Value of Fluid Fertilizer In Bio-energy Production

In controlled-environment tests, overall agronomic efficiency of P fluid fertilizers was improved by biochar applications.

Drs. John Kovar and Douglas Karlen

The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Fall 2012 • Vol. 20, No. 4, Issue# 78

Summary: *In field trials, analysis of whole corn plants at V6 and ear leaves at mid-silk showed adequate levels of all macronutrients, which suggests that nutrient management was balanced both for conventional and intensively managed (twin-row) planting scenarios and the amount of stover removed from the field with the 2010 harvest. Management scenario, tillage, and previous stover removal did not affect corn grain yields, which varied from 172 to 182 bu/A in 2011. In addition, biochar application and cover crop growth had no effect on grain or stover yields. The amount of dry stover collected for the 90 percent stover removal treatment averaged 2.9 tons/A compared to 1.8 tons/A for the 50 percent treatment. In 2011, the intensively managed plots did not produce more grain or dry stover than the conventional plots. In a separate controlled-climate chamber study, biochar and phosphorus (P) fertilizer amendments affected soil P supply and corn seedling growth during five consecutive plant growth cycles. Plants grown in soil with only 100 lbs/A of P_2O_5 had greater shoot to root dry matter ratios for both legacy and fresh biochar treatments. Although cumulative shoot dry matter production tended to be higher for treatments without biochar, the overall agronomic efficiency of the P fluid fertilizer was improved by biochar application. Further statistical analysis of plant growth and nutrient uptake data is expected to provide a clearer picture of the fertilizer value of biochar, any biochar-fertilizer interactions, and how legacy or fresh biochar affect juvenile corn nutrition.*

The use of corn as a bio-energy feedstock has attracted the attention of many producers, especially in the Corn Belt states. With the focus shifting from grain-based to cellulose-based ethanol production, corn stover (stalks and cobs) is now an important feedstock material. 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. Regardless of post-harvest processing, the short- and long-term effects of both increasing grain yields and harvesting stover on soil nutrient cycling, physical properties and biological activity must be understood to ensure that soil productivity and ecosystem services are maintained.

To ensure long-term sustainability, the bio-energy industry initially focused on determining the amount of crop residues that must remain in the field to prevent wind and water erosion and subsequently, loss of soil organic carbon. Through collaborative ARS, university, and private industry research, studies have shown that the use of no-till production can reduce the rate of residue decomposition, thus offering a mechanism to maintain soil organic carbon after removing a site-specific portion of the stover.

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. To provide more quantitative fertility guidelines, soil management studies are needed focusing on cropping systems, tillage, fertilizer rates and placement, use of cover crops, and controlled wheel traffic. Because it would be difficult to address all of these variables in a single project, the research in this particular study focuses on nutrient requirements, specifically P, potassium (K), and sulfur (S) for no-till corn bio-energy production systems.

There has also been 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. Biochars have some plant nutrient content, but nutrient availability can vary widely. Biochars cannot be considered a substitute for fertilizers, although there have been reports 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 soil 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.

Research goal

The goal of this project is to evaluate the use of NPKS fluid fertilizers to enhance corn grain and stover productivity. A secondary goal is to determine the role of biochar application 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” for sustaining soil quality, and the use of cover crops to build soil carbon and help offset potential negative impacts of stover removal.

Our specific objectives for 2011 were to:

- Evaluate the use of surface or subsurface bands of NPKS fluid fertilizers to optimize positional and temporal availability of nutrients
- Evaluate the effect of previous (2007) and recent biochar application on P availability and cycling in Clarion-Nicollet-Webster soils.

Biomass removal

Plant nutrition. Management scenario, tillage, and the amount of stover removed from the field with the 2010 harvest did not affect early plant growth and nutrient content of whole plants at the V6 stage. Levels of all primary and secondary macro-nutrients were adequate for optimal growth (Table 1). Nitrogen (N) concentrations were well above the published critical value of 3.5 percent, suggesting that preplant N fertilizer and soil N were sufficient to support the corn crop before additional N was sidedressed six weeks after planting.

"Efficiency of P was improved by biochar application"

At mid-silk in 2011, no differences in ear-leaf nutrient concentrations were detected among the treatments (Table 2). Unlike previous years, N concentrations in ear leaves were above the critical value of 2.7 percent, while P concentrations were within the sufficiency range of 0.25 percent to 0.50 percent. Potassium concentrations were also within the sufficiency range of 1.7 to 3.0 percent as were S concentrations for all treatments.

Plant analysis results suggest that fertilizer inputs and nutrient removals were more balanced than in previous years, although the hybrid was changed in 2011, which could have affected nutrient uptake and use efficiency. During the first growing season of the trial in 2008, N, K, and S deficiencies were recorded and N deficiencies persisted in 2009. These deficiencies were not a problem with the Pioneer Brand P0461xr hybrid in 2011.

Corn/stover yield. In 2011, management scenario, tillage, and previous stover removal had little effect on corn grain yield (Table 3). In addition, the biochar and cover crop treatments had no effect on grain and stover yields, so data were pooled with the conventional treatments. In 2009 and 2010, grain yields tended to be lower when corn stover was not removed than when 50 or 90 percent was removed, but this was not the case in 2011. These results lend support to previous work demonstrating yield decreases when excessive amounts of plant residues are removed. Although N immobilization related to the residues

Table 1. 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 five management scenarios in 2011. Values (%) are means of 8 to 16 replications depending on treatment. Standard deviations are in parentheses below each mean.

Nutrient	Critical Value	Control	Biochar 1†	Biochar 2‡	Twin-Row	Annual CC§
N	3.5	3.82	3.69	3.66	3.93	4
		-0.25	-0.16	-0.21	-0.27	-0.18
P	0.3	0.44	0.42	0.45	0.45	0.47
		-0.04	-0.04	-0.05	-0.03	-0.04
K	2.5	3.94	3.82	4.15	4.01	4.14
		-0.3	-0.35	-0.28	-0.31	-0.28
Ca	0.3	0.53	0.52	0.54	0.53	0.54
		-0.04	-0.04	-0.04	-0.04	-0.03
Mg	0.15	0.38	0.36	0.36	0.37	0.4
		-0.05	-0.04	-0.04	-0.04	-0.03
S	0.2	0.29	0.28	0.29	0.3	0.29
		-0.02	-0.02	-0.02	-0.02	-0.01

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

Table 2. 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 five management scenarios in 2011. Values (%) are means of 8 to 16 replications depending on treatment. Standard deviations are in parentheses below each mean.

Nutrient	Critical Value	Control	Biochar 1†	Biochar 2‡	Twin-Row	Annual CC§
N	2.7	3.06	3.07	2.99	3.01	3.11
		-0.13	-0.12	-0.11	-0.13	-0.13
P	0.25	0.44	0.45	0.47	0.44	0.45
		-0.03	-0.03	-0.03	-0.03	-0.03
K	1.7	1.8	1.83	1.9	1.81	1.82
		-0.11	-0.09	-0.14	-0.15	-0.09
Ca	0.21	0.49	0.5	0.51	0.47	0.52
		-0.04	-0.04	-0.04	-0.04	-0.04
Mg	0.2	0.33	0.33	0.33	0.32	0.34
		-0.03	-0.03	-0.03	-0.03	-0.03
S	0.1	0.19	0.19	0.19	0.19	0.19
		-0.01	-0.01	-0.01	-0.01	-0.01

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

Table 3. Management system, tillage, and residue removal effects on corn grain and stover yields in 2011. Values are means of 4 to 12 replications depending on treatment. Standard deviations are given in parentheses.

Treatment	Tillage	Percent Removal	Grain† (bu/ac)	Stover (t/ac)
Conventional	No-tillage	0	178 (6.1)	0
Conventional	No-tillage	50	177 (5.9)	1.63 (0.57)
Conventional	No-tillage	90	178 (2.8)	2.68 (0.28)
Conventional	Chisel Plow	0	173 (2.8)	0
Conventional	Chisel Plow	50	182 (2.9)	1.74 (0.19)
Conventional	Chisel Plow	90	176 (3.7)	2.94 (0.65)
Twin-Row	No-tillage	0	177 (6.1)	0
Twin-Row	No-tillage	50	182 (4.4)	1.86 (0.23)
Twin-Row	No-tillage	90	175 (10.6)	3.22 (0.96)
Twin-Row	Chisel Plow	0	172 (2.7)	0
Twin-Row	Chisel Plow	50	179 (5.8)	1.90 (0.24)
Twin-Row	Chisel Plow	90	170 (7.0)	2.69 (0.35)

† Grain yields adjusted to 15.5% moisture.

Table 4. Corn shoot and root dry matter accumulation, root:shoot ratios, and agronomic efficiency of phosphorus (P) fertilizer as affected by legacy (2007) and fresh (2010) biochar application. Plants were harvested after 20 days of growth in a controlled-climate chamber. Data represent dry matter accumulation after one harvest and after five harvests. Values are means of four replications. Standard deviations are shown in parentheses.

Treatment	P Fertilizer	Shoot Dry Weight	Root Dry Weight	Root:Shoot Ratio	Agronomic Efficiency
	lb. P2O5/A	G	g		g shoot DM/g P
Harvest 1					
Control	0	2.97 (0.17)	1.68 (0.14)	0.57	
	100	3.22 (0.10)	2.08 (0.08)	0.65	5.8
2007 Biochar†	0	1.90 (0.10)	1.49 (0.08)	0.78	
	100	2.16 (0.15)	1.60 (0.06)	0.74	6.2
2010 Biochar†	0	2.33 (0.16)	1.51 (0.05)	0.65	
	100	2.46 (0.14)	1.57 (0.18)	0.64	3.1
Cumulative‡					
Control	0	10.13 (0.81)	7.40 (1.11)	0.73	
	100	10.87 (0.30)	8.03 (0.72)	0.74	17.1
2007 Biochar†	0	7.71 (0.10)	6.57 (0.42)	0.85	
	100	8.93 (0.52)	5.81 (0.23)	0.65	28.3
2010 Biochar†	0	9.10 (0.31)	6.14 (0.35)	0.67	
	100	10.08 (0.29)	6.17 (0.56)	0.61	22.7

†8 tons biochar/A; ‡ Values are cumulative for five harvests of dry matter.

remaining in the soil can negatively affect mid-season corn growth and subsequent grain yields, fertilizer N rates for the 2011 crop appear to have been sufficient to offset any decreased N availability. The warm and humid weather in central Iowa during the late spring/early summer provided ideal growing conditions for the corn crop, although high humidity kept overnight low temperatures persistently higher than normal. Precipitation was greater than normal for five of the first six months of the year, which continued the very wet pattern of the previous three years. However, dry conditions quickly developed during late July and continued into August and September. These conditions during grain fill likely decreased final yield of the crop.

As expected, the amount of dry stover collected for the 90 percent (low cut) treatment (2.9 tons/A) was much greater than for the high cut treatment 1.8 ton/A). Similar to 2009 and 2010, the intensively managed (twin row) plots did not produce more dry stover than the conventional plots. Whole plants collected at physiological maturity and residue samples from the machine harvest were analyzed to determine elemental composition, so that we could calculate the total amount of nutrients removed. These values were used to guide fertilizer recommendations for 2012.

Biochar study

Both biochar and P fertilizer amendments affected soil P supply and corn seedling growth during five consecutive plant growth cycles in a controlled environment study. Relative differences in shoot and root dry matter production observed at “Harvest 1” 20 days after planting, tended to hold throughout the trial (Table 4). Plants grown in soil amended with P_2O_5 at 100 lbs/A alone had the highest shoot and root dry matter values, while those grown in soil amended with biochar in 2007 (legacy biochar) without P had the lowest values. Addition of P_2O_5 at 100 lbs/A numerically increased shoot and root dry matter accumulation, regardless of biochar amendment. This result was somewhat unexpected, given the initial high levels of available soil P (Table 5).

Higher root to shoot dry weight ratios were recorded for the legacy biochar treatments, suggesting that the plants were allocating more resources to root growth than to shoot growth. Without plant nutrient content data, however, it is difficult to speculate on the reason for this result. Although cumulative shoot dry matter production tended to be higher for the treatments without biochar, the overall agronomic efficiency of the P fertilizer was improved by biochar application (Table 4).

Further statistical analysis 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 5. Initial soil test levels for Clarion loam collected in 2010. Legacy biochar refers to an 8 ton/acre application to this soil in the fall of 2007.

Soil Test Parameter	Control Soil	Legacy Biochar Soil
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

Dr. Kovar is a Research Soil Scientist and Dr. Karlen is a Supervisory Research Soil Scientist and Research Leader at the USDA Agricultural Research Service National Laboratory for Agriculture and the Environment in Ames Iowa.