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Abstract

Increasing bio-energy production will result in increased by-products which will need proper disposal methods to prevent economic and/or ecological problems. Land application has potential for disposal and/or nutrient cycling if these by-products have crop nutritive value. Our objective was to compare the fertilizer effects of two by-products of bio-energy production, dry distillers grains (DDG) and charcoal with urea in corn (*Zea mays* L.) and evaluate nutrient uptake. Treatments were DDG under no-till and tilled at four location-years and charcoal under no-till and tilled at three location-years. No-till urea was used as a baseline at all location-years. Nitrogen (N) rates ranged from 0 to 180 kg N ha^{-1}. All materials were spring applied before tillage and planting. Corn yields for DDGs and urea were similar across tillage treatments and locations. Corn yields over all charcoal rates and tillage treatments were the same as 0 kg N ha^{-1}. The charcoal, because of immobilization or lack of decomposition, did not contribute to the corn N nutrition. Neither material showed any negative effects on the corn yields. Stalk N, phosphorus (P), potassium (K), and grain N followed expected trends and had few effects compared with those from urea. Land application of DDGs and charcoal has merit for disposal/nitrogen cycling with DDGs being preferred for its N contribution.

With the growing concerns, environmentally and politically, over the use of petroleum distillates, an effort to supplement, if not offset petroleum with biofuels has arisen. The use of fuels produced from plant biomass or animal waste, called bio-fuels (EISA of 2007, sec 201), have increased to fill the niche. The Energy Independence and Security Act of 2007, sec. 202 mandated that 36 billion gallons of bio-fuels be produced for American consumers by 2022.

Ethanol currently makes up the majority of the bio-fuels produced in the U.S. Pyrolysis is another method for producing biofuels. Pyrolysis is a process in which high temperatures and low levels of oxygen cause organic material to decompose. Depending on the material used, three by-products are produced in different proportions; syngas, bio-oil, and charcoal. All three by-products can be used for fuel/energy (Spath and Dayton, 2003; Stassen, 1995; Pels et al., 2005; Brewer et al., 2009).

With the increase in production and use of bio-energy comes an increase in related by-products. Improper disposal of bio-energy by-products might cause future economic and/or ecological problems. There are several methods of possible by-product disposal/reuse. Of these methods, land application appears to be an environmentally feasible and potentially constructive method to dispose of bio-energy related by-products (Pels et al., 2005). Application on crop land could have the greatest potential if nutritive value/nutrient cycling can be established.

With the dry-milling-ethanol process three co-products are produced in almost equal proportions. Carbon dioxide, ethanol, and dried distillers grains with solubles (DDGs) are produced at proportions of approximately one-third each of total corn inputs (Bowman and Geiger 1984; Renewable Fuels Association, 2010).

Because DDGs are produced from corn or sorghum (*Sorghum bicolor* L. Moench) they are typically used as an animal feed. Dry distillers grains with solubles are used primarily as a nutrition supplement for cattle (*Bos taurus* L.) (Sasikala-Appukuttan et al., 2008; Schingoethe et al., 2009), but pigs (*Sus scrofa domestica* L.*)* and poultry (*Gallus gallus domesticus* L.) can be fed DDGs as well (Al-Suwaiegh et al., 2002; Fastinger et al., 2006; Schingoethe et al., 2009). Dry distillers grains with solubles are known to be a high protein, high fiber, and low energy supplement for animal diets. Typically DDGs have an approximate nutritive breakdown of 25% protein (approximately 4% nitrogen), 8% fiber, and 4000 kcal kg^{-1} (Spiehs et al., 2002; Schingoethe et al., 2009). Some preliminary research with pot studies on horticultural plants, reported that DDGs suppressed weeds with surface application and incorporation (Boydston et al., 2008). Nelson et al. (2009) reported that application of DDGs, as a N source, produced similar corn yields as urea and anhydrous ammonia, when environmental conditions were not limiting. In 2008, 27 million Mg of DDGs were consumed as animal feed in the U.S (Renewable Fuels Association, 2010).

With an increase of pyrolysis and gasification for bio-energy production the by-products are equally increased. The residual materials from combustion, pyrolysis, and gasification can range from light ash to a black ash or charcoal-like material, based upon the conditions in which it was burned (Pels et al., 2005).

Charcoal can be defined as the organic residual material, with greater then 30% carbon (that can be re-burned for energy as charcoal), produced from low-temperature anoxic combustion, pyrolysis, or gasification. All the methods mentioned produce different hydro-carbon 'residual' structures with different characteristics (Brewer et al., 2009).

Not much is known about the plant nutritive value (N) of charcoal, especially in temperate regions. Mozaffari et al. (2000, 2002) reported that charcoal (called ash, but was 42% carbon) from gasification could be a potential source of K and P, as well as an effective liming agent. Gaskin et al. (2010) reported no increase in corn tissue N with the field application of charcoal but reported responses to K, calcium, magnesium, and sulfur (depending on source material). Charcoal application in tropical environments/soils seems to also have some liming capabilities and nutritive benefits for plants because of the higher pH (base saturation) of the material and increased K, P, Ca, and Mg availability, as well as reductions of available Al (Major et al., 2010; Chan et al., 2007; Rondon et al., 2007). Steiner et al. (2007) reported that the addition of charcoal without fertilizer did not affect nutrient concentrations in rice (*Oryza sativa* L.) or sorghum. Charcoal application along with N fertilizer have been reported to increase radish (*Raphanus sativus*) and corn yields above that of fertilizer alone but applications of charcoal alone resulted in no yield increase (Chan et al., 2007; Major et al., 2010).

The hypotheses of this experiment are that 1) application of DDGs will produce the same/similar yield responses as urea in both no-till and tilled systems and may also increase P and K availability, and 2) charcoal will have no N benefit for corn production, but may increase plant available P and K.

The main objective of this experiment was to compare the corn yield response to DDGs and charcoal in no-till and tilled systems with no-till corn yield utilizing urea as a source of N fertilizer. The secondary objective was to observe the affects of DDGs and charcoal on plant uptake of P and K.

Methods and Materials

Plots were located at three locations in northeast Kansas over three years; Doniphan in 2007, Riley in 2008 and 2009, and Marshall County in 2009. At Doniphan County in 2007, the plot design was a randomized complete block design with DDGs at four rates: 45, 90, 135, and

180 kg N ha $^{-1}$ under no-till and tilled management. Source material (DDGs) nutrient analysis is reported in Table 1. Urea (46% N) was applied for comparison at the same rates in no-till. One zero rate was used per replication with four replications. The plot was planted on the top terrace of a cooperator's field east of Bendena, KS (39°44′ N, 95°10′W). The predominant soil type at this location was a Marshall silt loam (fine-silty, mixed, superactive, mesic Typic Hapludolls). Soil test results (N, P, K, organic matter (O.M.), and pH) are reported in Table 2. The previous crop was soybean. Source material (DDGs and urea) application, tillage, and corn planting were completed on 19 April 2007. The corn hybrid used was Pioneer '33K40' (RM 114 days, Pioneer Hi-Bred Int. Johnston, IA). Tillage operations were preformed with an offset disk.

At Riley County in 2008, treatment sources and rates were the same as in 2007 except for the addition of charcoal. Charcoal was applied based on the N content at rates to achieve applications rates of 45 and 90 kg N ha $^{-1}$ within each tillage treatment. Plots were planted at the Ashland Bottoms Research Farm located south of Manhattan, KS (39°8′N, 96°38′W). The soil type was a Belvue silt loam (Coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvents). The previous crop was soybean. Source material (charcoal, DDGs, and urea) application, tillage, and corn planting were completed on 19 May, 2008. The corn hybrid used was Croplan '6831' (RM 111 days, Croplan Genetics, St. Paul, MN). Tillage plots had source material incorporated with a field cultivator (No-till plots were not incorporated).

In 2009 at the Riley and Marshall County sites, split block designs with four replications were used. Tillage treatments were the main plots, N sources and rates were the sub plots. Dry distillers grains and charcoal were applied at rates of 45, 90, 135, and 180 kg N ha $^{-1}$ within each main plot. A no-till urea control at the same rates plus a zero rate within both tilled and no-till was used. At the Riley location soil type, and previous crop were the same as in 2008; the plots were planted approximately 100 meters south of the 2008 plots. The plots at Marshall were planted south of Marysville, KS on a cooperator's field (39°48′N, 95°10′W). The soil type was a Wymore silty clay loam (fine, smectitic, mesic Aquertic Argiudolls). The previous crop was wheat. Both locations in 2009 were planted to the Dekalb corn hybrid 'DKC63-42'(RM 113 days, Monsanto Co., St. Louis, MO). Application of source material, tillage and planting were completed on 18 May and 19 May 2009, for Riley and Marshall County, respectively. Source incorporation (tillage treatments) was preformed with a field cultivator at Riley and an offset disk at Marshall.

Dry distillers grains in 2007 and 2008 were produced and donated by ICM (Wichita, KS). In 2009 the DDGs were procured from a local animal feed outlet. Different sources of charcoal were used in 2008 compared with 2009. In 2008, charcoal produced from combustion of pericarp from corn grain fractionated via dry milling was used. In 2009, the charcoal was produced from the gasification of corn residue produced by a fluidized bed gasifier (ICM Inc, Newton, KS). Nitrogen contents of the DDGs were greater than those of the charcoal used, with both being quite low (Table 1). All DDGs and charcoal treatments were hand-applied based on total N and corrected for moisture.

Experimental units consisted of four 0.76 cm rows with the final plots dimensions of 3.1 by 9.2 m. Corn was planted at 75 000 plants ha^{-1} in all years and locations except Riley County in 2008, which was planted at 60 000 plants ha^{-1}. Weeds were controlled using chemical herbicides.

All plots were hand-harvested. Harvest dates for Doniphan 2007, Riley 2008, Marshall 2009, and Riley 2009 were 22 August, 20 September, 1 November, and 27 November, respectively. The harvested areas in 2007 and 2008 were 1.5 by 4.6 m and in 2009 harvested areas were increased to 1.5 by 6.1 m. During harvest, the number of plants and ears were counted within the harvested area and used to determine ears m^{-2} and grain weight per ear. Plot grain weights were measured after shelling with an Almaco ECS Sheller (Almaco, Nevada, IA). Moisture contents were measured at shelling and used to correct plot weights to 155 g kg^{-1} water content. Individual seed weights were determined from the weight of 100 seeds dried for 48 hours at 105°C.

Plant samples were only taken at the two locations in 2009. Ten sequential whole plant samples were taken the same day as grain was harvested from one of the two harvest rows of each plot. All plant and grain samples were ground to pass through a 2 mm sieve. Plant samples were analyzed for N, P, and K concentration. Grain samples in 2008 and 2009 were analyzed for N concentration. Plant and grain samples were analyzed by the Kansas State University Soils lab using methods described by Brown et al., (1997).

Soil samples were taken in the spring before planting at all locations (Table 2). Soil samples consisted of at least 15 cores and were taken to a depth of 30 cm. Soil samples were analyzed by the Kansas State University Soils lab for O.M., nitrate, ammonium, pH, P and K using methods described by Brown et al., (1997).

Due to experimental design differences (2007, 2008, and 2009) and unequal variance (2009) all location-years data were analyzed separately. Data were analyzed with regression and orthogonal contrast using PROC REG, NLIN, and MIXED in SAS version 9.1 (SAS Institute, Cary, NC). Variance between locations in 2009 was tested with the Brown–Forsythe (Brown and Forsythe (1974) test for equality of variances. Orthogonal contrasts were used to determine the overall differences and regression was used to describe the plant responses to increasing rates of DDGs, charcoal, and urea. Due to the limited number of contrasts allowed (four), contrasts that compared nutrient sources and tillage systems were chosen. Each contrast simply tested if the overall means of each source were different (source main effect test). If these contrasts were significant, regression analyses was used to determine the responses of those treatments. All regression responses were tested with linear, quadratic, and linear/quadratic plateau models and were fit to the model that had the lowest RMSE, highest r^2, and best fit the bias for the response.

Results

Grain Yield

Average grain yield over all treatments, locations, and years was 9.2 Mg ha^{-1} and ranged from 4.6 to 16.2 Mg ha^{-1} with Marshall County having the lowest yield and Doniphan County having the highest (Table 2). The low yields at Marshall County in 2009 are likely due to a dry period from July to September (Table 2). Marshall County received about 200 mm less precipitation during the growing season than Riley County in 2009. Doniphan County had better growing conditions (865 mm of precipitation) as well as no charcoal treatments to reduce the average grain yield. Without charcoal treatments included, the average grain yield at Marshall County was still approximately 2 Mg ha^{-1} lower than at Doniphan without charcoal. Riley County in 2009 had the highest average yield and had similar temperatures all season.

At Doniphan County in 2007, grain yields averaged 10.9 Mg ha^{-1} and no differences in yields were detected between urea and DDG N sources (Table 3). In 2008 at Riley County, there were yield differences between urea and charcoal but not between urea, DDG no-till, and DDG tilled (Table 3). No differences were found between the DDG no-till and tilled treatments. Application of DDGs under no-till and surface applied urea resulted in yield responses to N that fit linear plateau models (Fig. 1). In these models, the optimum N rate or inflection point in the plateau (X_o) for DDG no-till was 106 kg N ha^{-1} and X_0 for urea was 89.6 kg N ha^{-1} (Table 4). With DDG tilled, yield increased in a linear manner over the range of treatments.

At Riley County in 2009, as in 2008, the charcoal did not affect yields regardless of application rate and and yields were lower than with urea (Table 3). Yields from the DDG no-till were lower than with either DDG tilled or urea. For urea and both DDG treatments, yields increased in a linear manner as rates increased (Fig. 1). No-till applications of DDGs responded in a linear plateau with the X_o equal to 100.2 kg N ha^{-1} (Table 4).

In 2009 at Marshall County, grain yields did not respond to charcoal applications and were lower than those from urea (Table 3). Urea yielded less than DDG tilled and there were no differences between DDG no-till and urea nor were there differences between DDG no-till and DDG tilled. Responses for DDG no-till, DDG tilled, and urea were all linear plateaus, with the X_o equal to 83.5, 110.5, and 108.1 kg N ha^{-1}, respectively (Fig.1, Table 4).

Ears m^{-2} and Ear weight

In 2007 and 2008, no differences in ears m^{-2} were found between treatments (Table 3). At Riley County in 2009, ears m^{-2} increased as fertilizer rate increased (Table 4). At Marshall County, ears m^{-2} increased as charcoal in both tillage systems and DDG in the tilled system rates increased (Table 4).

Only at Riley County in 2008 were ear weights affected by any treatments. Ear weights from the charcoal treatments were lower than those from urea treatments (Table 3). Charcoal and DDG no-till both produced lower ear weights, at 130 and 176 g ear^{-1}, respectively. Ear weights increased for all treatments as fertilizer rates increased (data not shown).

Kernel Weight

Kernel weights were the most dynamic yield component. At Doniphan County, no differences were found between the sources (Table 3) and kernel weight increased as soil amendment rates increased (Table 4, Fig. 2). In 2008, no difference was found between the DDG no-till and tilled (Table 3). Kernel weights were unaffected by charcoal applications. Kernel weights increased in a linear manner as rates increased for both DDG treatments whereas kernel weight response to urea applications was quadratic (Fig. 2).

At Marshall County, DDG no-till and tilled were not different from each other (Table 3). Urea and both charcoal treatments were not different. Urea and both DDG treatments resulted in kernel weights increasing as soil amendment rates increased (Table 4, Fig. 2). The charcoal treatments did not affect kernel weights. At Riley County in 2009, the only difference elucidated by the contrasts was between urea and DDG tilled (Table 3). Charcoal, DDG no-till, and urea had similar kernel weights. The two DDG treatments and urea resulted in increasing kernel weights with increasing rates (Table 4, Fig. 2).

Stalk Nitrogen

At Marshall County, charcoal was the only treatment causing differences in stalk N compared with the urea treatment. The two DDG treatments produced different stalk N responses (Table 5). Stalk N levels increased linearly as rates increased in the DDG tilled and the urea treatments (Table 6, Fig. 3). At Riley County, charcoal and DDG no-till resulted in lower stalk N levels than urea. The DDG tilled was the same as urea and DDG no-till (Table 5). Urea resulted in a peculiar response in stalk N levels, with level declining as urea rates initially increased and then increasing at higher rates (Fig. 3). A plateau with an increase is more likely the true response.

Stalk Phosphorus

At Riley, urea resulted in different stalk P levels compared with both DDG and both charcoal treatments. This was the result of the DDG and charcoal treatments having little impact on stalk P levels and stalk P levels declining as application rates increased and then reaching a plateau at rates lower than approximately 66 kg N ha^{-1} (Table 6, Fig. 4).

At Marshall, the only significant contrast was urea vs charcoal (Table 5). Stalk P responses to urea and DDG were similar to those reported for urea at Riley, stalk P levels declined as application rates increased with all three exhibiting a quadratic to declining plateau response (Table 6, Fig. 4).

Stalk Potassium

At Riley, no contrasts were significant and only the two no-till treatments resulted in significant responses in stalk K levels (Table 7, Fig. 5). In these two cases, stalk K levels increased and then reached a plateau.

At Marshall, the contrasts between urea and the two DDG treatments were significant (Table 5). Unlike at Riley, the two tilled treatments resulted in significant responses and in both, stalk K rates increased as application rates increased (Table 7, Fig. 5).

Grain Nitrogen

At Riley in both 2008 and 2009, there were treatment differences between all contrasts tested (Table 5). Charcoal applications did not affect grain N content (Table 7, Fig. 6). Applications of DDG and urea resulted in increased grain N content, with the highest levels occurring from the highest urea applications (Fig. 6).

At Marshall, all contrasts were significant except the Urea vs. DDG no-till (Table 5). Grain N responses to soil amendment applications were similar to those found at Riley both years. Charcoal applications did not affect grain N content and it increased linearly as urea and DDG application rates increased (Table 7, Fig. 6).

Discussion

In all years and locations, except Riley County in 2009, grain yields with DDGs applications were not different than grain yields with urea applications. This illustrates that if DDGs ever became so abundant that prices were reduced significantly, land application to replace N fertilizer would be a viable option. Also, depending on regulations, DDGs might also be a valid organic fertilizer. No-till and tilled DDG treatments had grain yields that were not different at all but one location. The exact reason for this is unknown but one possible explanation could be slower mineralization of the DDGs in the no-till environment. From the soil analysis, the only factor that might be limiting is N. Nelson (2009) hypothesized that DDGs mineralize and become available in a similar fashion as manure. Also about 65% of the time the r^2 values for DDG no-till regressions were lower and more variable than the other sources (DDG tilled and urea). It is believed that this was caused by the mineralization process in no-till being more affected by environmental constraints (water and temperature). But even at a location-year where yields were reduced due to lower precipitation (Marshall County) DDG no-till had the same grain yield as urea. It seems that the more efficient fertilizer (urea) and the faster mineralization of the tilled DDGs were able to release N faster, especially in a year with high rainfall and no major heat stress (more ideal conditions for decomposition). At this point it should be pointed out that although DDG no-till had a lower grain yield than DDG tilled and urea, it was still able to average 11 Mg ha^{-1} of grain at Riley County in 2009.

Stalk N followed the same trend as the DDGs and urea with charcoal having no response. Stalk P concentrations decreased with increasing rates of DDGs and urea both years. With the soil analysis it is believed that neither P nor K was limiting. Since this experiment was designed mainly as a N yield response study and not for observing response to P or K, most of the results for P and K will be speculative. A possible explanation for the decrease of P in the plant tissue could be either a dilution effect because of the higher biomass yields or it could be that the plant translocated the P to the developing grain. Grain P concentration was not tested, so no conclusions can be stated. Stalk K at some locations decreased and increased at others. Our data is not extensive enough in this area so no explanation can be given.

Conversely, charcoal applications did not produce yields higher than urea. Gaskin (2010) and Major (2010) reported similar grain yield responses to charcoal applications in corn (no N fertilizer). Stalk N in the charcoal treatment was lower than urea treatments. Similar tissue N results were found in corn and other species by Chan et al. (2007), Rondon et al. (2007), Gaskin et al. (2010), and Steiner et al. (2007). Because stalk N is a way to measure plant uptake of N, this could explain why the charcoal treatments had lower overall yield. In essence, the charcoal treatments took up less N and with all other sources of environmental stress controlled within the plot, it can be surmised the source material was the cause of the lower N availability. The lower individual seed weights for the charcoal treatments also help to explain this. The growth stage at which N uptake is the most limiting is during the grain filling stages in corn. Charcoal treatments also did not have yields higher than the control across all rates. The regression analysis validates this with the charcoal having a slope of zero. The stable or almost unaffected stalk P and K levels could be an indication that charcoal helps to improve availability of these nutrients. Of course it is difficult to be certain since these concentrations were similar to the control in almost all the relationships. The stability in stalk P and K could be because the corn was not limited in P or K. Grain N follows the same trend as yield supporting the notion that N was the most limiting factor for the charcoal-treated corn.

Land application does seem to have potential for disposal and/or nutrient cycling of DDGs and charcoal, with DDGs being preferred because of its N contribution. Charcoal may contribute P and K as well as micronutrients to the soil. Unfortunately conclusions regarding this are beyond the scope of this experiment. This experiment was not designed to observe/comment on any of the long term effects of DDGs and charcoal on O.M. , microbiological activity, and physical properties, but some of the observations and chemical analysis indicate that both materials are high in carbon and seem to decompose slowly, with charcoal being the slower of the two. Charcoal may also have benefits when it comes to storing carbon as suggested by Boateng (2007) or adding CEC to soils but neither was observed.

Conclusions

The application of DDGs produced the same yields and similar N responses as urea, in six out of seven treatments. The no-till and tilled treatments had the same grain yield at all locations except one, with the DDG-tilled treatment still producing yields similar to urea. Conversely, corn yields did not respond to charcoal applications in any of the location-years it was applied.

With these results, DDG could function as a replacement for urea and perform as well. Both materials can also be a source of P and K if available. Bulk and price are the biggest limitation to future use of DDG as a fertilizer. Both DDGs and charcoal have to be applied at high rates (22 and 55 kg kg^{-1} N) to achieve the same amount of total N as urea (around 2 kg urea to supply one kg N). At the higher application rates, cost of material as well as transportation cost will be a major concern.

References

Al-Suwaiegh, S., K.C. Fanning, R.J. Grant, C.T. Milton, and T.J. Klopfenstein. 2002. Utilization of distillers grains from the fermentation of sorghum or corn in diets for finishing beef and lactating dairy cattle. Journal of Animal Sci. 80:1105-1111.

Boateng, A.A. 2007. Characterization and thermal conversion of charcoal derived from fluidized-bed fast pyrolysis oil production from switchgrass. Ind. Eng. Chem. Res. 46:8857-8862.

Bowman, L. and E. Geiger. 1984. Optimization of fermentation conditions for alcohol production. Biotechnology and Bioengineering 26:1492-1497.

Boydston, R., H.P. Collins, and S.F. Vaughn. 2008. Response of weeds and ornamental plants to potting soil amended with dried distillers grains. HortScience 43:191-195.

Brown, J.R., 1997. Recommended chemical soil test procedure for the North Central region. North Central Regional Res. Publ. 221. Univ. of Missouri Exp. Stn., Columbia, MO.

Brown, M. B. and Forsythe, A. B. 1974. Robust tests for equality of variances. Journal of the American Stat. Assoc. 69:364–367.

Brewer, C., K. Schmidt-Rohr, J.A. Satrio, and R.C. Brown. 2009. Characterization of biochar from fast pyrolysis and gasification systems. Environmental Progress and Sustainable Energy 28:3. doi:10.1002/ep.10378.

Chan, K.Y., L.V. Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2007. Agronomic values of greenwaste biochar as a soil amendment. Aust. J. of Soil Res. 45:629–634.

Fastinger, N.D., J.D. Latshaw, and D.C. Mahan. 2006. Amino acid availability and true metabolizable energy content of corn distillers dried grains with solubles in adult cecectomized roosters. Poultry Sci. 85:1212-1216.

Gaskin, J.W., R.A. Speir, K. Harris, K.C. Das, R.D. Lee, L.A. Morris, and D.S. Fisher. 2010. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. Agron. J. 102:623-633.

H.R. 6: The Energy Independence and Security Act of 2007. United States of America. Public Law 110-140. 110th Congress. December 19, 2007. Available Online at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

Major, J., M. Randon, D. Molina, S.J. Riha, and J. Lehmann. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant and Soil 333:117-128.

Mozaffari, M., C.J. Rosen, M.P. Russelle, and E.A. Nater. 2000. Corn and soil response to application of ash generated from gasified alfalfa stems. Soil Sci. 165:896-907.

Mozaffari, M., M.P. Russelle, C.J. Rosen, and E.A. Nater. 2002. Nutrient supply and neutralizing value of alfalfa stem gasification ash. Soil Sci. Soc. of Am. J. 66:171-178.

Nelson, K. A., P. P. Motavalli, and R. L. Smoot 2009. Utility of dried distillers grain as a fertilizer for corn. J. of Agric. Sci. 1:3-12.

Pels, J.R., D.S. Nie, and J.H.A. Kiel. 2005. Utilization of ashes from biomass combustion and gasification. 14th European Biomass Conference and Exhibition, Paris, France, 17-21 October 2005.

Renewable Fuels Association. 2010. Ethanol Production and Co-products. Available online at: http://chooseethanol.com/what-is-ethanol/entry/how-is-it-made/. And: http://chooseethanol.com/what-is-ethanol/entry/food-fuel/. Renewable Fuels Association: Washington, DC.

Rondon, M.A., J. Lehmann, J. Ramirez, M. Hurtado. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-charcoal additions. Biology and Fertility of Soils. 43:699-708.

SAS Institute. 2002. SAS version 9.1. SAS Institute, Cary, NC.

Sasikala-Appukuttan, A.K., D.J. Schingoethe, A.R. Hippen, K.F. Kalscheur, K. Karges, and M.L. Gibson. 2008. The feeding value of corn distillers solubles for Lactating Dairy Cows. J. of Dairy Sci. 91:279-287.

Schingoethe, D.J., K.F. Kalscheur, A.R. Hippen, and A.D. Garcia. 2009. Invited review: The use of distillers products in dairy cattle diets. J. of Dairy Sci. 92:5802-5813.

Spath, P. L. and D. C. Dayton. 2003. Preliminary screening- technical and economic assessment of synthesis gas to fuels and chemicals with emphasis on the potential for biomass-derived syngas. National Renewable Energy Laboratory. 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA.

Spiehs, M.J., M.H. Whitney, and G.C. Shurson. 2002. Nutrient database for distiller’s dried grains with solubes produced from new ethanol plants in Minnesota and South Dakota. J. of Animal Sci. 80:2639-2645.

Steiner, C., W. Teixeira, J. Lehmann, T. Nehls, J. de Macêdo, W. Blum, and W. Zech. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant and Soil 291:275–290.

Stassen, H.E. 1995. Small-Scale Biomass Gasifiers for Heat and Power. World Bank Technical Paper. 296. The International Bank for Reconstruction and Development/ The World Bank. 1818 H Street, N.W. Washington, D.C. 20433, USA.

Table 1. Nutrient concentration of charcoal and DDGs for 2007, 2008, and 2009 in Kansas.

Source and Year	Carbon	Nitrogen	Phosphorus	Potassium
Nutrient Concentrations				
	------------------- $g\ kg^{-1}$ -------------------			
Charcoal				
2008	589	19	28.5	42
2009	392	18	1.7	15
DDG				
2007	431	41	7.8	9
2008	433	47	7.5	5
2009	432	47	7.2	7

Table 2. Corn yield, soil test values, average monthly maximum temperatures, and monthly precipitation at experimental sites in Doniphan County in 2007, Riley County in 2008, Marshall County in 2009, and Riley County in 2009, Kansas.

Location-year	Yield	NH_4	NO_3	P	K	O.M.	pH	Apr	May	Jun	Jul	Aug	Sep	Apr	May	Jun	Jul	Aug	Sep
	Mg ha^{-1}	ppm	ppm	Ppm	ppm	%		- Average high temperature (°C) -						- - - - - - Precipitation (mm) - -- - - - - -					
Doniphan 2007	10.6	4.3	9.1	52.0	260	2.4	6.6	16.2	24.3	28.1	30.6	32.7	27.0	74	238	40	14	261	55
Riley 2008	9.3	3.5	7.3	48.0	246	1.0	7.2	16.4	24.5	30.7	31.7	30.4	26.1	57	126	290	120	134	138
Marshall 2009	7.4	2.1	6.6	20.1	268	1.4	5.9	17.0	23.7	28.9	28.8	29.1	24.7	100	60	159	71	96	36
Riley 2009	9.1	3.2	8.1	51.4	230	1.3	7.7	17.9	24.7	30.9	29.9	30.2	25.5	133	25	215	166	114	52

Table 3. Orthogonal contrast probabilities for corn grain yield, ears m^{-2}, ear weight, and kernel weight as affected by charcoal, DDG, and urea at four location-years in Kansas.

Treatment	Doniphan 2007	Riley 2008	Marshall 2009	Riley 2009
Grain Yield	- - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - -	
Urea vs. Charcoal	-	0.01	0.01	0.01
Urea vs. DDG no-till	0.08	0.18	0.72	0.01
Urea vs. DDG tilled	0.35	0.24	0.03	0.74
DDG no-till vs. tilled	0.38	0.86	0.08	0.02
Ears m^{-2}				
Urea vs. Charcoal	-	0.22	0.04	0.80
Urea vs. DDG no-till	0.60	0.1	0.52	0.03
Urea vs. DDG tilled	0.60	0.54	0.96	0.43
DDG no-till vs. tilled	1.00	0.40	0.49	0.14
Weight ear^{-1}				
Urea vs. Charcoal	-	0.01	0.74	0.14
Urea vs. DDG no-till	0.12	0.04	0.68	0.07
Urea vs. DDG tilled	0.51	0.19	0.84	0.92
DDG no-till vs. tilled	0.35	0.42	0.83	0.09
Kernel weight				
Urea vs. Charcoal	-	0.01	0.58	0.40
Urea vs. DDG no-till	0.15	0.01	0.01	0.31
Urea vs. DDG tilled	0.10	0.01	0.01	0.03
DDG no-till vs. tilled	0.18	0.32	0.36	0.21

Table 4. Regression equation results for corn grain yield, ears m^{-2}, and kernel weight in response to charcoal, DDG, and urea applications in three location-years in Kansas.

	X_0	Equation	R^2	Equation	R^2	Equation	R^2
		Grain Yield		Ears m^{-2}		kernel weight	
Doniphan 2007							
Charcoal no-till	-	-	-	-	-	-	-
Charcoal tilled	-	-	-	-	-	-	-
DDG no-till	-	Y = 9.2 + 0.012x†	0.24	Y = 8.1 + 0.003x	0.11	Y = 261 + 0.137x	0.24*
DDG tilled	-	Y = 9.1 + 0.017x	0.54*	Y = 7.5 – 0.002x	0.06	Y = 251 + 0.250x	0.44*
Urea	41.0	Y = 8.8 + 0.064x	0.40*	Y = 7.9 + 0.000x	0.02	Y = 263 + 0.192x	0.32*
Riley 2008							
Charcoal no-till	-	Y = 8.3 - 0.043x	0.02	Y = 5.9 – 0.000x	0.01	Y = 244 – 0.003x	0.01
Charcoal tilled	-	Y = 8.3 - 0.087x	0.06	Y = 6.0 – 0.000x	0.01	Y = 247 – 0.013x	0.01
DDG no-till	106.0	Y = 8.1 + 0.024x	0.62*	Y = 6.1 – 0.003x	0.16	Y = 247 + 0.331x	0.73*
DDG tilled	-	Y = 8.6 + 0.014x	0.62*	Y = 5.7 – 0.000x	0.01	Y = 250 + 0.349x	0.53*
Urea	89.6	Y = 8.2 + 0.027x	0.69*	Y = 6.1 – 0.004x	0.05	Y = 247 + 0.095x -0.003x^2	0.66*
Riley 2009							
Charcoal no-till	-	Y = 6.3 + 0.012x	0.18	Y = 6.7 – 0.001x	0.01	Y = 100.3 + 0.109x	0.09
Charcoal tilled	-	Y = 7.0 - 0.043x	0.05	Y = 7.2 – 0.004x	0.05	Y = 95.4 + 0.041x	0.01
DDG no-till	100.2	Y = 6.3 + 0.057x	0.64*	Y = 7.8 – 0.006x	0.21*	Y = 108.4 + 0.455x	0.37*
DDG tilled	-	Y = 7.7 + 0.043x	0.60*	Y = 6.7 – 0.010x	0.09	Y = 129.7 + 0.317x	0.14
Urea	-	Y = 6.7 + 0.065x	0.81*	Y = 6.5 + 0.008x	0.24*	Y = 102.9 + 0.643x	0.63*
Marshall 2009							
Charcoal no-till	-	Y = 6.3 - 0.010x	0.01	Y = 7.34 - 0.004x	0.30*	Y = 248 + 0.046x	0.08
Charcoal tilled	-	Y = 5.7 + 0.002x	0.00	Y = 7.11 - 0.004x	0.21	Y = 248 – 0.008x	0.01
DDG no-till	83.5	Y = 6.4 + 0.031x	0.51*	Y = 7.39 - 0.002x	0.06	Y = 251 + 0.130x	0.44*
DDG tilled	110.5	Y = 6.3 + 0.032x	0.74*	Y = 6.87 + 0.002x	0.18	Y = 248 + 0.134x	0.42*
Urea	108.1	Y = 6.2 + 0.028x	0.76*	Y = 7.18 + 0.000x	0.00	Y = 247 + 0.049x	0.72*

* indicates that the regression equation was significant at an alpha = 0.05 level.

† x indicates kg N ha^{-1}

Table 5. Orthogonal contrast probabilities for corn stalk nitrogen, stalk phosphorus, stalk potassium, and grain nitrogen as affected by charcoal, DDG, and urea at four location-years in Kansas.

Treatment	Riley 2008	Marshall 2009	Riley 2009
Stalk Nitrogen	- - - - - - - - - -	Pr>F	- - - - - - - - - - - -
Urea vs. Charcoal	NA†	0.01	0.01
Urea vs. DDG no-till	NA	0.57	0.02
Urea vs. DDG tilled	NA	0.16	0.11
DDG no-till vs. tilled	NA	0.05	0.45
Stalk Phosphorus			
Urea vs. Charcoal	NA	0.01	0.01
Urea vs. DDG no-till	NA	0.17	0.01
Urea vs. DDG tilled	NA	0.88	0.04
DDG no-till vs. tilled	NA	0.13	0.19
Stalk Potassium			
Urea vs. Charcoal	NA	0.21	0.95
Urea vs. DDG no-till	NA	0.04	0.28
Urea vs. DDG tilled	NA	0.03	0.69
DDG no-till vs. tilled	NA	0.97	0.49
Grain Nitrogen			
Urea vs. Charcoal	0.01	0.01	0.01
Urea vs. DDG no-till	0.01	0.46	0.01
Urea vs. DDG tilled	0.01	0.01	0.02
DDG no-till vs. tilled	0.05	0.01	0.03

‡NA, not available

Table 6. Regression equations for corn stalk nitrogen, and phosphorus for charcoal, DDG, and urea applications in three location-years in Kansas.

	Stalk Nitrogen		Stalk Phosphorus		
	Equation	R^2	X_0	Equation	R^2
Riley 2009					
Charcoal no-till	Y = 3.34 - 0.002x†	0.07	-	Y = 2.00 - 0.003x	0.08
Charcoal tilled	Y = 2.96 - 0.001x	0.03	-	Y = 1.36 + 0.001x	0.01
DDG no-till	Y = 3.46 - 0.002x	0.06	-	Y = 2.06 - 0.005x	0.13
DDG tilled	Y = 2.98 - 0.004x	0.16	-	Y = 1.30 - 0.001x	0.01
Urea	$Y = 3.65 - 0.015x + 1.18E\text{-}5x^2$	0.33*	65.8	Y = 2.36 - 0.260x	0.66*
Marshall 2009					
Charcoal no-till	Y = 2.69 + 0.000x	0.00		Y = 1.05 + 0.001x	0.07
Charcoal tilled	Y = 2.63 – 0.000x	0.00		Y = 0.85 + 0.002x	0.21
DDG no-till	Y = 2.78 + 0.003x	0.18		$Y = 1.03 - 0.007x + 2.63E\text{-}5x^2$	0.48*
DDG tilled	Y = 2.68 + 0.006x	0.28*		$Y = 0.76 - 0.005x + 1.20E\text{-}5x^2$	0.57*
Urea	Y = 2.63 + 0.005x	0.60*		$Y = 1.03 - 0.009x + 3.27E\text{-}5x^2$	0.67*

* indicates that the regression equation was significant at an alpha = 0.05 level.

† x indicates kg N ha^{-1}

Table 7. Regression equations for corn stalk potassium and grain nitrogen for charcoal, DDG, and urea applications in three location-years in Kansas.

		Stalk Potassium		Grain Nitrogen	
	X_0	Equation	R^2	Equation	R^2
Riley 2009					
Charcoal no-till	79.6	Y = 14.0 + 0.044x†	0.40	Y = 8.38 + 0.001x	0.03
Charcoal tilled		Y = 15.4 + 0.007x	0.03	Y = 8.08 - 0.001x	0.03
DDG no-till	44.0	Y = 14.0 + 0.006x	0.41*	Y = 8.13 + 0.005x	0.15
DDG tilled		Y = 15.0 + 0.017x	0.16	Y = 7.81 + 0.011x	0.59*
Urea		Y = 14.5 + 0.019x	0.26*	Y = 8.19 + 0.012x	0.72*
Marshall 2009					
Charcoal no-till		Y = 11.8 + 0.005x	0.10	Y = 8.42 + 0.001x	0.02
Charcoal tilled		Y = 10.9 + 0.012x	0.27*	Y = 8.31 + 0.001x	0.02
DDG no-till		Y = 12.1 + 0.006x	0.12	Y = 8.54 + 0.006x	0.34*
DDG tilled		Y = 10.8 + 0.017x	0.41*	Y = 8.33 + 0.016x	0.73*
Urea		Y = 11.3 + 0.006x	0.15	Y = 8.24 + 0.011x	0.59*

*indicates that the regression equation was significant at an alpha = 0.05 level.

† x indicates kg N ha^{-1}