Nutrient Management in Biofuel Crop Production

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Objectives:

1. To determine the optimum nutrient management practices for environmentally safe and economically viable biofuel crop production.
2. To evaluate long-term effects of biofuel crop production on selected chemical, physical and microbiological properties of crop land

Procedures:

- Experimental plots established for research on biofuel crops production and management practices at Research and Extension Centers near Columbia and Novelty are used in this study. The experimental design is a 8x3 factorial laid out in a split-plot design with three to four replications.
- The main plots consisted of eight bio-fuel cropping systems as listed below:
    1. Continuous Corn for grain only
    2. Continuous Corn for grain and stover removal
    3. Corn-soybean rotation for grain only
    4. Soybean-corn rotation for grain only
    5. Sweet Sorghum /Wheat double crop
    6. Miscanthus
    7. Switchgrass
    8. Tall Fescue
- The subplots received the following three fertilizer treatments:
    1. University of Missouri Fertilizer and lime recommendations with a 4 year P and K Buildup
    2. Fertilizer recommendations based on annual crop removal values with one year P and K buildup
    3. Control- 0 P, 0K
- The following soil chemical, physical and microbiological measurements collected each year.
    1. Initial Soil fertility measurements (pH, NA, P, K, Ca, Mg, OM, CEC)
    2. Organic C and total N measurements
    3. Wet aggregate stability measurements to determine structural changes
    4. Carbon and Nitrogen mineralization using selected soil enzyme assays
    5. End of season soil fertility measurements
- Plant measurements:
    1. Dry matter production (Treatments 2, 5-8)
    2. Grain yield (Treatments 1-4)
    3. Nutrient uptake (based on dry matter production and grain yield)

Results:

Initial Soil Tests:

The initial soil test results from the Bradford and Greenley sites are provided in Tables 1 and 2. The fertilizer treatments were calculated based on initial soil tests using the University of Missouri fertilizer recommendations and nutrient removal values calculated based on yields and nutrient content of grain, stover and dry matter yields from the previous growing season.

Table 1. Initial soil characteristics at the Bradford site in 2009.

Cropping System	pHs (1:1)	NA meq/100g	Bray P 1 lbs/a	K lbs/a	Ca lbs/a	Mg lbs/a	CEC meq/100g	OM %
Cont Corn Grain	5.9	1.9	24	121	3599	299	12.3	2.4
Cont.Corn Grain + Stover	5.9	1.9	29	144	3742	310	12.7	2.5
Corn/Soybean Rotation	5.8	1.8	27	116	3588	314	12.2	2.5
Miscanthus	6.0	1.8	31	147	4141	348	13.7	2.6
Soybean/Corn Rotation	6.0	1.5	27	140	3992	326	13.0	2.5
Sweet Sorghum	5.8	2.2	31	147	3567	326	12.6	2.5
Switchgrass	5.9	1.9	38	157	3622	315	12.4	2.7
Tall Fescue	6.2	1.3	34	175	4053	336	13.0	2.6

Table 2. Initial soil characteristics at the Greenley site in 2009.

Cropping System	pHs (1:1)	NA meq/100g	Bray P 1 lbs/a	K lbs/a	Ca lbs/a	Mg lbs/a	CEC meq/100g	OM %
Cont. Corn grain	5.8	2.8	23	222	4242	402	15.3	3.3
Cont. Corn Grain + Stover	6.3	1.4	34	231	4622	394	14.9	3.5
Corn/Soybean Rotation	6.0	2.4	24	220	4224	383	14.8	3.0
Miscanthus	5.9	2.4	24	236	4196	412	14.9	2.9
Soybean/Corn Rotation	6.0	2.1	30	203	4342	365	14.7	3.2
Sweet Sorghum	6.0	2.3	24	206	4623	422	15.9	3.0
Switchgrass	6.0	2.3	30	271	4274	434	15.2	3.1
Tall Fescue	6.0	2.2	19	213	4160	394	14.5	3.2

Initial Soil Quality Analysis:

Total organic carbon (TOC) and total nitrogen (TN) contents for each soil sample were determined by dry combustion at 900C using a LECO TruSpec CN analyzer. Statistical analyses performed on TOC, TN, and C:N ratio revealed no significant difference between soils from each cropping system within each bio-fuel production site at the time the experiment was initiated; however, soils at the Greenley site appeared to possess about 14% more TOC than the Bradford site (Table 3). The difference in TOC may reflect past management of crop residues or type of vegetation at the field sites selected for this study. Total N did not vary between sites as widely as TOC. Generally, TOC ranged from 15.6 to 19.55 g C kg^{-1} soil (2.68 – 3.4% soil organic matter [SOM]) with a mean content of 17.5 g C kg^{-1} soil (3.0% SOM) at Bradford and 18.43 to 22.77 g C kg^{-1} soil (3.2 – 3.9% SOM) with a mean content of 19.94 g C kg^{-1} soil (3.4% SOM) at Greenley. The C:N ratios calculated from the TOC and TN values for each cropping system were within a range of 9.8 to 11.9 for both sites, suggesting that SOM quality is adequate to facilitate mineralization of organic N that would be readily available for plant uptake.

A wet-sieving method was used to determine stability of soil aggregates (>250 µm diameter) for each soil sample. The proportion of water-stable aggregates is a reflection of soil structure and is directly related to water infiltration (porosity), aeration, plant root development, C sequestration, and general microbial activity. Soil and crop management practices can greatly affect soil aggregation. For the initial soil sampling, water-stable aggregation appears to be higher for the Bradford site relative to Greenley possible indicating previous management imposed at each site (Table 4). Bradford site was under long-term perennial vegetation (pasture), which contributes to development of soil aggregation; the Greenley site was in a crop-pasture rotation and was subjected to more tillage or cultivation, which destroys aggregation. Soil microbial activity was assessed by measuring two enzyme activities, dehydrogenase, which indicates overall microbial activity based on this involvement of this enzyme in the respiration process, and glucosaminidase, an indicator of N mineralization. Unfortunately, dehydrogenase results for Greenley are not completed for this report due to technical problems but completion of the follow-up analyses is in progress. Dehydrogenase activity for Bradford is within a narrow range, not significantly different among the cropping systems, and reflects a level of activity representative of the Mexico silt loam soil quality noted in previous studies. Glucosaminidase activity also represented an acceptable level for good soil quality for this soil, however, soils at the Bradford site exhibited about a 50% higher activity relative to Greenley. The apparent contrast between sites regarding glucosaminidase activity may reflect differences in soil management and quality of SOM (i.e., types and amounts of N-containing organic substances).

In summary, the organic and biological properties measured suggest the plot locations selected for each site are relatively uniform and changes resulting from response of these properties to bio-fuel crop and imposed management should be detected within the study timeframe. The initial differences between the two sites, primarily in soil C content and glucosamindase activity, may require separate analyses for the sites as the project progresses.

Table 3. Total organic carbon, total nitrogen and C:N of soils in bio-fuel cropping systems at study initiation, spring 2009.

Cropping System	Total organic C (g kg^{-1} soil)	Total N (g kg^{-1} soil)	C:N
	Bradford Farm, Boone County		
Continuous corn – grain	18.88	2.00	9.83
Continuous corn – grain + stover	16.98	1.73	9.77
Corn-Soybean – grain	16.58	1.71	9.81
Soybean-Corn – grain			
Sweet sorghum-Wheat	15.60	1.59	10.11
Miscanthus	17.75	1.61	10.96
Switchgrass	17.93	1.80	10.03
Indiangrass	16.60	1.58	10.52
Big bluestem	19.55	1.83	10.97
	Greenley Research Center, Knox County		
Continuous corn – grain	20.93	1.95	10.77
Continuous corn – grain + stover	22.77	2.02	11.16
Corn-Soybean – grain	19.20	1.72	11.22
Soybean-Corn – grain	18.43	1.70	10.85
Sweet sorghum-Wheat	20.37	1.84	11.07
Miscanthus	18.53	1.69	10.97
Switchgrass	19.53	1.67	11.89
Tall fescue	19.93	1.85	10.82

Table 4. Water-stable aggregation and enzyme activity for soils in bio-fuel cropping systems at study initiation, spring 2009.

Cropping System	Water-stable aggregates (%)	Dehydrogenase[1] (μg TPF g^{-1} soil)	Glucosaminidase[3] (μg PNP g^{-1} soil)
	Bradford Farm, Boone County		
Continuous corn – grain	25.6	326.5	1072.1
Continuous corn – grain + stover	30.3	237.9	1095.4
Corn-Soybean – grain	24.3	268.9	1077.6
Soybean-Corn – grain			
Sweet sorghum-Wheat	26.2	273.0	1119.8
Miscanthus	25.2	217.9	1066.6
Switchgrass	24.3	235.3	974.2
Indiangrass	20.2	231.1	1061.4
Big bluestem	30.6	284.6	1038.9
	Greenley Research Center, Knox County		
Continuous corn – grain	15.3	[2]	660.1
Continuous corn – grain + stover	21.6		729.8
Corn-Soybean – grain	7.2		733.4
Soybean-Corn – grain	11.5		694.6
Sweet sorghum-Wheat	14.9		717.4
Miscanthus	16.0		651.8
Switchgrass	10.2		705.8
Tall fescue	34.6		754.8

[1] Dehydrogenase activity expressed as concentration of product, triphenyl formazam (TPF), formed during enzyme assay.
[2] Results of dehydrogenase assay for Greenley site is incomplete pending completion of validation analyses.
[3] Glucosaminidase activity expressed as concentration of product, *p*-nitrophenol (PNP), formed during enzyme assay.

Grain and Biomass Yield:

The 2009 growing season was characterized by unusually wet and cool conditions which delayed planting, maturity, and harvest. Nitrogen loss was also a major factor and was dependent upon source (anhydrous ammonia at Greenley and urea+agrotain at Bradford) and time of application with dry fertilizer applied no-till resulting in the greatest losses. Overall grain yields at the Greenley Research Center were excellent with corn yields over 200 bushels/acre (Table 5a). However, at Bradford wet conditions resulted in significant nitrogen losses that became evident near tasseling and resulted in much lower grain yield (Table 6a). At both locations corn grain yield responded to P and K application in the continuous corn treatments. Soybean yield was lower with P and K treatments at Greenley. However, these are early treatments and rotation effects which may change over the next few years as P and K soil levels change and soil quality factors are affected.

Biomass yield varied greatly across species and with the exception of Miscanthus. At both locations biomass yields of each species was very similar (Table 5 b and 6 b). Miscanthus yield was much lower at Greenley since this was the first year of establishment. The Miscanthus stand at Bradford is in its second and third year with biomass yields near 8 tons/acre (Table 6b). Although corn grain yield was significantly reduced at Bradford from nitrogen loss stover yield was very similar to Greenley (Tables 5a and 6a) indicating that the nitrogen loss occurred later in the growing season and that dry matter yield is not as sensitive to nitrogen as grain yield. Overall there was little difference in biomass yield in response to P and K application although with some species such as sweet sorghum there tended to be an increase in biomass yield with P and K application. Differences in grain and biomass yield due to P and K application were not expected the first year since initial P and K levels were near optimal. Over time treatment effects may change as P and K levels either buildup or are depleted. The plant and grain nutrient analysis is currently underway at this time (mid December 2009), but when nutrient removal is calculated for each species and treatment a much better understanding of the significance of the P and K treatments as well as the impact of nutrient removal will be realized.

Summary:

Initial soil test and soil quality measurements indicate that the there is little difference between the treatments and only slight differences between locations. Grain and biomass yield was not greatly affected by fertilizer treatment the initial yield. However, nutrient analysis of grain and biomass will indicate if luxury consumption of nutrients is occurring.

Table 5a. Grain yield at the Greenly Research Center near Novelty, Missouri in 2009.

Crop	Fertilizer	Grain Yield	Mean Yield
		bu/acre	bu/acre
Continuous Corn (Grain Only)	0 P and K	163 a*	191 b**
	Buildup	189 a	
	Removal	222 a	
Continuous Corn (Stover removed)	0 P and K	247 a	265 a
	Buildup	281 a	
	Removal	267 a	
Corn/Soybean Rotation	0 P and K	232 a	233 ab
	Buildup	232 a	
	Removal	237 a	
Soybean/Corn Rotation	0 P and K	56 a	48 c
	Buildup	47 ab	
	Removal	40 b	

*Different letters indicate significant differences within fertilizer treatments of each crop at the 0.05 probability level.

**Different letters indicate significant differences between crops at the 0.05 probability level.

Table 5b. Biomass yield at the Greenley Research Center near Novelty, Missouri in 2009.

Crop		Biomass Yield	Mean Yield
		Tons/acre	Tons/acre
Continuous Corn	0 P and K	3.50 a	3.40 b
(Stover removed)	Buildup	3.60 a	
	Removal	3.11 a	
Miscanthus	0 P and K	0.05 a	0.06 c
	Buildup	0.06 a	
	Removal	0.07 a	
Sweet Sorghum	0 P and K	5.66 a	6.34 a
	Buildup	6.46 a	
	Removal	6.90 a	
Switchgrass	0 P and K	4.52 a	3.43 b
	Buildup	2.45 a	
	Removal	3.32 a	
Tall Fescue	0 P and K	3.04 a	3.15 b
	Buildup	3.26 a	
	Removal	3.15 a	

*Different letters indicate significant differences within fertilizer treatments of each crop at the 0.05 probability level.
**Different letters indicate significant differences between crops at the 0.05 probability level.

Table 6a. Grain yield at the Bradford Research and Extension Center near Columbia, Missouri in 2009.

Crop	Fertilizer	Grain Yield	Mean Yield
		bu/acre	bu/acre
Continuous Corn (Grain Only)	0 P and K	90 b*	119 a**
	Buildup	128 a	
	Removal	140 a	
Continuous Corn (Stover removed)	0 P and K	62 a	86 b
	Buildup	101 a	
	Removal	96 a	

*Different letters indicate significant differences within fertilizer treatments of each crop at the 0.05 probability level.
**Different letters indicate significant differences between crops at the 0.05 probability level.

Table 6b. Biomass yield at the Bradford Research Center near Columbia, Missouri in 2009.

Crop		Biomass Yield	Mean
		Tons/acre	Tons/acre
Continuous Corn+Stover	0 P and K	2.93 a	3.28 c
(Stover removed)	Buildup	3.44 a	
	Removal	3.48 a	
Miscanthus	0 P and K	6.98 a	7.81 a
	Buildup	7.51 a	
	Removal	8.94 a	
Sweet Sorghum	0 P and K	4.78 b	5.75 ab
	Buildup	6.79 a	
	Removal	5.68 ab	
Switchgrass	0 P and K	4.52 a	4.31 bc
	Buildup	4.76 a	
	Removal	3.64 a	
Tall Fescue	0 P and K	2.73 a	2.92 c
	Buildup	3.16 a	
	Removal	2.86 a	

*Different letters indicate significant differences within fertilizer treatments of each crop at the 0.05 probability level.

**Different letters indicate significant differences between crops at the 0.05 probability level.