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Drs. John Kovar and Douglas Karlen

Optimizing Nutrient Management for Sustainable Bio-energy Feedstock Production

Studies conducted using NPKS fluid fertilizers to enhance corn grain and biomass productivity.

Summary: *In 2008, results for conventional and twin-row management averaged 171 and 183 bu/A, respectively. Dry corn stover yields averaged 2.5, 2.9, 2.8, and 3.1 tons/A for the high (just below ear shank) and low (~4-inch stubble) cuts for the two planting configurations, respectively. In 2009, neither management system (including planting configuration, plant population, and fertilization rate) nor tillage (chisel vs no-till) affected corn grain yield; however, grain yield was lower, averaging 142 bu/A, in plots where corn stover was not harvested in 2008. We attribute this response to the total amount of fertilizer, particularly N, that was applied to the non-removal plots.*

Bio-energy feedstock production has attracted the attention of many growers, especially in the Corn Belt states, because current U.S. energy policy calls for annual production of 36 billion gallons of renewable fuels by 2022. Both corn grain and stover are being evaluated as potential feedstock. To ensure that sustainable grain and stover yields meet both current and new demands, the short- and long-term effects of removing grain and stover on soil properties must be understood. Research has shown that no-tillage can reduce the rate of residue decomposition, thus offering a mechanism to maintain soil organic carbon, even if some portion of the crop residue is removed for biofuel production. Up to this point, the biofuel industry has relied on estimates to determine the amount of crop residue that must remain on the land to sustain both the farming and ethanol production enterprises. To provide more quantitative guidelines, soil management studies are needed focusing on tillage, fertilizer rates and placement, cover crops, and other management tools. It would be difficult to address all of the variables in a single project, so we focused on evaluating surface or subsurface bands of N-P-K-S fluid fertilizers to optimize positional and temporal nutrient availability and thus increase both corn grain and stover yield.

Methodology

In 2008, a long-term study was initiated on the Clarion-Nicollet-Webster soil association in central Iowa. Continuous corn is being grown, using a variety of soil and crop management systems including: (1) conventional 30" row spacing with "standard" fertility management, (2) twin-row, high-population with increased nutrient addition in split-applications, (3) conventional management with biochar additions (a by-product of thermochemical biomass conversion technologies), and (4) annual or perennial cover crops incorporated into conventional management systems. The study focuses on rates of residue removal (0, 50, and 90%) and tillage (chisel plow versus no-tillage) within each of the management systems. Each plot is 40' wide by 300' long. Recognizing that harvesting crop residue substantially increases N, P, K, and S removal compared to corn and soybean grain production systems, fertilizer inputs must generally be increased, especially for the higher-population, twin-row treatments when both grain and stover are harvested. In 2008, the total fertilizer application was 190+140+290+20 lbs/A (N-P_2O_5-K_2O-S) for the standard fertility treatment and 250+152+294+30 lbs/A (N-P_2O_5-K_2O-S) for the high fertility treatment. Based on grain and stover nutrient removals in 2008, and a desire to reduce the potential for nitrate leaching, fertilizer application rates for 2009 were decreased. Conventional weed and insect control practices were followed both years. Overall, this 25-acre study includes 22 treatments that are replicated four times. Early-season whole plant samples and ear-leaf samples are collected and analyzed to determine the nutritional status of the crop. Corn stover and grain are harvested with a single-pass combine harvester equipped with an 8-row head.

Table 1. Plant tissue analysis at V6 and anthesis for conventional and intensive (twin-row) management systems in central Iowa in 2008.

Nutrient	V6 (whole plant)		Anthesis (ear leaf)	
	Conventional	Twin-Row	Conventional	Twin-Row
	---------------%	---------------		
N	3.09	2.81	2.53	2.44
P	0.40	0.36	0.33	0.32
K	3.86	3.72	1.86	1.92
Ca	0.44	0.44	0.57	0.55
Mg	0.29	0.31	0.29	0.31
S	0.18	0.16	0.17	0.16

In-season plant nutrition

2008. During the first year of the study, measurements from the various management scenarios were pooled within the conventional and twin-row systems. Analysis of the V6 and ear-leaf samples (Table 1) indicated (1) N levels for both systems were lower than desired at both growth stages (3.5 to 5.0% or 2.75 to 3.25%, respectively), (2) S was approaching the lower level at V6 (0.15 to 0.5%), and (3) K concentrations at anthesis were approaching the lower level (1.75 to 2.25%)--presumably because Ca levels were above the high rating (0.4%). The low N and S levels in the young corn plants suggested that both the fertilizer applied at planting and the soil N and S mineralized in the weeks following planting were not sufficient to support the crop during the early part of the growing season. This may have been due to losses caused by excessive rainfall received during the period.

2009. Management scenario, tillage, and the amount of residue removed from the field with the 2008 harvest did not affect nutrient content of the whole plants at the V6 stage. Levels of all primary and secondary macronutrients were adequate for optimal growth (Table 2). Nitrogen concentrations were well above the published critical value of 3.5 percent, suggesting that preplant

Table 2. N, P, K, Ca, Mg, and S critical values and concentrations in whole plants at the V6 growth stage for 5 management scenarios in 2009. 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	3.82	3.93	3.69	3.79	3.68	3.65
		0.28	0.19	0.23	0.30	0.21	0.23
P	0.30	0.46	0.46	0.46	0.45	0.41	0.40
		0.06	0.06	0.02	0.07	0.06	0.06
K	2.50	4.81	5.18	5.03	4.75	4.15	3.88
		0.61	1.13	0.94	1.11	0.53	0.59
Ca	0.30	0.52	0.51	0.50	0.53	0.47	0.47
		0.05	0.05	0.04	0.04	0.04	0.02
Mg	0.15	0.33	0.33	0.32	0.34	0.32	0.32
		0.06	0.04	0.03	0.04	0.05	0.02
S	0.15	0.22	0.21	0.21	0.21	0.19	0.19
		0.01	0.02	0.02	0.02	0.03	0.01

†4.32 tons biochar/A; ‡8.25 tons biochar/A; §CC = cover crop.

N fertilizer and soil N were sufficient to support the corn crop before additional N was sidedressed six weeks after planting. At mid-silk, no differences in ear-leaf nutrient concentrations were detected among the treatments (Table 3), but concentrations of both N and S were below the critical values. Both P and K concentrations in ear leaves were within the sufficiency ranges of 0.25 to 0.50 percent for P and 1.7 to 3.0 percent for K for all treatments, reflecting our efforts to raise the overall levels of available P and K in the soil. Once again, however, low N and S uptake suggests that the soil supply was not sufficient to meet crop demand at mid-silk. We speculate that cool, wet growing conditions in central Iowa during July and early August may have limited N and S mineralization and availability.

Corn/stover yields

2008. Grain yields for the conventional and twin-row systems averaged 171 and 183 bu/A, respectively. Corn stover was harvested at two heights--just below the ear shank and at a stubble height of approximately 4 inches. The amount of dry stover collected averaged 2.5, 2.8, 2.9, and 3.1 tons/A for the high and low cuts of the conventional and twin-row treatments, respectively. Whole plants collected at physiological maturity were processed to estimate total biomass production and nutrient accumulation. The amount of residue and nutrients returned to the soil was then calculated by subtracting measured amounts in the grain and stover from the estimated totals based on the hand-harvested samples.

2009. Management scenario and tillage did not affect corn grain yields (Table 4). Grain yields, however, were significantly different depending on the amount of residue removed from the field during the 2008 harvest. Plots from which corn stover was not removed yielded less than those from which a moderate or high amount of residue was removed. This result contradicts previous work demonstrating yield decreases when plant residues were removed, presumably because the amount of N fertilizer was insufficient. Fertilizer application rates were based solely on nutrient removals by the 2008 crop. For plots where stover was not removed, fertilizer application rates were lower than where stover was harvested. Although early-season N supply was more than adequate (Table 2), a combination of less total applied N, increased immobilization with residue decomposition, and less mid-season mineralization appear to have negatively affected corn grain yield.

The amount of dry stover harvested was higher for the 90 percent removal (low cut) treatment for both conventional and twin-row scenarios (Table 4). Unlike 2008, the intensively managed (twin-row) plots did not yield more dry stover than the control plots in 2009. Cool, cloudy conditions in central Iowa during the growing season presumably limited the performance of the twin-row treatments. Whole plants collected at physiological maturity and residue samples from the machine harvest are being processed to determine nutrient composition and removal amounts. These values will be used to guide fertilizer recommendations for the 2010 growing season.

After two years of field trials, our research confirms that nutrient management is critical and will differ from grain-only systems if both grain and stover are to be harvested. The use of fluid fertilizers will certainly provide greater flexibility with regard to what is applied and when it is applied.

Sulfur Fertility

Sulfur is an essential nutrient that has been largely ignored, and generally is not recommended for corn production in the upper Midwest. During the past several years, however, positive yield responses to S fertilizer have

Table 3. N, P, K, Ca, Mg, and S critical values and concentrations in ear leaves for five management scenarios in 2009. 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	2.41	2.29	2.42	2.30	2.42	2.45
		0.22	0.18	0.14	0.18	0.12	0.17
P	0.25	0.27	0.27	0.28	0.27	0.27	0.27
		0.03	0.03	0.03	0.03	0.03	0.01
K	1.70	1.96	1.88	2.04	1.92	1.81	1.84
		0.21	0.25	0.22	0.26	0.28	0.27
Ca	0.21	0.53	0.55	0.58	0.50	0.53	0.53
		0.05	0.06	0.04	0.06	0.04	0.06
Mg	0.20	0.29	0.30	0.31	0.30	0.29	0.30
		0.07	0.03	0.04	0.04	0.02	0.03
S	0.21	0.17	0.16	0.17	0.16	0.17	0.16
		0.02	0.02	0.02	0.02	0.01	0.02

†4.32 tons biochar/A; ‡8.25 tons biochar/A; §CC = cover crop.

Table 4. Corn grain and stover yields for five management scenarios in 2009 near Ames, IA. Values are means of 4 replications. Grain yields adjusted to 15.5% moisture.					
Treatment	**Tillage**	**Percent Removal**	**Fertilizer Applied**	**Grain**	**Stover**
			lb / ac	**(bu / ac)**	**(t / ac)**
Control	No-Tillage	0	160+75+60+20	146	0
Control	No-Tillage	50	199+162+147+20	174	2.16
Control	No-Tillage	90	202+177+162+20	195	3.59
Control	Chisel Plow	0	160+75+60+20	146	0
Control	Chisel Plow	50	199+162+147+20	196	1.89
Control	Chisel Plow	90	202+177+162+20	188	3.35
			LSD (0.05)	12	0.84
Twin-Row	No-Tillage	0	167+75+60+30	132	0
Twin-Row	No-Tillage	50	211+162+147+30	188	2.46
Twin-Row	No-Tillage	90	214+177+162+30	176	2.81
Twin-Row	Chisel Plow	0	167+75+60+30	135	0
Twin-Row	Chisel Plow	50	211+162+147+30	193	1.82
Twin-Row	Chisel Plow	90	214+177+162+30	192	3.26
			LSD (0.05)	14	0.42
Biochar 1†	Chisel Plow	0	160+75+60+20	136	0
Biochar 1	Chisel Plow	50	199+162+147+20	195	2.03
Biochar 1	Chisel Plow	90	202+177+162+30	196	2.96
			LSD (0.05)	12	0.80
Biochar 2‡	Chisel Plow	0	160+75+60+20	156	0
Biochar 2	Chisel Plow	50	199+162+147+20	188	2.24
Biochar 2	Chisel Plow	90	202+177+162+20	194	3.23
			LSD (0.05)	8	0.78
Annual CC§	No-Tillage	50	199+162+147+20	181	1.87
Annual CC	No-Tillage	90	202+177+162+20	197	2.99
			LSD (0.05)	NS	0.63
Perennial CC§	No-Tillage	50	199+162+147+20	182	1.74
Perennial CC	No-Tillage	90	202+177+162+20	189	3.20
			LSD (0.05)	10	0.45
†4.32 tons biochar/A; ‡8.25 tons biochar/A; §CC = cover crop.					

been documented. Responsive sites often have coarse-textured soil, with relatively low organic matter content, which indicates that mineralization of organic S plays an important role in the soil supply of S to the crop. In areas where soil erosion is a problem, or crop residues will be removed for conversion to biofuels, organic matter levels in the surface soil may be decreased, thus reducing S mineralization. In these situations, the probability of a yield response to S fertilizer is greater.

Beginning in 2006, S fertility trials targeting Clarion soils found on eroded hill slopes have been conducted. With few exceptions, S availability and organic matter content at our sites were low, while other nutrient levels were adequate for corn production. We compared a granular S-enhanced fertilizer material [SEF (13-33-0-15S)], granular ammonium sulfate [AMS (21-0-0-24S)], and liquid ammonium thiosulfate [ATS (12-0-0-26S)] as S sources for corn in these trials.

Preplant application of S at 30 lbs/A (as SEF) significantly increased plant dry weight at the V5 growth stage each year. Preplant AMS and ATS showed a similar trend. Whole-plant S concentrations at V5 were generally higher in treated plots than in control plots for all S sources. By mid-silk, however, S concentrations were often below the sufficiency range, even when S fertilizer had been applied. This suggests that S fertilizer rates and timing may need to be adjusted.

Grain yield responses were measured in each of the four years of field trials (Figure 1). Applying S at 30 lbs/A increased grain yield by as much as 12 bu/A on these eroded, low organic matter Clarion soils. At this point, no one S source has proven superior, but our results suggest that an S application of 30 lbs/A is beneficial. Because surface soil on hill slopes is (1) often eroded, (2) common fertilizer materials contain less S as an impurity, and (3) atmospheric deposition of S has decreased, S may quickly become a limiting nutrient for corn production in many areas of the upper Midwest.

Dr. Kovar is soil scientist and Dr. Karlen is research leader, USDA-Agricultural Research Service (ARS), Ames IA.

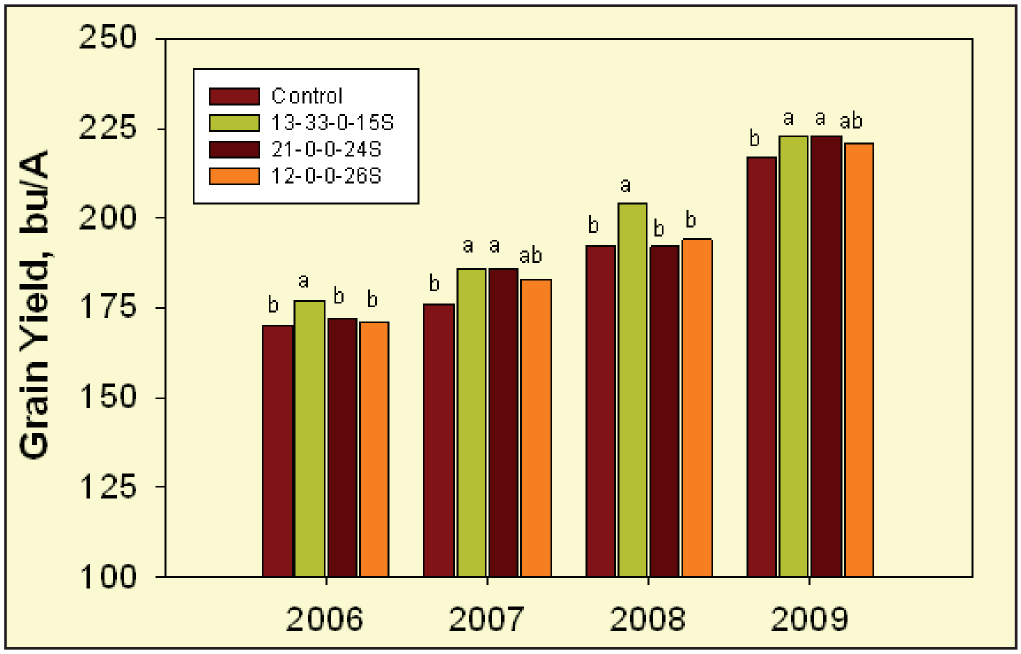

Figure 1. *Effect of S at 30 lbs/A on corn grain yields during four years of field trials with three S fertilizers.Values are means of four replications. Within each year, bars with the same letter are not significantly different.*