NUTRIENT MANAGEMENT STUDIES IN BIO-FUEL CROPPING SYSTEMS

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Abstract

Research was conducted to determine the effect of nutrient management practices on bio-fuel crop production, and to evaluate long term effects of bio-fuel crop production on selected chemical, physical and microbiological properties. Experimental plots for research on bio-fuel crops production were established in 2008 at two sites in Missouri. The experimental design was an 8x3 factorial laid out in a split plot design. The main plots were eight bio-fuel cropping systems including: 1) continuous corn for grain (CCG), 2) continuous corn for grain and stover removal (CCGS), 3) corn-soybean rotation for grain (CSG), 4) soybean-corn rotation for grain (SCG), 5) sweet sorghum-wheat double crop (SSW), 6) miscanthus (MIS), 7) switch grass (SWI) and 8) tall fescue (TF). Subplots received the following fertilizer treatments: 1) University of Missouri recommended P and K with a 4 year buildup; 2) fertilizer recommendations based on annual crop removal values; and 3) control without P and K. Soil samples were collected for soil fertility analysis (pH, P, K, Ca, Mg, OM and CEC), total organic C (TOC) and total N (TN), wet aggregate stability (WSA), and potential C and N mineralization by measuring dehydrogenase (DEHYD) and glucosaminidase (GLUCO) enzyme activities using in vitro assays. Grain yield, dry matter production and nutrient uptake were measured. This presentation reports preliminary results of the grain and biomass yields, nutrient uptake, soil fertility analysis and soil quality. In continuous corn cropping system P and K applications based upon maintenance and buildup had the highest grain yield; however, stover yield was greatest when P and K application was based upon removal. Luxury P and K consumption and removal were found in tall fescue and sweet sorghum. In the first two years of this study, it is apparent that in order to maximize dry matter and grain yield in a monoculture system P and K levels will need to be closely monitored. A trend for improved soil quality based on WSA and enzyme activity analyses is becoming evident in perennial crops. Enzyme activities increased, suggesting their high sensitivity for detecting rapid changes in soil quality due to changes in management. Few changes in TOC, TN, and C: N are evident at this early stage; however, we expect differences to evolve due to management as this long-term field study progresses.

Introduction

Concern over higher energy prices as well as environmental issues such as global warming has increased interest and use of alternative energy sources such as ethanol and biodiesel. The federal government has issued tax incentives for the production of ethanol and has set goals of future renewable energy use. The largest source of ethanol has been derived from corn grain and use has increased rapidly in the past decade with 7.5 billion gallons of ethanol produced using approximately 20% of the US corn crop in 2007. This trend will continue since more ethanol plants are coming on line and the federal government set a target in 2005 of 7.5 billion gallons of ethanol blended by 2012 and in 2007 increased that target to 35 billion gallons by 2017. Other federal programs have set goals as high as 30% of the gasoline demand to be derived from cellulosic materials by 2025 (45 billion gallons). To meet this and other goals, sources other than corn grain must be used since the entire US corn crop can only produce 35 billion gallons of ethanol. Most analysts put the cap on ethanol derived from corn grain at approximately 14 billion gallons leaving over 30 billion gallons coming from cellulosic sources. The conversion of corn stover as well as forage and biomass crops such as switchgrass and miscanthus into ethanol is necessary to meet this demand.

To meet the demands for bio-fuel production, farming practices will change from an annual rotation of corn and soybean to continuous corn production for both grain and stover. The entire above ground biomass production of annual and perennial crops will also need to be harvested and removed for cellulosic ethanol production. Removal of the entire above ground biomass can result in changes in many soil properties through the loss of organic matter and degradation in the quality of soil structure resulting in a loss of water exchange, aeration, and biological activity. Cellulosic ethanol production from perennial crops such as switchgrass and miscanthus may be a better choice than from annual crops such as corn and sorghum since their root systems are more extensive, may not result in a loss of soil organic matter, and provide more consistent soil biological activity critical for nutrient cycling.

Current Missouri fertilizer recommendations do not reflect removal of the entire biomass and will need to be adjusted to meet the demands from these practices. Simple calculations of the removal of 2/3's of the corn stover per acre is equal to removal of 10 lb P_20_5/acre and 80 lb K_20/acre with a cost of nearly $50/acre. Utilizing switchgrass as a bio-fuel has the potential to take off as much as 45 lb P_2O_5/acre and 230 lb K_2O/acre when dry matter yields are 5 tons/acre/. These numbers are only estimates and do not reflect data collected in Missouri in replicated trials. We also do not know if luxury consumption by plants due to a buildup of soil P and K levels within one year will result in a larger than expected removal of soil nutrients. For Missouri producers to be competitive with new market opportunities using bio-fuels, they will need to know how to manage soil fertility inputs and crop selection.

Therefore this study on bio-fuel nutrient management was established with the goal to determine the optimum P and K nutrient management practices for environmentally safe and economically viable bio-fuel crop production, and to evaluate the long-term effects of bio-fuel crop production on selected chemical, physical and microbiological properties of crop land. A preliminary report on bio-fuel nutrient management studies is presented in this report.

Procedures

Experimental plots for research on bio-fuel crops production were established in 2008 at the Bradford and Greenley Research and Extension Centers. The experimental design was an 8x3 factorial laid out in a split plot design. The main plots were eight bio-fuel cropping systems: 1)continuous corn for grain (CCG), 2) continuous corn for grain and stover removal (CCGS), 3) corn-soybean rotation for grain (CSG), 4)soybean-corn rotation for grain (SCG), 5) sweet sorghum-wheat double crop (SSW), 6) miscanthus (MIS), 7) switch grass (SWI) and 8) tall fescue (TF). Subplots received the fertilizer treatments: 1) MU recommended P and K with a 4 year buildup 2) fertilizer recommendations based on annual crop removal values and 3) control without P and K.

Dry matter production and grain yields were obtained each year based on the cropping systems and grain and biomass samples were analyzed for N, P, and K to estimated nutrient uptake and removal. (Dry matter production on treatments 2, 5-8; and grain yields on Treatments 1-4). Nutrient uptake was calculated for all bio-fuel cropping systems.

Soil samples were collected each year in spring and fall for soil chemical, physical and microbiological measurements. Soil samples were analyzed for soil fertility status (pHs, P, K, Ca, Mg, neutralizable acidity, organic matter and cation exchange capacity) using University of Missouri recommended soil test procedures. Soil quality measurements were made for: organic C and total N; wet aggregate stability to determine structural changes; and carbon and nitrogen mineralization using selected soil enzyme assays. The total organic carbon (TOC) and total N (TN) by dry combustion, and C: N ratios were calculated. A wet sieving method was used to determine stability of aggregates (WSA; >250 um diameter). Soil microbial activity was assessed by measuring dehydrogenase (DEHYD) and glucosaminidase (GLUCO) enzyme activities using in vitro assays.

Fertilizer Treatments for 2010 were determined by spring 2010 soil test measurements for University of Missouri Soil Test Recommendation P and K treatments (Tables 1 and 2) or based upon removal from 2009 grain, stover, and dry matter yield (Tables 3 and 4). Each rep of each treatment was measured individually and fertilizer treatments were applied based upon those individual measurements. A summary of the mean fertilizer amounts applied across all replications at Bradford and Greenley are listed in Table 5. Generally, P and K fertilizer rates were greater when based upon MU recommended rates (maintenance and buildup) rather than based on removal with the exceptions of tall fescue and sweet sorghum. (Note: P and K treatments based on removal for tall fescue at Greenley were much higher than at Bradford. This is due to two harvest of tall fescue during the 2009 growing season at Greenley and only one harvest at Bradford).

Statistical analysis was performed on grain and biomass yields, TOC, TN, C: N, DEHYD, and GLUCO using SAS analysis.

Results and Discussions

Nutrient Uptake

In 2009, there was limited luxury uptake of P and K in corn or soybean regardless of fertilizer treatments. (Table 1 and 2). Although removal of P and K was greater in some treatments, the total uptake was based on higher yield response to P and K treatments. There was luxury uptake of P and K in tall fescue and sweet sorghum plots because these two cropping systems were harvested at the vegetative stage, they did not have an opportunity to remobilize nutrients out of the leaves and stems into the roots as in the perennial crops. It was surprising to note that the corn stover did not remove more P and K as reported by other researchers. Apparently some P and K had been leached into the soil after harvest.

Grain and Biomass Yield

Continuous corn yield responded to P and K fertilizer treatments at both locations especially when stover was removed (Table 6). However, there was no response to P and K fertilizer applications when corn was rotated with soybean. This lack of response may indicate soybean cropping system was over fertilized although there was only a slight increase in soybean yield with the P and K treatments. At both locations with the continuous corn treatment (grain only), there was a yield advantage of applying MU recommended maintenance + buildup P and K rather than based upon removal. However, when stover was removed, the greatest yield response occurred when P and K treatment was based upon removal. This indicated that when continuous corn was grown that P and K uptake and corn yields were dependent upon P and K availability from the previous year's corn stover. Corn responded differently to P and K fertilizer application in the soybean/corn rotation in 2010 at Bradford and Greenley which may have been related to poor soybean yields at Bradford in 2009 where little P and K was removed.

Corn stover yield response was similar to that of grain with a response to increasing P and K applications (Table 7). Biomass response to P and K treatment was different at each location which was partially due to the age and variety of the crop. The Miscanthus plots at Bradford are one year older than Greenley which at this stage makes a tremendous difference in dry matter yield. However, it seems that highest Miscanthus yield was not related to P and K fertilization. Switchgrass yield was much higher, 2 tons/acre, at Greenley than Bradford and responded to P and K fertilization although it did not make a difference whether it was maintenance and build up or removal. The higher yield at Greenley may have been a result of the difference in variety Blackwell at Greenley and Cave in Rock at Bradford. In general, there was not a response to P and K applications for tall fescue or sweet sorghum-wheat cropping systems.

Soil Quality Analysis

The TOC, TN and C: N ratio measured at initial sampling (spring) date was not significantly different for different cropping systems at both sites (Table 8). The same trend was observed at the end of the growing season (fall) samples at Bradford. However, there were significant differences in the TOC and C: N ratios at Greenley in fall samples at the end of the growing season (Table 8). The continuous corn grain and stover, soybean-corn rotation, sweet sorghum wheat double crop and miscanthus cropping systems had significantly higher levels of TOC than switch grass (Table 8). In general soils at the Greenley site appeared to have about 14% more TOC than at the Bradford site. At both sites, there is drop in TOC from spring to fall in most of the bio-fuel cropping systems.

During the initial sampling time (spring), WSA seemed to be higher at Bradford (Avg. 26.1%) than at Greenley site (Avg. 18.9%). Even though there were no significant differences amongst cropping systems at Bradford site, there were significant differences amongst cropping systems at Greenley (Table 9). The tall fescue, continuous corn for grain and stover and miscanthus plots had significantly higher WSA than continuous corn grain only, soybean-corn rotation, sweet sorghum-wheat and switchgrass plots. At the end of growing season (fall) there were significant differences between cropping systems in WSA at both sites and the values were higher in fall than spring (Avg. Bradford 31%, Greenley 31.2%). At Bradford, the WSA was highest at the tall fescue plots (34.4%) was lowest at the corn-soybean rotation (26.1%). At Greenley, WSA was highest at the miscanthus plots and lowest at corn-soybean rotation and soybean-corn rotation plots. DEHYD and GLUCO decreased from spring to fall at both sites suggesting possible seasonal effects (Table 9). More importantly, high enzyme activities in fall 2009 were generally associated with perennial crops (sweet sorghum -wheat, miscanthus, tall fescue) which was likely due to persistent viable roots facilitating continuous soil biological activity. Associated increases in WSA support the overall benefit of the perennial crops to increase soil quality compared with most of the annual cropping systems in this study.

Summary

Continuous corn grain only treatments responded to P and K applications at MU recommended rates (maintenance and buildup) whereas, grain and stover removed treatments responded best when fertilized based upon removal. In 2009, there was luxury consumption and removal of P and K with sweet sorghum and tall fescue due to these crops being harvested at the vegetative stages. It will be interesting to see how if this was repeated in 2010 with a different yield environment. Biomass response to P and K application is somewhat variable and depends on total yield. In the first two years of this study, it is apparent that in order to maximize dry matter and grain yield in a monoculture system P and K levels will need to be closely monitored.

The initial trend for improved soil quality based on WSA and enzyme activity analyses is becoming evident in perennial crops. Increases in enzyme activities agree with previous reports, suggesting their highly sensitive ability to detect rapid changes in soil quality due to changes in management. Few changes in TOC, TN, and C: N are evident at this early stage; however, we expect differences to evolve due to management as this long-term field study progresses.

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Table 1. Grain and biomass nutrient concentration, and nutrient removal based on 2009 harvest grain, stover, and biomass at Greenley.

Cropping Systems	Fertilizer	N	P	K	P_2O_5	K_2O
		%	%	%	lb/acre	lb/acre
Continuous Corn (Grain only)	0 P and K	1.460	0.271	0.275	53.7	29.1
	MU Recommend	1.456	0.299	0.308	71.2	39.2
	Removal	1.385	0.301	0.306	83.8	45.2
Continuous Corn (Stover removed)	0 P and K	1.362	0.315	0.304	117.2	103.8
	MU Recommend	1.392	0.308	0.305	132.9	123.3
	Removal	1.514	0.325	0.307	128.4	107.0
Corn/Soybean Rotation	0 P and K	1.535	0.272	0.266	81.1	41.5
	MU Recommend	1.521	0.293	0.288	86.5	44.5
	Removal	1.507	0.300	0.288	91.3	45.6
Miscanthus	0 P and K	0.616	0.146	0.241	0.3	0.3
	MU Recommend	0.659	0.160	0.325	0.3	0.4
	Removal	0.549	0.120	0.259	0.4	0.4
Soybean/Corn Rotation	0 P and K	5.361	0.594	1.701	46.0	69.2
	MU Recommend	5.346	0.614	1.716	39.5	57.8
	Removal	5.346	0.630	1.754	35.4	51.4
Sweet Sorghum	0 P and K	1.182	0.236	0.876	61.4	119.0
	MU Recommend	1.275	0.243	0.963	72.1	148.6
	Removal	1.197	0.241	1.162	76.5	196.3
Switchgrass	0 P and K	0.792	0.136	0.400	27.9	41.5
	MU Recommend	0.818	0.124	0.356	13.7	20.4
	Removal	0.693	0.142	0.428	20.7	35.5
Tall Fescue	0 P and K	1.537	0.263	1.854	34.5	107.5
	MU Recommend	1.458	0.279	1.940	40.3	130.9
	Removal	1.851	0.333	2.209	44.2	139.3

Means	N	P	K	P_2O_5	K_2O
	%	%	%	lb/acre	lb/acre
Continuous Corn (Grain only)	1.434	0.290	0.296	69.5	37.8
Continuous Corn (Stover removed)	1.422	0.316	0.306	126.2	111.3
Corn/Soybean Rotation	1.521	0.288	0.280	86.3	43.9
Miscanthus	0.608	0.142	0.275	0.4	0.4
Soybean/Corn Rotation	5.351	0.613	1.724	40.3	59.5
Sweet Sorghum	1.218	0.240	1.000	70.0	154.6
Switchgrass	0.768	0.134	0.395	20.8	32.5
Tall Fescue	1.615	0.292	2.001	39.7	125.9

Table 2. Grain and biomass nutrient concentration, and nutrient removal based on 2009 grain, stover, and dry matter yield at Bradford.

Cropping Systems	Fertilizer	N	P	K	P_2O_5	K_2O
		%	%	%	lb/acre	lb/acre
Continuous Corn (Grain only)	0 P and K	1.329	0.303	0.314	34.7	18.9
	MU Recommend	1.275	0.311	0.320	51.3	27.5
	Removal	1.445	0.296	0.315	53.3	29.6
Continuous Corn (Grain + stover)	0 P and K	1.328	0.321	0.341	60.0	57.6
	MU Recommend	1.363	0.327	0.308	72.9	72.4
	Removal	1.421	0.338	0.292	74.8	72.2
Corn/Soybean Rotation	0 P and K	1.520	0.337	0.288	30.2	13.6
	MU Recommend	1.488	0.327	0.282	44.0	19.9
	Removal	1.552	0.338	0.294	45.5	20.7
Miscanthus	0 P and K	0.366	0.097	0.345	30.0	56.6
	MU Recommend	0.343	0.100	0.304	27.8	44.3
	Removal	0.387	0.097	0.393	34.5	73.7
Soybean/Corn Rotation	0 P and K	6.858	0.640	1.231	26.4	26.6
	MU Recommend	6.636	0.636	1.210	26.2	26.2
	Removal	6.764	0.637	1.468	26.3	31.8
Sweet Sorghum	0 P and K	0.635	0.193	0.692	41.8	80.8
	MU Recommend	0.724	0.208	0.854	64.9	137.4
	Removal	0.623	0.209	0.866	52.6	124.5
Switchgrass	0 P and K	0.213	0.131	0.281	27.3	30.4
	MU Recommend	0.207	0.126	0.267	26.5	29.9
	Removal	0.216	0.154	0.371	24.8	32.9
Tall Fescue	0 P and K	1.444	0.285	1.439	35.6	94.8
	MU Recommend	1.674	0.285	1.740	42.6	138.2
	Removal	1.461	0.294	1.636	38.8	114.9

Means	N	P	K	P_2O_5	K_2O
	%	%	%	lb/acre	lb/acre
Continuous Corn (Grain only)	1.350	0.303	0.316	46.4	25.3
Continuous Corn (Grain + stover)	1.370	0.329	0.313	69.2	67.4
Corn/Soybean Rotation	1.520	0.334	0.288	39.9	18.1
Miscanthus	0.365	0.098	0.347	30.8	58.2
Soybean/Corn Rotation	6.752	0.637	1.303	26.3	28.2
Sweet Sorghum	0.661	0.203	0.804	53.1	114.2
Switchgrass	0.212	0.137	0.306	26.2	31.1
Tall Fescue	1.527	0.288	1.605	39.0	115.9

Table 3. Soil test characteristics at Bradford in Spring, 2010.

Cropping Systems	Fertilizer	pHs	P	K	OM	CEC
			lb/acre	lb/acre	%	
Continuous Corn (Grain only)	0 P and K	6.0	26	146	2.70	13.2
	MU Recommend	5.9	36	153	2.60	13.2
	Removal	5.8	39	201	2.83	12.8
Continuous Corn (Grain + stover)	0 P and K	6.1	30	148	2.88	13.1
	MU Recommend	5.9	32	161	2.95	12.7
	Removal	5.9	44	197	2.88	12.6
Corn/Soybean Rotation	0 P and K	5.9	22	152	2.88	13.7
	MU Recommend	5.8	35	187	2.93	13.9
	Removal	5.8	37	228	2.98	13.7
Miscanthus	0 P and K	6.0	29	148	3.00	12.9
	MU Recommend	5.8	35	184	3.00	12.5
	Removal	5.9	35	193	3.00	13.3
Soybean/Corn Rotation	0 P and K	5.8	24	133	2.70	12.5
	MU Recommend	5.7	36	189	2.80	12.9
	Removal	5.8	41	181	2.70	12.2
Sweet Sorghum	0 P and K	5.9	30	159	3.00	12.6
	MU Recommend	5.8	41	174	3.00	12.8
	Removal	5.9	42	192	2.98	13.1
Switchgrass	0 P and K	5.8	32	149	2.98	13.3
	MU Recommend	5.9	29	173	2.88	13.3
	Removal	5.9	29	177	2.95	13.4
Tall Fescue	0 P and K	6.0	31	186	2.88	13.0
	MU Recommend	5.9	30	211	2.90	13.5
	Removal	6.0	37	236	2.88	13.1

Means	pHs	P	K	OM	CEC
		lb/acre	lb/acre	%	
Continuous Corn (Grain only)	5.9	34	167	2.71	13.0
Continuous Corn (Grain + stover)	5.9	35	169	2.90	12.8
Corn/Soybean Rotation	5.8	31	189	2.93	13.8
Miscanthus	5.9	33	175	3.00	12.9
Soybean/Corn Rotation	5.8	34	167	2.73	12.5
Sweet Sorghum	5.9	38	175	2.99	12.8
Switchgrass	5.9	30	166	2.93	13.3
Tall Fescue	5.9	33	211	2.88	13.1

Table 4. Soil test characteristics at Greenley in spring, 2010.

Cropping Systems	Fertilizer	pHs	P	K	OM	CEC
			lb/acre	lb/acre	%	
Continuous Corn (Grain only)	0 P and K	5.9	25	170	3.13	15.5
	MU Recommend	5.8	26	154	3.07	15.4
	Removal	6.0	30	188	2.97	15.2
Continuous Corn (Grain + stover))	0 P and K	6.2	31	165	3.33	16.2
	MU Recommend	6.2	40	173	3.20	15.7
	Removal	6.3	37	215	3.07	16.3
Corn/Soybean Rotation	0 P and K	5.9	23	157	3.03	15.4
	MU Recommend	5.9	23	164	2.97	15.0
	Removal	6.1	33	159	2.80	14.7
Miscanthus	0 P and K	5.9	21	191	2.83	14.7
	MU Recommend	5.8	24	181	2.80	14.1
	Removal	6.2	25	192	2.80	14.7
Soybean/Corn Rotation	0 P and K	6.0	23	167	2.80	13.4
	MU Recommend	5.9	27	153	3.20	14.3
	Removal	6.2	32	163	2.97	13.8
Sweet Sorghum	0 P and K	5.7	29	142	3.03	15.1
	MU Recommend	5.8	32	129	3.03	14.8
	Removal	6.1	39	166	3.00	15.0
Switchgrass	0 P and K	6.2	34	205	2.87	15.3
	MU Recommend	6.0	29	215	3.00	15.6
	Removal	6.0	33	222	2.87	15.2
Tall Fescue	0 P and K	5.9	17	150	3.33	15.0
	MU Recommend	5.9	25	144	3.10	14.5
	Removal	6.1	36	158	3.07	15.1

Means	pHs	P	K	OM	CEC
		lb/acre	lb/acre	%	
Continuous Corn (Grain only)	5.9	27	171	3.06	15.4
Continuous Corn (Grain + stover)	6.2	36	184	3.20	16.1
Corn/Soybean Rotation	6.0	26	160	2.93	15.0
Miscanthus	6.0	24	188	2.81	14.5
Soybean/Corn Rotation	6.0	27	161	2.99	13.8
Sweet Sorghum	5.9	33	146	3.02	15.0
Switchgrass	6.1	32	214	2.91	15.4
Tall Fescue	6.0	26	151	3.17	14.9

Table 5. Average fertility treatments based on soil test recommendations and crop removal at Bradford and Greenley in spring , 2010.

Cropping Systems	Fertilizer	N lb/acre	P_2O_5 lb/acre	K_2O lb/acre	N lb/acre	P_2O_5 lb/acre	K_2O lb/acre
		---------	Bradford	---------	--------	Greenley	-------
Continuous Corn (Grain only)	0 P and K	240	0	0	220	0	0
	MU Recommend	240	108	146	220	135	152
	Removal	240	58	40	220	87	47
Continuous Corn (Grain + stover)	0 P and K	240	0	0	220	0	0
	MU Recommend	240	119	140	220	98	138
	Removal	240	58	40	220	130	110
Soybean/Corn Rotation	0 P and K	0	0	0	0	0	0
	MU Recommend	0	85	153	0	100	170
	Removal	0	50	40	0	92	48
Miscanthus	0 P and K	60	0	0	60	0	0
	MU Recommend	60	20	142	60	33	117
	Removal	60	45	84	60	20	20
Corn/Soybean Rotation	0 P and K	240	0	0	220	0	0
	MU Recommend	240	111	123	220	132	150
	Removal	240	40	40	220	37	53
Sweet Sorghum	0 P and K	120	0	0	120	0	0
	MU Recommend	120	56	98	120	123	163
	Removal	120	58	130	120	80	198
Switchgrass	0 P and K	60	0	0	60	0	0
	MU Recommend	60	25	109	60	20	87
	Removal	60	28	35	60	25	40
Tall Fescue	0 P and K	120	0	0	120	0	0
	MU Recommend	120	54	128	120	73	170
	Removal	120	45	122	120	80	285

Table 6: Grain yields at Bradford and Greenley sites, 2010.

Cropping Systems	Fertilizer Treatments	Yield bu/ac	Means bu/ac	Yield bu/ac	Means bu/ac
		Bradford		Greenley	
Continuous Corn (Grain only)	0 P and K	84b	107a	85a	97b
	MU Recommend	124a		112a	
	Removal	113ab		93a	
Continuous Corn (Grain+stover)	0 P and K	99a	111a	83b	117ab
	MU Recommend	112a		125ab	
	Removal	121a		142a	
Soybean 2009/Corn 2010 Rotation	0 P and K	132a	121a	145a	149a
	MU Recommend	116a		142a	
	Removal	115a		161a	
Corn 2009/Soybean 2010 Rotation	0 P and K	61	64	68	70
	MU Recommend	64		70	
	Removal	67		72	

Different letters indicate significant differences (*P* = 0.05) within a column.

Table 7: Biomass yields at Bradford and Greenley sites, 2010.

Cropping Systems	Fertilizer Treatments	Biomass tons/ac	Means tons/ac	Biomass tons/ac	Means tons/ac
		Bradford		Greenley	
Continuous Corn (Grain +stover)	0 P and K	2.90a	3.35c	3.03a	2.94c
	MU Recommend	4.03a		2.24a	
	Removal	3.00a		3.56a	
Miscanthus	0 P and K	8.29ab	3.97a	1.67a	2.65c
	MU Recommend	6.62b		4.08a	
	Removal	9.00a		2.21a	
Sweet sorghum-wheat	0 P and K	2.08a	1.83d	5.02a	5.02b
	MU Recommend	1.69a		4.64a	
	Removal	1.72a		5.40a	
Switchgrass	0 P and K	3.84a	3.60c	5.65a	6.98a
	MU Recommend	3.48a		7.52a	
	Removal	3.49a		7.76a	
Tall Fescue	0 P and K	6.45a	6.80b	5.91a	5.95ab
	MU Recommend	7.17a		6.06a	
	Removal	6.79a		5.88a	

Table 8: Total organic carbon, total N and C: N ratios for soils for Bradford and Greenley sites in different bio-fuel cropping systems, spring and fall, 2009.

Cropping Systems	TOC g kg^{-1}Soil	TN g kg^{-1}Soil	C:N	TOC g kg^{-1}Soil	TN g kg^{-1}Soil	C:N
			Bradford			
		Spring			Fall	
Continuous Corn (Grain only)	18.9a	2.00a	9.83a	16.3a	1.64a	9.94ab
Continuous Corn (Grain +stover)	17.0a	1.73a	9.77a	17.2a	1.70a	10.15ab
Corn/Soybean Rotation	16.6a	1.71a	9.81a	16.8a	1.74a	9.70b
Miscanthus				16.5a	1.62a	10.22ab
Soybean/Corn Rotation	15.6a	1.59a	10.11a	16.6a	1.61a	10.35a
Sweet Sorghum	17.8a	1.61a	10.96a	16.8a	1.63a	10.31a
Switchgrass	17.9a	1.80a	10.03a	16.0a	1.61a	9.93ab
Tall Fescue				16.6a	1.69a	9.81ab
Pr>F	*0.602*	*0.629*	*0.635*	*0.923*	*0.645*	*0.187*
			Greenley			
		Spring			Fall	
Continuous Corn (Grain only)	20.9ab	1.95ab	10.77a	17.6bc	1.79ab	9.83ab
Continuous Corn (Grain+Stover)	22.6a	2.02a	11.16a	19.4a	1.89ab	10.30a
Corn/Soybean Rotation	19.2b	1.72ab	11.22a	17.7abc	1.91a	9.26b
Miscanthus	18.4b	1.70b	10.85a	18.0ab	1.89ab	9.55b
Soybean/Corn Rotation	20.4ab	1.84ab	11.07a	18.7ab	1.93a	9.65b
Sweet Sorghum	18.5b	1.69b	10.97a	18ab	1.83ab	9.82ab
Switchgrass	19.5b	1.67b	11.89a	16.1c	1.72b	9.34b
Tall Fescue	19.9ab	1.85ab	10.82a	18.4ab	1.9ab	9.73b
Pr>F	*0.114*	*0.212*	*0.769*	*0.033*	*0.248*	*0.027*

1) continuous corn for grain (CCG), 2) continuous corn for grain and stover removal (CCGS), 3) corn-soybean rotation for grain (CSG), 4) soybean-corn rotation for grain (SCG), 5) sweet sorghum-wheat double crop (SSW), 6) miscanthus (MIS), 7) switch grass (SWI) and 8) tall fescue (TF).

Table 9: Water-stable aggregates (WSA) and enzyme activity for soils for Bradford and Greenley sites in different bio-fuel cropping systems, spring and fall, 2009.

Cropping Systems	WSA %	DEHYD µg TPF g^{-1} soi	GLUCO µg PNP g^{-1} soil	WSA %	DEHYD µg TPF g^{-1} soi	GLUCO µg PNP g^{-1} soil
			Bradford			
		Spring			Fall	
Continuous Corn (Grain only)	26.5a	276.5a	1072.1a	30.8ab	185.9bcd	928.0bc
Continuous Corn (Grain+Stover)	30.3a	237.9a	1095.4a	31.2ab	157.2d	868.8c
Corn/Soybean Rotation	24.3a	243.9a	1077.6a	26.1c	157.9d	969.1ab
Miscanthus				30.6ab	192.5abc	991.8ab
Soybean/Corn Rotation	26.2a	248.0a	1119.9a	32.9ab	198.2ab	987.2ab
Sweet Sorghum	25.2a	217.9a	1066.6a	32.7ab	223.1a	1047.5a
Switchgrass	24.3a	235.3a	974.3a	29.3bc	175.7bcd	995.0ab
Tall Fescue				34.4a	166.5cd	1037.5a
Pr>F	*0.710*	*0.691*	*0.437*	*0.014*	*0.001*	*0.003*
			Greenley			
		Spring			Fall	
Continuous Corn (Grain only)	20.7bc	225.3ab	660.0a	29.5c	156.5d	573.5ab
Continuous Corn (Grain+Stover)	25.0ab	174.2c	729.8a	32.3bc	175.7d	481.9dc
Corn/Soybean Rotation	10.5c	175.7c	733.4a	23.9d	189.7cd	517.9bc
Miscanthus	12.9bc	136.2d	694.7a	19.9d	167.5d	438.1dc
Soybean/Corn Rotation	18.3bc	205.8bc	717.4a	36.3ab	245.1b	547.9ab
Sweet Sorghum	22.6abc	184.9c	651.8a	38.7a	288.6a	599.4a
Switchgrass	13.5bc	184.2c	705.8a	32.5bc	218.4bc	595.5a
Tall Fescue	34.6a	249.0a	754.8a	36.3ab	320.4a	485.4dc
Pr>F	*0.026*	*0.001*	*0.514*	*0.001*	*0.001*	*0.001*

Dehydrogenase (DEHYD) activity expressed as concentration of product, triphenyl formazam (TPF), formed during enzyme assay.
Glucosaminidase (GLUCO) activity expressed as concentration of product, *p*-nitrophenol (PNP), formed during enzyme assay.

PROCEEDINGS OF THE

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NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 27

November 16-17, 2011
Holiday Inn Airport
Des Moines, IA

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Published by:
International Plant Nutrition Institute
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Brookings, SD 57006
(605) 692-6280
Web page: www.IPNI.net