Utilizing Ash as a Nutrient Source for Corn

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Introduction

Land application of industrial materials and by-products has been common for decades. Recent expansion of the biofuel industry has resulted in significantly large quantities of these by-products, like dried distillers' grains (DDG) and solubles. Utilizing these by-products is critical to the future success, profitability, and sustainability of the biofuel industry.

Three biofuel, ash by-product sources were used in this study. A "co-fire" ash was obtained from Fibrominn, a power plant in Benson, Minnesota. This plant burns turkey manure as fuel to generate electricity and the resultant ash is land applied as a fertilizer source for crop production. A second ash from a fluidized bed reactor was obtained from Corn Plus an ethanol plant in Winnebago, Minnesota. This ash comes from burning distiller solubles, which are used to generate heat for the plant. Both of these ash materials were in their "raw" or unprocessed form. The third source was a biochar ash from Chippewa Valley Ethanol Company, an ethanol plant in Benson, Minnesota. They use pyrolysis, a form of incineration that chemically decomposes organic material by heat and pressure in the absence of oxygen, to gasify wood chips and corn cobs (1). The by-products of this gasification process are syngas (similar to natural gas and is used as fuel for the plant) and biochar.

Biochar is a fine-grained charcoal high in organic carbon and largely resistant to decomposition. As a soil amendment biochar has potential agronomic and environmental benefits. From an agronomic perspective, it has been shown to reduce soil acidity and be a fertilizer (2). Environmentally, it may help combat global climate change by being a stable carbon sink (3) and by reducing emissions of nitrous oxides on some highly weathered soils (4).

The objectives of this study were: (i) to determine the availability of phosphorus (P) and potassium (K) contained in ash from the biofuels industry in Minnesota, by measuring their effects on corn growth, corn grain yield, nutrient concentrations in small corn plants and corn grain; and (ii) to measure changes in soil test parameters before and after ash application (preplant and post harvest).

Materials and Methods

An experiment was conducted at the University of Minnesota Southern Research and Outreach Center in 2008 to evaluate the performance of three forms of ash as fertilizer sources for corn. The research site had been managed with minimal commercial inputs for the last several years and was cropped to alfalfa from 2005 through 2007. Nine treatments were replicated four times in a randomized complete-block design on a pattern, tile-drained (75-foot spacing) Webster clay loam soil. Each plot measured 15 ft. wide (six, 30-inch rows) by 25 ft. long.

Treatments consisted of two ash sources [turkey manure (co-fire) and distillers solubles (fluidized bed)] compared with triple super phosphate (TSP) fertilizer at rates of 80 and 240 lb P_2O_5/A, one ash source (char ash) compared with potash fertilizer at 120 lb K_2O/A, and an unfertilized control. Ash application rates were based on the total nutrient analyses presented in Table 1. Ash rates were 590, 1770, 455, 1365, and 11620 lb/A of CF (80 lb P_2O_5/A), CF (240), FB (80), FB (240) and char ash (120 lb K_2O/A), respectively. All treatments were broadcast-applied by hand on May 5, 2008 and incorporated with a disk. The plots were field cultivated on May 9, just prior to planting corn (Pioneer brand 35F44) at 32,000 seeds/A. Pre-emergence herbicides (Harness at 1.5 pt/A, Callisto at 5 oz/A, and Roundup WeatherMax at 12 oz./A) were applied with 10 gal/A of UAN as a carrier on May 14. Significant grassy weed pressure required applications of Roundup WeatherMax (24 oz/A) with AMS on May 28 and again on June 14. Supplemental N (30 lb/A as UAN) was injected on all plots on June 23. No other fertilizer N was applied as the previous crop was alfalfa.

In 2009, the residual effects of ash and fertilizer treatments applied in spring of 2008 were examined. Gypsum was broadcast-applied at 88 lb/A (15 lb S/A) on April 8. Urea was broadcast-applied at 160 lb

N/A and followed by field cultivation on April 15. Because of heavy corn residue the research plot was disked prior to planting corn (DeKalb 57-43) at 33,000 seeds/A with row cleaners on April 17. Weeds were controlled with a pre-emergence broadcast application of Harness (2.5 pt/A) and Callisto (5 oz/A) on April 24, a broadcast application of Roundup WeatherMax (1 qt/A) with AMS on May 22, and row cultivation on June 18. Emerged stands from the center four rows of each plot were counted on May 28 and plots were thinned to a uniform stand on June 5.

Experimental measurements included soil, plant, and grain samples. Soil samples (9 cores/plot, 0-6 inch depth) were taken from all plots prior to treatment application on April 30, 2008, post harvest on October 30, 2008 and November 13 (16 cores/plot), 2009. These samples were analyzed for pH, Bray P1, Exch. K, and Zn (Zn on select treatments). Small corn plants (8 plants/plot) were harvested at V7 on June 23, 2008. These samples were dried at 150 F., weighed when dry, ground, and submitted for elemental analysis. Total dry matter yields from the small plants were calculated along with nutrient concentration in the whole plants and nutrient uptake. Extended leaf plant heights (10 plants/plot) were measured on June 22, 2009. Corn grain yields and grain moisture were determined by combine harvesting the center four rows with a small plot combine on October 29, 2008 and November 11, 2009. Grain samples were dried, ground, and analyzed for P and K concentration in the grain.

Results and Discussion

Nutrient content (total elemental) in the ash was determined by microwave assisted acid digestion (EPA 3051 method) of two samples from each source by the University of Minnesota, Research Analytical Laboratory (Table 1). All ash materials were strongly basic and ranged in pH from 11.5 to 12.3. Generally, char ash contained very low levels of essential crop nutrients compared with co-fire (CF) and fluidized bed (FB) sources. Total N–P_2O_5–K_2O–S content was 0–13.5–6.6–1.6 and 0–17.6–16.2–5.7 for CF and FB ash, respectively. The ash used in this study contained detectable levels of the heavy metals: Cr, Cu, Ni, and Pb (except Pb in FB ash). Cadmium was not detected (detection limit <0.88 ppm) in any of the sources. Nutrient application rates in pounds of nutrient per acre for each treatment are listed in Table 1.

Corn production in 2008

Early growth of corn as measured by plant height was significantly greater with FB ash compared with TSP fertilizer and CF ash (Table 2). Plant heights were increased with the high rate of P/ash (240 lb

P_2O_5) compared with the low rate (80 lb P_2O_5). A significant source by rate interaction was not found. Statistical analysis of all nine treatments showed: (i) plant heights were increased above the control by all treatments except for the low P rate of TSP, (ii) char ash increased plant heights above the control, (iii) K fertilization (treatment #9) increased plant height, and (iv) tallest plant heights were obtained with the FB ash treatments.

Total dry matter yields from whole corn plants taken at V7 were affected by the main effect of source, but not by rate of application (Table 2). Total dry matter yields were greatest with FB ash, intermediate with TSP fertilizer, and least with CF ash. Dry matter yields were not affected by P/ash rate and a significant source by rate interaction was not found. Statistical analysis of all nine treatments showed total dry matter yields were increased above the control by both rates of TSP fertilizer and FB ash and by the high rate of CF ash, but yields were not increased by the low rate of CF ash, char ash, and potash (K) fertilizer. Greater variability, as evidenced by a 12.5% coefficient of variation (CV) for total dry matter yield vs. a CV of 4.2% for plant height, explained why char ash and K fertilizer significantly increased plant heights, but not dry matter yield.

Although significant differences in nutrient concentrations were found for treatment main effects, concentrations of all nutrients were greater than critical values reported in the literature (2). Phosphorus concentration in small corn plants was greater with TSP fertilizer compared with ash materials, but was not affected by P rate (Table 2). A significant P source by rate interaction was not found. Potassium concentration was greatest with FB ash, intermediate with CF ash, and least with TSP fertilizer. Greater K concentration was found with the high rate of P application compared with lower rate. A significant source by rate interaction was shown by K concentration not being affected by TSP, but K concentration increased with the high rate of ash. Statistical analysis of all nine treatments showed K concentration was increased above the control by char ash and that potash fertilization increased K in small plants more than char ash and similar to the high rate of FB ash. Sulfur concentration in whole plants was greater with FB ash compared with CF ash and TSP fertilizer. Sulfur concentration in small plants did not respond to rate of application and no significant interaction between source and rate was found. Zinc concentration in whole plants was greater with CF ash compared with other sources and was reduced slightly with the high rate of P. Other researchers have shown high rates of P fertilization can reduce Zn availablity in corn plants. These data support those findings, however all Zn concentrations reported in this study were greater than critical values. Boron concentration in whole plants was greater with TSP fertilizer compared with ash sources and concentration was greater with the high P/ash rate. A significant source by rate interaction is shown by ash application rate having no affect on B concentration in V7 corn plants, while B concentration increased with increasing rates of TSP fertilizer.

Concentration of heavy metals in small corn plants was measured for Cd, Cr, Ni, and Pb (data not shown). Lead was below detectable limits in all of the plant samples, while Cd and Ni were above detectable limits in 6% of samples. Chromium was detected in all plant samples and the average concentration was 0.86 ppm. Metal concentrations in small corn plants were not affected by the treatments.

Phosphorus uptake in small corn plants was greater with FB ash and TSP fertilizer compared with CF ash and was increased by increasing P rate (Table 2). A significant P source by rate interaction was not found. Potassium uptake was greater with FB ash compared with CF ash and TSP fertilizer and greater with the high rate of application. A significant source by rate interaction was shown by K uptake being increased by the higher rate of ash, while the high rate of TSP did not increase K uptake over the low TSP rate. Statistical analysis of all nine treatments showed K uptake was increased above the control by K fertilization (treatment # 9), but was not affected by char ash or the low rate of CF ash. Sulfur uptake in whole plants was greatest with FB ash, intermediate with TSP fertilizer, and least with CF ash. The difference in S uptake between TSP and CF sources was primarily due to increased dry matter with TSP fertilization as S concentrations were not different. Sulfur uptake was not affected by P/ash rate and no significant interaction between main effects was found. Zinc uptake was greater with FB ash compared with other sources, which again was primarily due to increased dry matter in the FB ash treatments. Zinc uptake was not affected by P/ash rate and no significant interaction between main effects was found. Boron uptake in whole corn plants at V7 was greatest with TSP fertilizer, intermediate with FB ash, least with CF ash, and was greater at the high fertilizer P rate. A significant source by rate interaction was explained by increased B uptake at the high application rate of TSP, while CF and FB application rates did not affect B uptake. Char ash and K fertilizer did not affect B uptake in whole plants.

Corn grain moisture and yield were affected by the main effects of source and rate (Table 3). Corn grain moisture was reduced with TSP and FB ash compared with CF ash. Moisture was also reduced by the high P/ash rate compared with the low rate. These data along with greater grain moisture with char ash, which contained very little P, and potash fertilizer treatments, which contained no P, showed how P fertilization reduced grain moisture content. Grain yields were greater with TSP and FB ash compared with CF ash, and yields were greater with the high P/ash rate compared with the low rate. Statistical analysis of all nine treatments showed corn yields were increased above the control by potash (K) fertilizer, but not by the char ash treatment. These yield data show: (i) some of the corn yield response to treatments was due to K fertilization, not just P fertilization and (ii) char ash did not increase corn yields equal to K fertilizer, which suggests the K in char ash was not as available to plants as K fertilizer. A signifcant source by rate interaction was shown by corn yields being increased 28 bu./A with the high rate of CF ash, whereas corn yields increased only 8-9 bu./A with increasing rate of TSP and FB ash. These data suggest greater first-year P availability with FB ash compared with CF ash.

Grain P and K concentration and uptake were affected by the main effects of ash/fertilizer source and rate (Table 3). Concentration and uptake of P and K were greater with TSP fertilizer and FB ash compared with the CF ash, and were increased with increasing rate of application. Significant interactions between main effects were not found. These data showed K concentration and uptake in grain increased when P concentration and uptake increased. Moreover, an analysis of all nine treatments showed K fertilization (treatment # 9) did not increase K concentration in corn grain, but treatment 9 did increase K uptake in grain due to greater grain yield. These data emphasize the importance of adequate P fertility for corn in Southern Minnesota.

<u>Corn production in 2009</u>

Early growth of corn as measured by extended leaf plant height and final plant population were not significantly affected by the residual effects of treatments in 2009 (Table 4). Plant heights only ranged from 30.5 inches in the control to 33.1 inches with the high rate of TSP and low rate of FB ash and heights averaged 32.0 inches. After thinning, plant population ranged from 29,100 to 30,500 plants/A and averaged 32,000 plants/A.

Corn grain moisture was not affected by the residual effects of treatments (Table 4). Grain yields were affected by the main effects of source and rate. Grain yields were greater with TSP and FB ash compared with CF ash, and yields were 32 bu/A greater with the high P/ash rate compared with the low rate. A significant source by rate interaction was shown by corn yields being increased 50 bu./A with the high rate of CF ash, whereas corn yields increased 27 and 21 bu./A with increasing rate of TSP and FB ash, respectively. The grain yield response between the low and high rates of P found in 2009 was considerably larger than what was found in the application year of 2008. These data clearly show the residual effect of the low rate of P (80 lb P_2O_5) from all sources (ash and fertilizer) was not adequate for corn production on this low testing (8-10 ppm Bray P in October of 2008) soil. Statistical analysis of all nine treatments showed a strong trend for increased corn yields above the control by potash (K) fertilizer, but it was not significant at the 0.10 level of significance. Yields were not increased above the control by the char ash and the low rate of CF ash treatments. Similar to 2008 findings, these data suggest greater P availability with FB ash compared with CF ash.

Grain P and K concentration and uptake were affected by the main effects of ash/fertilizer source and rate (Table 4). Concentration and uptake of P were greatest with TSP fertilizer, intermediate with FB ash, and least with the CF ash, and were increased by the high rate of application. Significant interactions between main effects were not found. Grain K concentration was greater with TSP fertilizer (no fertilizer K applied) than with CF ash (contained K) and K concentration and uptake were increased by the high rate of fertilizer/ash. Similar to 2008, these data showed K concentration and uptake in grain increased when P concentration and uptake increased. One possible explanation for this finding is P fertilization on this low P testing soil increased corn yield by increasing both root and shoot (biomass) growth. The enhanced root growth could result in greater K uptake and utilization by corn plants. An analysis of all nine treatments showed K fertilization (treatment # 9) did not increase K concentration or uptake in corn grain above the control.

Soil test interpretation across years

Soil test results for pH, Bray P1, exchangeable K, and DTPA Zn for samples taken prior to treatment application (initial) and after harvest in 2008 and 2009 are presented in Table 5. Prior to treatment application water pH ranged from 6.3 to 6.7 and averaged 6.4, whereas in October of 2008 pH ranged from 6.7 to 7.1 and averaged 6.9 and in November of 2009 pH ranged from 6.5 to 6.8 and averaged 6.7. Ash may provide some liming effect when applied, but none was found in these fall data.

Soil test P (Bray P1) from pre-application samples ranged from 4.5 (very low) to 9.3 ppm (low) among treatments and averaged 6.5 ppm (low). Bray P after harvest in 2008 ranged from a low 6.8 ppm in the potash treatment (# 9) to a high of 28.8 ppm in the 240 lb P_2O_5/A TSP treatment (# 3). Post harvest soil test P was affected by ash and fertilizer treatments, however considerable variability in the data (CV = 51 and 48% in 2008 and 2009, respectively) resulted in a large LSD values at the 0.10 level of significance. Thus, the author has chosen to use a 0.20 level of significance for these data. In 2008, soil test P was increased above the control by P fertilizer and CF and FB ashes at the 240 lb P_2O_5/A rate, but soil test P was not increased at the 80 lb P_2O_5/A rate by any source. By the November of 2009 sampling, soil test P had declined by 3.0 ppm compared with October of 2008, when averaged across treatments. The largest decline (9.3 ppm) occurred with the 240 lb P_2O_5/A rate of TSP. Only the high rate of TSP and FB ash had soil test P values significantly greater than the control in November of 2009. Olsen P from November 2009 samples ranged from 7.3 to 16.5 and averaged 9.7. Similar to the Bray P data, only the high rate of TSP and FB ash had Olsen P values significantly greater than the control.

Soil test K (exchangeable K) from pre-application samples ranged from 119 (medium) to 138 ppm (high) among treatments and averaged 129 ppm (high). After harvest in 2008, soil K ranged from 159 to 197 ppm and averaged 183 ppm across treatments. Post harvest soil test K was affected by ash and fertilizer treatments; however these treatment differences were over-shadowed by the large difference in soil test K observed between spring and post harvest samples. Soil test K averaged 45 ppm more in post harvest sampling compared with spring sampling in 2008. This phenomenon has been reported in the literature and is usaully associated with soil moisture at the time of sampling. In the fall of 2009 soil test K ranged from 196 to 215 ppm and no significant differences were found among treatments.

Soil test Zn was slightly greater in post harvest samples in both 2008 and 2009 compared with spring samples. However, no significant differences among treatments were found for the post harvest sampling.

Summary

Nutrient content (total elemental) of ash varied dramatically. Char ash contained very low levels ($\leq$ 1%) of essential crop nutrients while co-fire (CF, Fibrominn) and fluidized bed (FB, Corn Plus) sources contained 0–13.5–6.6–1.6 and 0–17.6–16.2–5.7 percent of N–P_2O_5–K_2O–S, respectively.

In 2008 corn plant height at V7 was significantly greater with FB ash compared with TSP fertilizer and CF ash and increased with increasing P/ash rate. Plant heights were increased above the control by all treatments except for the low P rate of TSP, and tallest plant heights were obtained with FB ash treatments. In 2009 plant heights were not affected by the residual effects of treatments.

Total dry matter yields from whole corn plants taken at V7 were greatest with FB ash, intermediate with TSP fertilizer, and least with CF ash. Dry matter yields were not significantly affected by P/ash rate. Generally, significant differences in P, K, S, Zn, and B concentration in whole corn plants were found for treatment main effects, however, concentrations of these nutrients were greater than critical values reported in the literature. Uptake of P, K, S, Zn, and B in corn plants was affected by the main effect of source, whereas uptake of only B and K was affected by the main effect of P/ash rate.

Corn grain yields were increased in 2008 and 2009 with P fertilization from fertilizer and ash sources, while grain moisture was reduced with fertilization from these sources only in 2008. Corn yields were greater with fertilizer P and FB ash compared with CF ash. Yields increased with the high P/ash rate compared with the low rate. Yields increased above the control with potash (K) fertilizer, but it was only statistically significant in 2008. Char ash had no effect on grain yield or moisture. These data showed: (i) most of the corn yield response at this site was a result of P fertilization from TSP and/or ash sources, (ii) some of the yield response was due to K (potash) fertilization, (iii) char ash did not produce corn yields equal to K fertilizer at equivalent rates of total K, (iv) this research site which had an intial soil test P of 6.5 (low) required a rate greater than 80 lb P_2O_5/A to maximize yield in the application year (2008), and yields in the residual year (2009) were significantly less with 80 lb P_2O_5/A rate compared with the 240 lb P_2O_5/A and (v) P fertilization with TSP or ash resulted in increased P and K concentration and uptake in corn grain.

Soil test P from spring samples, prior to application, averaged 6.5 ppm (low), whereas after harvest in 2008 it ranged from a low 6.8 ppm in the potash treatment (# 9) to a high of 28.8 ppm in the 240 lb P_2O_5/A TSP treatment (# 3). Soil test P was increased above the control by P fertilizer and CF and FB ashes at the 240 lb P_2O_5/A rate, but soil test P was not increased at the 80 lb P_2O_5/A rate. By the November of 2009 sampling, soil test P had declined by 3.0 ppm compared with October of 2008, and only the high rate of TSP and FB ash had soil test P values significantly greater than the control. Results from the Olsen P soil test, taken on November 2009 samples, produced similar results but with less variability than Bray P. Soil test K from spring samples averaged 129 ppm (high) and increased about 45 ppm after harvest in 2008. Treatment effects on soil test K were small in comparison to the large difference in soil test K observed between spring and post harvest samples. Soil test K averaged 206 ppm in November of 2009, a 23 ppm increase from fall of 2008, but no significant differences were found among treatments.

Conclusions

Corn response to the FB ash was very similar to what was found with TSP fertilizer. This suggests that the first year availability of P between sources was similar; however soil test P did not increase to the same level with FB ash as with TSP fertilizer. This could be explained by the Bray P soil test not effectively representing the available P in the soil after harvest. A more likely explanation is the assumption that P was the only limiting nutrient was wrong and K and S in the FB ash were also contributing to the yield response of corn in this study. This hypothesis can be supported by K and S concentration and uptake in small plants increasing when FB ash was applied compared with TSP fertilizer. In this study the FB ash provided the greatest agronomic benefit to corn of any of the ash used.

The lower rate of CF ash did not significantly affect the crop production parameters measured in this study. This suggests the “first-year” availability of the nutrients in the CF ash is somewhat lower than the total nutrient concentrations reported earlier in this report. The current fertilizer label for this product (personal contact) lists available P_2O_5 and K_2O at 8 and 5%, respectively, which is about 60% of the total. The higher rate of CF ash produced similar crop response to TSP and FB ash, while soil test P was slightly lower than with FB ash.

No measureable agronomic benefit to the char ash was found in this study. This could be a result of: (i) the short term nature of this experiment (spring applied for corn a crop that generally shows response to nutrients early in its development); (ii) the K and other nutrients in the char ash are not readily available to corn plants; or (iii) that many of the benefits of biochar have been found on highly weathered low organic matter soils, which this soil clearly is not.

Acknowledgement

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Table 1. Nutrient content and application rate of ash by treatment.

Nutrient content of ash	Trt.	pH	P	P_2O_5	K	K_2O	S	Zn	B	Mg	Mn	Fe	Ca	Cd	Cr	Cu	Ni	Pb
	#		%	%	%	%	%	ppm	ppm	%	ppm	%	%	ppm	ppm	ppm	ppm	ppm
Co-fire (Fibrominn)	4&5	12.3	5.92	13.5	5.5	6.6	1.55	670	140	2.01	923	0.45	14.5	<0.88	16.0	1167	32.1	19.8
Fluidized bed (Corn Plu	6&7	12.3	7.67	17.6	13.5	16.2	5.71	490	80	4.14	384	0.17	16.7	<0.88	15.1	20	27.3	<14.1
Char ash (CVEC)	8	11.5	0.06	0.1	0.9	1.0	0.03	111	39	0.29	440	0.55	4.5	<0.88	19.0	55	8.5	34.2
Rate of nutrient applied			-- lb per acre --															
Co-fire (Fibrominn)	4		35	80	33	39	9	0.4	0.1	12	0.5	3	86	ND	0.01	0.69	0.02	0.01
Co-fire (Fibrominn)	5		105	240	98	118	27	1.2	0.2	36	1.6	8	257	ND	0.03	2.07	0.06	0.04
Fluidized bed (Corn Plu	6		35	80	61	74	26	0.2	0.0	19	0.2	1	76	ND	0.01	0.01	0.01	ND
Fluidized bed (Corn Plu	7		105	240	184	221	78	0.7	0.1	56	0.5	2	228	ND	0.02	0.03	0.04	ND
Char ash (CVEC)	8		7	15	101	121	3	1.3	0.5	34	5.1	64	518	ND	0.22	0.64	0.10	0.40

Table 2. Plant height, total dry matter yield, nutrient concentration, and nutrient uptake of whole corn plants at V7 in 2008.

	Ash & Fertilizer Treatments			Plant	Whole plant samples at V7										
					DM	Concentrations					Uptake				
Trt	Source	P rate	K rate	Height	Yield	P	K	S	Zn	B	P	K	S	Zn	B
#				inch	ton/A	%	%	%	ppm	ppm	------------------	lb/A	-------------------		
1	Control	0	0	32.6	0.236	0.412	2.68	0.241	36.1	9.2	1.94	12.7	1.13	0.344	0.086
2	TSP (0-44-0)	80	0	34.2	0.313	0.461	2.73	0.235	33.7	10.0	2.90	17.2	1.47	0.424	0.126
3	TSP (0-44-0)	240	0	35.4	0.302	0.450	2.74	0.240	28.5	16.6	2.72	16.6	1.45	0.345	0.202
4	Co-fire (Fibrominn)	80	39	34.5	0.248	0.396	2.71	0.250	37.4	9.1	1.95	13.4	1.23	0.369	0.090
5	Co-fire (Fibrominn)	240	118	35.8	0.295	0.417	3.27	0.233	34.0	8.9	2.47	19.3	1.38	0.403	0.105
6	Fl. bed (Corn Plus)	80	74	37.3	0.343	0.417	3.18	0.259	32.5	9.1	2.87	21.8	1.78	0.447	0.124
7	Fl. bed (Corn Plus)	240	221	37.9	0.345	0.437	3.44	0.254	33.6	8.7	3.01	23.9	1.75	0.456	0.121
8	Char ash (CVEC)	15	121	34.5	0.263	0.415	2.91	0.252	39.2	9.5	2.20	15.4	1.32	0.412	0.100
9	Potash (0-0-60)	0	120	35.2	0.252	0.427	3.41	0.242	39.1	9.5	2.19	17.2	1.22	0.389	0.096
			Mean:	35.3	0.289	0.426	3.01	0.245	34.9	10.1	2.47	17.5	1.42	0.399	0.117
Statistical analysis of main effects (factorial arrangement) for treatments 2 through 7.															
Source															
TSP				34.8	0.308	0.456	2.73	0.237	31.1	13.3	2.81	16.9	1.46	0.384	0.164
Co-fire (Fibrominn)				35.1	0.271	0.407	2.99	0.242	35.7	9.0	2.21	16.4	1.31	0.386	0.098
Fluidized bed (Corn Plus)				37.6	0.344	0.427	3.31	0.257	33.0	8.9	2.94	22.8	1.77	0.451	0.123
LSD (0.10):				0.8	0.024	0.024	0.18	0.012	2.7	1.4	0.30	1.7	0.15	0.058	0.022
Rate lb P_2O_5/A															
80				35.3	0.301	0.425	2.87	0.248	34.5	9.4	2.57	17.5	1.49	0.413	0.113
240				36.3	0.314	0.435	3.15	0.243	32.0	11.4	2.73	19.9	1.53	0.401	0.143
P > *F*:				0.016	0.265	0.376	0.004	0.341	0.072	0.008	0.280	0.008	0.619	0.660	0.013
Interactions (P > F)															
Source × rate				0.657	0.111	0.448	0.051	0.293	0.156	0.001	0.163	0.015	0.526	0.232	0.018
CV (%):				2.5	8.9	6.4	6.6	5.5	9.4	15.5	13.0	10.4	11.2	16.2	20.0
Statistical analysis of treatment effects for all nine treatments.															
Treatment															
P > *F*:				0.001	0.001	0.073	<0.001	0.082	0.001	<0.001	0.002	<0.001	<0.001	0.267	<0.001
LSD (0.10):				1.8	0.044	0.034	0.21	0.015	3.5	1.6	0.48	2.8	0.23	NS	0.029
CV (%):				4.2	12.5	6.5	5.7	5.2	8.4	13.2	16.2	13.2	13.3	17.6	20.2

Table 3. Corn grain yield, moisture, and nutrient uptake in corn grain.

	Ash and Fertilizer Rates			Grain	Grain	Grain	Grain	Grain	Grain
Trt	Source	P_2O_5	K_2O	H_2O	Yield	[P]	[K]	P up	K up
#		lb/A	lb/A	%	bu/A	%	%	lb/A	lb/A
1	Control	0	0	23.7	192	0.21	0.31	19.2	28.4
2	TSP (0-44-0)	80	0	23.7	210	0.25	0.35	24.6	34.6
3	TSP (0-44-0)	240	0	22.9	219	0.29	0.38	30.1	39.7
4	Turkey, Fibrominn	80	39	24.5	190	0.20	0.31	17.8	27.7
5	Turkey, Fibrominn	240	118	23.9	218	0.24	0.34	25.2	35.1
6	Solubles, Corn Plus	80	74	23.8	213	0.25	0.35	25.5	35.4
7	Solubles, Corn Plus	240	221	23.2	221	0.27	0.37	28.4	38.6
8	Char ash (CVEC)	15	121	24.3	194	0.22	0.32	20.7	29.6
9	Potash (0-0-60)	0	120	24.5	208	0.23	0.33	23.2	33.0
			Mean:	23.8	207	0.24	0.34	23.9	33.5

Statistical analysis of main effects (factorial arrangement) for treatments 2 through 7.

	Grain H_2O	Grain Yield	Grain [P]	Grain [K]	Grain P up	Grain K up
Source						
TSP	23.3	215	0.27	0.37	27.4	37.1
Turkey (Fibrominn)	24.2	204	0.22	0.32	21.5	31.4
Solubles (Corn Plus)	23.5	217	0.26	0.36	26.9	37.0
LSD (0.10):	0.6	8	0.02	0.02	2.2	2.2
Rate lb P_2O_5/A						
80	24.0	204	0.23	0.33	22.6	32.6
240	23.3	219	0.27	0.36	27.9	37.8
P > *F*:	0.029	0.001	0.001	0.004	<0.001	<0.001
Interactions (P > F)						
Source × rate	0.969	0.092	0.458	0.706	0.220	0.287
CV (%):	2.7	4.5	8.9	6.2	9.8	7.3

Statistical analysis of treatment effects for all nine treatments.

	Grain H_2O	Grain Yield	Grain [P]	Grain [K]	Grain P up	Grain K up
Treatment						
P > *F*:	0.008	0.005	0.003	0.006	0.001	<0.001
LSD (0.10):	0.7	15	0.04	0.03	4.2	4.3
CV (%):	2.4	6.0	12.2	8.0	14.6	10.6

Table 4. Corn grain yield, moisture, and nutrient uptake in corn grain in 2009.

Trt #	2008 Ash and Fertilizer Rates: Source	P_2O_5 lb/A	K_2O lb/A	Grain H_2O %	Grain Yield bu/A	Grain [P] %	Grain [K] %	Grain P up lb/A	Grain K up lb/A	Plant Height inch	Plant Pop $p \times 10^3$/A
1	Control	0	0	22.9	139	0.17	0.32	11.4	20.8	30.5	29.1
2	TSP (0-44-0)	80	0	23.5	161	0.21	0.33	15.7	25.4	32.0	29.7
3	TSP (0-44-0)	240	0	23.6	188	0.26	0.36	22.8	32.0	33.1	30.1
4	Turkey, Fibrominn	80	39	22.7	126	0.15	0.29	8.8	17.5	31.3	30.3
5	Turkey, Fibrominn	240	118	23.3	176	0.21	0.34	17.4	28.1	32.3	29.9
6	Solubles, Corn Plus	80	74	23.1	162	0.18	0.31	13.8	24.2	33.1	30.1
7	Solubles, Corn Plus	240	221	23.5	183	0.24	0.35	20.3	30.2	32.7	30.0
8	Char ash (CVEC)	15	121	23.7	144	0.19	0.33	14.0	23.1	31.3	30.5
9	Potash (0-0-60)	0	120	24.2	159	0.17	0.33	12.8	24.4	32.0	30.3
			Mean:	23.4	160	0.20	0.33	15.2	25.1	32.0	30.0
Statistical analysis of main effects (factorial arrangement) for treatments 2 through 7.											
Source											
TSP				23.6	174	0.23	0.35	19.2	28.7	32.6	29.9
Turkey (Fibrominn)				23.0	151	0.18	0.31	13.1	22.8	31.8	30.1
Solubles (Corn Plus)				23.3	172	0.21	0.33	17.0	27.2	32.9	30.1
LSD (0.10):				NS	11	0.02	0.02	2.0	2.5	NS	NS
Rate lb P_2O_5/A											
80				23.1	150	0.18	0.31	12.7	22.4	32.2	30.0
240				23.5	182	0.23	0.35	20.1	30.1	32.7	30.0
P > *F*:				0.242	<0.001	<0.001	0.007	<0.001	<0.001	0.546	0.971
Interactions (P > F)											
Source × rate				0.829	0.077	0.896	0.790	0.659	0.244	0.730	0.761
CV (%):				3.3	7.3	12.5	8.4	14.2	11.0	6.6	3.7
Statistical analysis of treatment effects for all nine treatments.											
Treatment											
P > *F*:				0.127	<0.001	0.001	0.122	<0.001	<0.001	0.721	0.901
LSD (0.10):				NS	20	0.04	NS	3.8	4.2	NS	NS
CV (%):				2.9	10.5	16.1	9.2	20.9	13.9	6.9	4.2

Table 5. Soil test pH, Bray P, Olsen P, exchangeable K, and DTPA Zn as affected by nutrient sources and date of sampling.

	2008 Ash and fertilizer source and rate			Initial soil tests				Sampled Oct. 30, 2008				Sampled Nov. 13, 2009				
Trt.	Source	P_2O_5	K_2O	pH	Bray	K	Zn	pH	Bray	K	Zn	pH	Bray	Olsen	K	Zn
#		lb/A	lb/A		--------- ppm ---------				--------- ppm ---------				------------- ppm -------------			
1	None	0	0	6.4	6.8	130	1.34	6.8	7.0	189	1.42	6.5	6.5	7.3	200	1.48
2	TSP	80	0	6.5	5.3	119		6.8	8.8	159		6.6	8.0	9.0	199	
3	TSP	240	0	6.3	7.0	133		6.7	28.8	172		6.7	19.5	16.5	211	
4	Co-fire (Fibrominn)	80	39	6.7	4.5	129		7.1	8.3	197		6.8	5.0	7.5	200	
5	Co-fire (Fibrominn)	240	118	6.4	7.3	131	1.37	6.9	13.8	189	1.48	6.7	9.5	9.8	210	1.59
6	Fluidized bed (Corn Plus)	80	74	6.4	7.3	130		6.9	10.3	189		6.8	7.5	8.0	208	
7	Fluidized bed (Corn Plus)	240	221	6.6	5.8	121	1.30	6.9	14.8	190	1.61	6.8	11.3	13.3	215	1.55
8	Char ash (CVEC)	15	121	6.3	9.3	131		6.8	9.3	174		6.7	7.8	8.5	196	
9	0-0-60	0	120	6.5	5.3	138		6.9	6.8	191		6.7	4.8	7.8	211	
			Mean:	6.4	6.5	129	1.34	6.9	11.9	183	1.50	6.7	8.9	9.7	206	1.54
Statistical analysis of treatment effects																
Treatment																
$P > F$:				0.605	0.564	0.609	0.866	0.296	0.001	0.106	0.790	0.806	0.002	<0.001	0.746	0.596
LSD (0.10):				NS	NS	NS	NS	NS	7.4	NS	NS	NS	5.1	3.2	NS	NS
LSD (0.20):				NS	NS	NS	NS	NS	5.7	17	NS	NS	3.9	2.5	NS	NS
CV (%):				4	48	10	14	3	51	10	25	3	48	27	8	11