a single project, our research focuses on nutrient requirements, specifically phosphorus (P), potassium (K) and sulfur (S), for no-till corn bio-energy production systems.

There is also significant interest in the use of biochar as a soil amendment for sequestering carbon and improving agricultural soil quality. Crop yield increases and improvements in soil physical and chemical properties have been reported, but variability among the responses has been significant (Glaser et al., 2002; McHenry, 2009). Biochars have some plant nutrient content, but nutrient availability can vary widely (Chan et al., 2007; McHenry, 2009). Biochars cannot be considered a substitute for fertilizers. However, Chan et al. (2007) reported that yields of radish (*Raphanus sativus*) increased with increasing rates of biochar in combination with N fertilizer, suggesting that biochar played a role in improving N-use efficiency. Application of biochar to soils may also enhance P availability and improve P-use efficiency. Preliminary research has shown that additions of biochar tend to increase Mehlich 3-extractable P and reduce P leaching when applied in combination with animal manures (D.A. Laird, unpublished data).

The overall goal of this project is to evaluate the use of N-P-K-S fluid fertilizers to enhance corn grain and stover productivity. A secondary goal is to determine the role biochar application plays in nutrient cycling. This project is part of a long-term corn grain and stover removal study that focuses on standard and intensive fertility management, tillage, biochar additions to test the “charcoal vision” (Laird, 2008) for sustaining soil quality while producing bio-energy products, and use of cover crops to build soil carbon and help off-set potential negative impacts of stover removal. Our specific objectives for 2010 were to evaluate (i) the use of surface or subsurface bands of N-P-K-S fluid fertilizers to optimize positional and temporal availability of nutrients, and (ii) the effect of previous and recent biochar application on P availability and cycling in Clarion-Nicollet-Webster soils.

METHODS AND MATERIALS

Biomass Removal Study

The 25-acre field study established in 2008 on the Clarion-Nicollet-Webster soil association at the Iowa State University Agronomy & Agricultural/Biosystems Engineering Research Center (AAERC), southwest of Ames in Boone County, Iowa, was continued. This study focuses on rates of residue removal (0, ~50%, and ~90%), tillage (chisel plow versus no-tillage), a one-time biochar addition (4.32 and 8.25 tons/A), and use of annual and perennial cover crops. One set of plots (40 x 280 ft.) is managed with standard production practices, and a second set of plots is managed in a twin-row configuration with higher inputs. Conventional weed and insect control practices are being followed. The study includes 22 treatments that are replicated four times. Soil samples (0-2 and 2-6 inches) were collected with a hand probe from each plot 23 November 2009, and analyzed for pH, organic matter content, available P, exchangeable K, Ca, and Mg, extractable SO^{4-}, and CEC (Table 1). Pioneer Brand 36V75 corn was planted 27 April 2010. Fertilizer applications in 2010 (Table 2) were based on 2009 grain and stover removals and fall soil test results. Early-season whole-plant samples at the V6 growth stage (3 June 2010) and ear-leaf samples at the mid-silk stage (12 July 2010) were collected and analyzed to determine the nutritional status of the crop. Corn grain and stover were harvested with a single-pass combine with an 8-row head beginning 27 September. Sub-samples of stover and grain are being analyzed for nutrient content so that a more complete nutrient balance can be calculated.

Table 1. Initial soil test levels in two depth increments for the Clarion-Nicollet-Webster soil association in 2010. Range indicates variability among all plots in study.

Soil Test Parameter	Composite	Range	Composite	Range
	0-2 inch		2-6 inch	
Bray-1 P, ppm	50	21 – 103	23	7 – 52
Exch. K, ppm	229	133 – 364	138	76 – 339
Exch. Ca, ppm	2569	1680 – 4120	2730	1510 – 3890
Exch. Mg, ppm	318	212 – 509	334	171 – 547
Extract. S, ppm	5	1 – 10	5.5	2 – 12
pH	5.9	5.4 – 6.6	6.0	5.1 – 6.7
O. M., %	3.7	2.8 – 5.1	3.4	2.6 – 4.8
CEC, cmol(+)/kg	22.3	14.9 – 29.3	22.8	17.0 – 30.9

Biochar Study

Soil samples were collected from the bio-energy field trial site at the Iowa State University AAERC in April 2010. Surface soil (0-6 inches) from two plots was collected. One plot was a control that had standard management, chisel plow tillage, and 90% residue removal. The second was a biochar plot (8 ton/acre, fall 2007) that had standard management, chisel plow tillage, and 90% residue removal. The soil is classified as Clarion loam (fine-loamy, mixed, mesic Typic Haplaquolls). Initial soil physical and chemical properties (Table 3) were determined.

Table 2. Fertilizer management for the conventional and high-input (twin row) systems in 2010.

System	Stover Removal, %	Timing	Source
Conventional		Fall 2009	11-52-0 + 0-0-60
190+68+49+30S	0	Starter	32-0-0 (UAN)
215+79+124+30S	50		12-0-0-26S (ATS)
230+88+188+30S	90	Sidedress	32-0-0 (UAN)
Twin-Row		Fall 2009	11-52-0 + 0-0-60
220+65+46+40S	0	Starter	32-0-0 (UAN)
245+76+118+40S	50		12-0-0-26S (ATS)
260+82+165+40S	90	Sidedress	32-0-0 (UAN)

In order to determine the effect of previous (legacy) and fresh biochar applications in combination with liquid P fertilizer addition, a laboratory/climate chamber experiment was initiated. A commercially available hardwood-based biochar was added to subsamples of unamended soil at 0 and 8 tons per acre. Ammonium polyphosphate (APP, 10-34-0) was then applied to subsamples of biochar-amended soil to provide 100 lb. P_2O_5 per acre. Nitrogen, K, and S fertilizers were also applied to provide adequate amounts of these nutrients. The biochar and fertilizers were thoroughly mixed with the soil. Unamended soil is serving as a control treatment. After the amendments were added, the soils were incubated moist for four weeks. Following incubation, soil solution was displaced and analyzed for P, and Bray 1-P was determined in the treated and untreated soils. Relative changes in the values of these soil supply parameters will be used to compare the effects of the legacy and fresh biochar amendments on the soil supply of P.

Table 3. Initial soil test levels for Clarion loam collected in 2010. Legacy biochar refers to an 8 ton/acre rate applied to this soil in the fall of 2007.

Soil Test Parameter	Control	Legacy Biochar
Bray-1 P, ppm	65 (VH)	50 (VH)
Exchangeable K, ppm	159 (VH)	119 (L)
Exchangeable Ca, ppm	2034	1981
Exchangeable Mg, ppm	206	213
Extractable S, ppm	4	4
pH	5.6	5.7
Organic Matter, %	2.8	2.8
CEC, cmol(+)/kg	15.1	14.8

A pot experiment was then initiated. Pre-germinated corn (Pioneer Brand 36V75) seedlings were planted two per pot, and pots were placed in a controlled-climate chamber with 16 hours of light and 22°C/12°C day/night temperature. Each treatment combination was replicated four times. After 20 days, plants were harvested. Corn roots were separated from soil, and after fertilizing with replacement N (but not P), the same soil returned to each pot. New corn seedlings were planted and allowed to grow another 20 days. In order to investigate the effect of biochar addition on depletion of plant-available P, a third and possibly fourth cycle of growth is planned. At this point, measurements and data analyses are incomplete. Total dry matter production and nutrient uptake from each treatment will be compared. Phosphorus uptake efficiency and utilization efficiency also will be calculated for the various treatments. These data will be used to determine: i) the P fertilizer value of the biochar, ii) if biochar-P fertilizer interactions occurred, and iii) the differences between legacy and fresh biochar as it relates to the P nutrition of the corn. Because of the time and effort involved in carrying out this study, we anticipate concurrent measurements of N, K, and S uptake and utilization efficiencies. We are also monitoring water-use efficiency.

RESULTS AND DISCUSSION

Biomass Removal Study

Plant Nutrition

Management scenario, tillage, and the amount of residue removed from the field with the 2009 harvest did not affect nutrient content of whole plants at the V6 stage, and levels of all primary and secondary macro-nutrients were adequate for optimal growth (Table 4). Nitrogen concentrations were well above the published critical value of 3.5% (Mills and Jones, 1996), suggesting that pre-plant N fertilizer and soil N were sufficient to support the corn crop before additional N was sidedressed six weeks after planting.

At mid-silk in 2010, no differences in ear-leaf nutrient concentrations were detected among the treatments (Table 5). However, N concentrations in the tissue were below the critical values. Phosphorus and K concentrations in ear leaves were within the sufficiency ranges of 0.25% to 0.50% for P and 1.7% to 3.0% for K for all treatments (Mills and Jones, 1996). Sulfur concentrations were also within the sufficiency range of 0.10% to 0.30% (Jones et al., 1990). Low N uptake suggests that the soil supply was not sufficient to meet crop demand by mid-silk. The wet growing conditions in central Iowa during June and early July (Hillaker, 2011) may have caused significant nitrate leaching and denitrification, thus limiting N availability. If wet weather patterns continue, mid-season N applications may become necessary.

Corn Grain and Stover Yield

In 2010, management scenario and tillage and did not affect corn grain yields (Fig. 1). Yields, however, were related to the amount of residue removed from the field with the 2009 harvest. Plots from which corn stover was not removed tended to have lower yields than those from which ~50% or ~90% was removed. This result is similar to 2009 results and contradicts previous work demonstrating yield decreases when plant residues are removed (Blanco-Canqui and Lal, 2009). We suspect that in the short term, higher residues in the soil result in cooler, wetter conditions that negatively affect early-season corn root growth and function. Moreover, when stover was not removed, fertilizer application rates were lower. A combination of less fertilizer N, greater N immobilization because of the residues remaining in the soil, and increased N leaching losses would negatively affect mid-season corn growth and subsequent grain yields.

Although data are still being processed, the amount of dry stover collected was higher for the 90% removal (low cuts) treatments of all management scenarios. However, the wet conditions in central Iowa during the middle of the growing season (Hillaker, 2011) likely limited the performance of all treatments. Whole plants collected at physiological maturity residue samples from the machine harvest are being processed to determine elemental composition, so that the total amount of nutrients removed can be calculated. These values will be used to guide fertilizer recommendations for 2011.

Table 4. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) critical values and concentrations in whole plants at the V6 growth stage for six management scenarios in 2010. Values (%) are means of 8 to 16 replications depending on treatment. Standard deviations are given below each mean.

Nutrient	Critical Value	Control	Biochar 1[†]	Biochar 2[‡]	Twin-Row	Perennial CC[§]	Annual CC
N	3.50	3.99	3.96	3.90	4.04	3.44	4.03
		0.21	0.14	0.16	0.14	0.18	0.23
P	0.30	0.53	0.55	0.55	0.54	0.54	0.58
		0.03	0.04	0.05	0.03	0.06	0.07
K	2.50	4.24	4.13	4.46	4.13	3.56	4.15
		0.37	0.34	0.35	0.45	0.40	0.32
Ca	0.30	0.54	0.57	0.55	0.56	0.57	0.57
		0.03	0.03	0.03	0.05	0.05	0.07
Mg	0.15	0.39	0.40	0.38	0.39	0.40	0.42
		0.04	0.03	0.03	0.05	0.07	0.04
S	0.20	0.28	0.29	0.28	0.29	0.27	0.27
		0.02	0.01	0.01	0.02	0.02	0.02

[†]4 tons biochar/A; [‡]8 tons biochar/A; [§]CC = cover crop.

Table 5. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) critical values and concentrations in ear leaves at mid-silk stage for six management scenarios in 2010. Values (%) are means of 8 to 16 replications depending on treatment. Standard deviations are given below each mean.

Nutrient	Critical Value	Control	Biochar 1[†]	Biochar 2[‡]	Twin-Row	Perennial CC[§]	Annual CC
N	2.70	2.49	2.56	2.55	2.45	2.58	2.57
		0.19	0.45	0.21	0.18	0.13	0.13
P	0.25	0.31	0.30	0.31	0.32	0.33	0.33
		0.03	0.03	0.03	0.04	0.02	0.02
K	1.70	2.14	2.13	2.24	2.13	2.20	2.18
		0.24	0.29	0.20	0.24	0.11	0.18
Ca	0.21	0.44	0.44	0.45	0.44	0.44	0.46
		0.05	0.05	0.04	0.04	0.03	0.02
Mg	0.20	0.25	0.26	0.25	0.25	0.25	0.27
		0.04	0.02	0.03	0.04	0.02	0.03
S	0.10	0.17	0.17	0.17	0.17	0.17	0.18
		0.01	0.01	0.01	0.01	0.01	0.01

[†]4 tons biochar/A; [‡]8 tons biochar/A; [§]CC = cover crop.

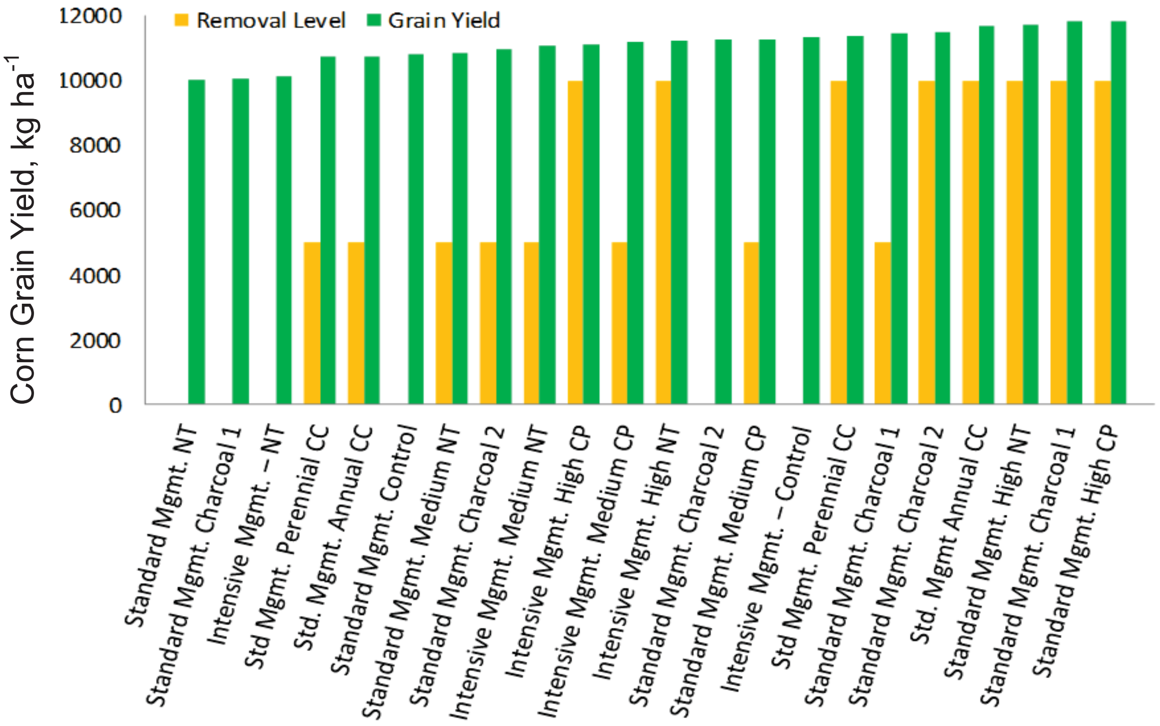

Fig. 1. Corn grain yields as affected by crop management, tillage, stover removal, cover crop, and biochar application in 2010. Yellow bars indicate 0%, 50%, and 90% stover removals, not actual stover yields.

Biochar Study

Shoot and root dry matter data suggest that both biochar and P fertilizer amendments had some effect on corn growth (Table 6). Twenty-day-old plants grown in soil with only 100 lb. P_2O_5/A had the highest shoot and root dry matter values, while those grown in soil amended with biochar in 2007 without P fertilizer had the lowest values. Addition of 100 lb. P_2O_5/A, increased numerical values of shoot and root dry matter accumulation, regardless of biochar amendment. This result is unexpected, given the initial high levels of available soil P (Table 3). Higher root:shoot dry weight ratios were recorded for the legacy biochar treatments, suggesting that the plants were partitioning more resources to root growth, rather than shoot growth. Without plant nutrient content data, however, it is difficult to speculate on the reason for this result. Continued generation of plant growth and nutrient uptake data should provide a clearer picture of the fertilizer value of the biochar, any biochar-fertilizer interactions, and whether legacy or fresh biochar affect the nutrition of juvenile corn in different ways.

Table 6. Corn shoot and root dry matter accumulation and root:shoot ratio as affected by legacy (2007) and fresh (2010) biochar application and phosphorus (P) fertilizer. Plants were harvested after 20 days of growth in a controlled-climate chamber. Values are means of 4 replications. Standard deviations are shown in parentheses.

Treatment	P Fertilizer	Shoot Dry Weight	Root Dry Weight	Root:Shoot
	lb. P_2O_5/A	g	g	
Control	0	2.97 (0.17)	1.68 (0.14)	0.57
	100	3.22 (0.10)	2.08 (0.08)	0.65
2007 Biochar†	0	1.90 (0.10)	1.49 (0.08)	0.78
	100	2.16 (0.15)	1.60 (0.06)	0.74
2010 Biochar†	0	2.33 (0.16)	1.51 (0.05)	0.65
	100	2.46 (0.14)	1.57 (0.18)	0.64

†8 tons biochar/A.

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