UTILIZATION OF DRY DISTILLERS GRAINS AND CHARCOAL AS NITROGEN FERTILIZER IN CORN

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Abstract

With the increase in bio-energy production there is also an increase in by-products. Without proper disposal, these by-products might cause future economic and/or ecological problems. Land application has potential as a disposal and/or nutrient cycling method if these by-products have nutritive value for agricultural crops. The purpose of the study was to compare the use of two by-products of bio-energy production, dry distillers grains (ethanol) and charcoal (pyrolysis), as fertilizer with urea in corn (*Zea mays* L.). The experiment consisted of four location-years in Kansas. Treatments were dry distiller's grains (DDG) no-till and tilled for four location-years and char no-till and tilled for three location-years. No-till urea was used as a baseline for comparison at all location-years. The Nitrogen rates ranged from 45 to 180 kg N ha^{-1}. All source material was spring applied before tillage and planting. The corn yields for DDGs and urea were the almost the same across tillage treatments and locations. For DDG no-till, DDG tilled, and urea, the rates at which to achieve the same yields were 97, 111, 78 kg N ha^{-1}, respectively. Corn yields for char at all rates and tillage treatments were the same as no fertilizer. The char, because of immobilization or lack of decomposition, did not contribute to the nitrogen needs of the corn. Neither material showed any inhibitory or otherwise negative effects on the corn in terms of grain yield compared with the control. But both DDGs and char had to have large amounts of material applied to achieve the same amount of nitrogen as urea. Land application of DDGs and char has potential merit for disposal/nitrogen cycling with DDGs being preferred for its nitrogen contribution.

Table of Contents

List of Tables

List of Figures

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CHAPTER 1 - Introduction

Bio-energy

With the growing concerns, environmentally and politically, over the use of petroleum distillates, an effort to supplement, if not offset petroleum 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 is one of the many bio-fuels that are currently being researched and produced as an alternative fuel source for automobiles (EISA of 2007, sec. 202). Ethanol, currently, makes up the majority of the bio-fuels produced in the US. The production of ethanol is from the fermentation of sugars, mainly from the malted starch of small grains. The fermented liquid is distilled to produce higher purity ethanol (Renewable Fuels Association, 2010; Bowman et al. 1984; Boruf and Blaine, 1953). At room temperatures ethanol is a liquid and when mixed with gasoline at a 10% solution (10% ethanol) can be used as fuel in automobiles without alterations to the vehicle (Scheller and Mohr, 1975; Renewable Fuels Association, 2010).

Pyrolysis is another method for producing bio-energy/fuels. Pyrolysis is a process in which high temperatures and low levels of oxygen cause organic material to decompose. Depending on the material used and the process, flash pyrolysis, slow pyrolysis, or gasification, 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.

Dry Distillers Grains

Ethanol is produced from the fermentation of simple sugars in an anoxic environment. The mixture of liquids and solids is separated and the liquid is heated to 78.4 degrees Celsius to vaporize the ethanol. The ethanol vapor is condensed to produce a higher purity end product. With the dry-milling 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 (*Zea mays* L.) inputs (Bowman and Geiger 1984; Renewable Fuels Association, 2010).

Because DDGs are produced from corn or sorghum (*Sorghum bicolor* L. Moench) it can be 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, with the use of DDGs has been reported to suppress weeds with surface application and incorporation (Boydston et al., 2008). Nelson et al. (2009) reported that application of DDGs, as a nitrogen source, had similar corn yields as compared with urea and anhydrous ammonia, when environmental conditions were not limiting. In 2008, 27 million Mg of DDGs were produced as animal feed in the US (Renewable Fuels Association, 2010).

Charcoal

With an increase of pyrolysis and gasification for bio-energy production the by-products are equally increased. Two of the three by-products are used directly for energy, bio-oil and syngas. Flash pyrolysis and slow pyrolysis (pyrolysis) produce more bio-oil. Bio-oil is a hydrocarbon similar to crude oil and can be used in refining hydrocarbon fuels similar to gasoline. Gasification favors the production of mainly syngas, because of higher temperatures and more 'complete' decomposition. Syngas is a mixture of hydrogen and carbon monoxide which can be burned directly for energy (steam turbine generator) or used to also create gasoline-like hydrocarbons with the Fischer-Tropsch process (Spath and Dayton, 2003; Stassen, 1995; Pels et al., 2005; Brewer et al., 2009). In an effort to improve efficiency some ethanol bio-refineries use unfermentables/ waste products as an energy source (heat/electrical) for distillation and system operations (Khullar et al., 2009). The unfermentables will be defined as the seed parts which have low starch/sugars. The endosperm is the major source of fermentable sugars, the rest of the seed, pericarp, germ, and tip cap, have no major value in fermentation (Murthy et al., 2009; Khullar et al., 2009). Milling systems are available to cost effectively separate these components of the grain. One example of using unfermentables is to burn the dried pericarp and germ (after it has been pressed for oil) to heat the liquid 'beer' during the distillation process, an example being LifeLine Foods LLC. St. Joseph, MO. Pyrolysis processes can also be used by ethanol bio-refineries. Pyrolysis or gasification can be used with the unfermentables, other waste material, or local crop residues to produce electricity, bio-oil, or syngas for systems operations (Stassen, 1995; Spath and Dayton, 2003). The residual materials from combustion, pyrolysis, and gasification can range from light ash to a black ash or charcoal (char) like material, based upon the conditions in which it was burned (Pels et al., 2005).

Char will 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). These extra processes to produce energy (syngas), fuels (bio-oil), or improve production returns for ethanol bio-refineries create another potential waste by-product, char.

Not much is known about the plant nutritive value (nitrogen) of char, especially in temperate regions. Mozaffari et al. (2000, 2002) reported that char (called ash but was 42% carbon) from gasification could be a potential source of potassium and phosphorus, as well as an effective liming agent. Gaskin et al. (2010) reported no increase in corn tissue nitrogen with the field application of char but reported responses to potassium, calcium, magnesium, and sulfur (depending on source material). Char 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 potassium, phosphorus, calcium, and magnesium availability, as well as reductions of available aluminum (Major et al., 2010; Chan et al., 2007; Rondon et al., 2007). Steiner et al. (2007) reported that the addition of char without fertilizer did not affect nutrient concentrations in rice (*Oryza sativa* L.) or sorghum. Char application along with nitrogen fertilizer have been reported to increase radish (*Raphanus sativus*) and corn yields above that of fertilizer alone but no yield increase with just char (Chan et al., 2007; Major et al., 2010).

Hypothesis

The hypothesis of this experiment is that the application of DDGs will have the same/similar yield responses as urea in both no-till and tilled systems and may also increase phosphorus and potassium availability. It is believed that the char will have no nitrogen benefit for the corn, but may increase plant available phosphorus and potassium.

Objectives

The main objective of this experiment was to compare the yield response of DDGs and Char in no-till and tilled systems with no-till urea as a source of nitrogen fertilizer in corn. The secondary objective was to observe the affects of DDGs and char on plant uptake of phosphorus and potassium as well as establish a simple price comparison between fertilizer sources.

CHAPTER 2 - 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 dry distillers grains (DDGs) at four rates: 45, 90, 135, and 180 kg N ha^{-1} in no-till and tilled. Source material (char and DDGs) nutrient analysis can be found on Table 1. Urea (46% nitrogen) 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 (Latitude 39.737 and Longitude -95.162). 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, O.M., and pH) can be found on Table 2. The previous crop was soybean. Source material (DDGs and urea) application, tillage, and corn planting were completed, in that order, on 19 April, 2007. The corn hybrid used was Pioneer '33K40'. 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 char, at nitrogen rates of 45 and 90 kg ha^{-1} within each tillage treatment. Plots were planted at the Ashland Bottoms Research Farm located south of Manhattan, KS (Latitude 39.138 and Longitude -96.637). The soil type was a Belvue silt loam (Coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvents). The previous crop was soybean. Source material (Char, DDGs, and urea) application, tillage, and corn planting were completed, in that order, on 19 May, 2008. The corn hybrid used was Croplan '6831'. The field was fall chiseled and spring cultivated before planting. 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, nitrogen sources and rates were the sub plots. Dry distillers grains and char 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. The plots at Marshall were planted south of Marysville, KS on a cooperator's field (Latitude 39.803 and Longitude -95.162). 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'. Application of source material, tillage and planting were completed, in that order, 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.

At the same location as the Riley County plot in 2008, corn was planted to measure residual nitrogen via yield, for each treatment, after one year (resample). Dekalb 'DKC63-42' was planted no-till on 6 May, 2009. No new source material or fertilizer was applied. The plot was hand harvested on 11 December, 2009.

Dry distillers grains in 2007 and 2008 were produced and donated by LifeLine Foods LLC, St. Joseph, MO. In 2009 the DDGs were procured from Key Feeds, Clay Center, KS. Different sources of char were used in 2008 compared with 2009. In 2008, char produced from combustion of pericarp from corn grain fractionated via dry milling was used (produced by LifeLine Foods LLC, St. Joseph, MO). In 2009, the char was produced from the gasification of corn residue produced by a fluidized bed gasifier (ICM Inc, Newton, KS). Nitrogen content of the DDGs and char were approximately the same. All DDGs and char treatments were applied based on total nitrogen and corrected for moisture.

Experimental units consisted of four row "plots" 3.1 by 9.2 m; rows were spaced 0.76 m apart. 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 taken at all locations and years to measure nitrogen uptake. In 2007 and 2008, samples were taken according to the Iowa State stalk nitrate test, 15 sequential stalk sections were taken 15.2 cm above ground and were 20.3 cm in length. In 2007, stalk samples were taken from only two replications. In 2009, ten sequential whole plants samples were taken. Samples for both methods 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 22mm sieve. Plant samples were analyzed for nitrogen, phosphorus, and potassium concentration. Grain samples were analyzed for nitrogen concentration. Plant and grain samples were analyzed by the Kansas State University Soils lab.

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 30cm. Soil samples were analyzed by the Kansas State University Soils lab for organic matter, nitrate, ammonium, pH, phosphorus and potassium.

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 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, char, and urea. All regression lines 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.

CHAPTER 3 - Results

Introduction

This study took place in Northeast Kansas where temperatures and rainfall are adequate to grow dryland corn most years. The 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}. The lowest plot yield of 4.6 Mg ha^{-1} was at Marshall County and the highest plot yield of 16.2 Mg ha^{-1} was at Riley County, both were in 2009. The average yields for all locations and years remained within 1.7 Mg ha^{-1} of the total average, with Marshall County having the lowest yield and Doniphan County having the highest. The lower overall yield at Marshall County may be due to a dry period from July to September (Table 3). Marshall County also had about 20 cm lower total rainfall during the growing season then Riley County in 2009. The Doniphan County location had better growing conditions (around 80 cm of precipitation) as well as no char treatments to reduce the average grain yield. Without char treatments included, the average grain yield at Marshall County was still approximately 2 Mg ha^{-1} lower than at Doniphan without char Riley County in 2009 had the highest average yield and had similar temperatures all season.

Grain Yield

Doniphan County in 2007 had an average grain yield of 10.9 Mg ha^{-1} and no differences in yields were detected between nitrogen sources (Table 4). In 2008 at Riley County, grain yield was different between urea and char but not between urea, DDG no-till, and DDG tilled, with average yields for char and urea of 7.8 and 10.3 Mg ha^{-1}, respectively. No differences were found between the DDG no-till and tilled treatments. In 2009 at Marshall County, grain yield for char was 2.5 Mg ha^{-1} lower than urea with an average yield of 6.0 Mg ha^{-1}. Urea yielded less than DDG tilled at 8.5 and 9.2 Mg ha^{-1}, respectively. There were no differences between DDG no-till and urea. There was also no difference between DDG no-till and DDG tilled. At Riley County in 2009, grain yield for char was lower than urea at 7.1 compared with 12.4 Mg ha^{-1}. With an average yield of 10.9 Mg ha^{-1}, DDG no-till yield was lower than both DDG tilled and urea. At 12.2 Mg ha^{-1}, no differences were found between DDG tilled and urea. Grain yields were the same for all the treatments in the residual nitrogen resample of the 2008 plot (Table 5).

When grain yield is plotted as a response to nitrogen (for each source); urea was fit to a linear plateau model with the X_o equal to 41 kg N ha^{-1} and an r^2 of 0.40 in 2007 (Figure 1). Both DDG no-till and DDG tilled fit linear models, with r^2 of 0.24 and 0.54, respectively. At Riley County in 2008, DDG no-till and urea were fit to linear plateaus, with the X_o equal to 106 and 89.6 kg N ha^{-1} and r^2 of 0.62 and 0.69, respectively (Figure 2). The DDG tilled fit a linear model best with r^2 of 0.62. At Marshall County, DDG no-till, DDG tilled, and urea were all fit to linear plateaus, with the X_o equal to 83.5, 110.5, and 108.1 kg N ha^{-1} and r^2 of 0.51, 0.74, and 0.76, respectively (Figure 3). At Riley County in 2009 DDG no-till was fit to a linear plateau with the X_o equal to 100.2 kg N ha^{-1} and r^2 of 0.64. Both DDG tilled and urea, were fit to linear regression models, with r^2 of 0.60 and 0.81, respectively (Figure 4). With the nitrogen resample plot, DDG no-till fit a linear plateau model with the X_o equal to 91.6 kg N ha^{-1}, and r^2 of 0.42 (Figure 5). The DDG tilled and urea fit linear regressions, with r^2 of 0.28 and 0.34, respectively. Char, in all years and locations, could not be fit to any regression models.

Ears m^{-2}

In 2007 and 2008, no differences were found between treatments, at either location, for ears m^{-2} (Table 6). At Marshall County, char treatments had fewer ears m^{-2} than the other treatments, with 6.8 ears m^{-2}. At Riley County in 2009, the DDG no-till had the most ears at 7.6 ears m^{-2}. All other treatments were not different from urea. With the resample plot, only char was different from urea, with char being higher at the 45 and 90 kg N ha^{-1} rates (Table 5). Urea had 7.4 ears m^{-1} and char had 7.9 ears m^{-1}.

When ears m^{-2} are plotted with nitrogen applied as char, DDGs, and urea only two locations had responses, Riley County in 2008 and Marshall County in 2009. In 2008 char and DDG tilled could not be fit to any regression models (Figure 6). Urea and DDG no-till were both fit to linear models with negative slopes and r^2 of 0.14 and 0.51 for DDG and urea, respectively. At Marshall County the opposite of 2008 occurred with urea and DDG no-till not being able to be fit to any models (Figure 7). Both char no-till and char tilled were fit to linear models with negative slopes and r^2 of 0.30 and 0.21, respectively. The DDG tilled treatment fit a linear model with a positive slope and r^2 of 0.18.

Grain Weight Ear^{-1}

Only at Riley County in 2008 were any treatment means different from urea. Char and DDG no-till both had lower ear weights, at 130 and 176 g ear^{-1}, respectively (Table 7). With a mean ear weight of 58 g, for the resample plot, char was lower than urea, which had 75 g ear^{-1} (Table 5).

When grain weight ear^{-1} is plotted with nitrogen applied as char, DDGs, and urea, three of the four location-years, as well as the nitrogen resample of 2008 plot, showed responses. At Doniphan County, DDG no-till, DDG tilled, and urea all had positive linear responses to nitrogen applied with r^2 of 0.16, 0.55, and 0.25, respectively (Figure 8). In 2008 at Riley County, both char treatments could not be fit to any models. The three other treatments, DDG no-till, DDG tilled, and urea all had linear responses to nitrogen applied with positive slopes and r^2 of 0.73, 0.53, and 0.66, respectively (Figure 9). At Riley County in 2009, char no-till and urea fit linear models with r^2 of 0.17 and 0.24 (Figure 10). Charcoal tilled, DDG no-till, and DDG tilled could not be fit to any models. The residual nitrogen resample of 2008 in 2009 had the same responses as 2008, with DDG no-till, DDG tilled, and urea all fitting linear models with positive slopes and both char treatments not fitting any models. The r^2 for the lines are 0.35 for DDG no-till, 0.18 for DDG tilled, and 0.21 for urea.

Individual Seed Weight

At Doniphan County, like grain yield, seed weight had no differences between source treatments. In 2008, urea had the heaviest seed weight at 303 mg $seed^{-1}$ (Table 8). No difference was found between the DDG no-till and tilled at 283 mg $seed^{-1}$. The char treatments had lower seed weights than urea at 243 mg $seed^{-1}$. At Marshall County, the DDG no-till and tilled had the highest seed weights at 263 mg $seed^{-1}$ and were not different from each other. Urea and both char treatments were the same at 250 mg $seed^{-1}$. At Riley County in 2009, the only difference was the DDG tilled with the highest seed weight of 276 mg $seed^{-1}$. Char, DDG no-till, and urea were the same with an average seed weight of 265 mg $seed^{-1}$. With the nitrogen resample plot, DDG tilled has lower seed weight than urea at 237 mg $seed^{-1}$ (Table 5). Urea compared against char, at 45 and 90 kg N ha^{-1}, was not different (the only char rates used in 2008). DDG no-till was also the same as urea at 243 mg $seed^{-1}$.

Seed weight showed responses to nitrogen applications at all location-years. At Doniphan County, DDG no-till, DDG tilled, and urea all fit linear models with positive slopes and r^2 of 0.24, 0.44, and 0.32, respectively (Figure 12). In 2008 at Riley County both char treatments did not show any response (Figure 13). Both of the DDG treatments were fit to linear models with r^2 of 0.73 for DDG no-till and 0.76 for DDG tilled. Urea was fit to a quadratic model with r^2 of 0.82. At Marshall County only DDG no-till and DDG tilled could be fit to any models, both of which were linear with r^2 of 0.44 and 0.42, respectively (Figure 14). In 2009 at Riley County, char no-till and char tilled could not be fit to any models (Figure 15). The two DDG treatments and urea all fit to linear models with r^2 of 0.24 for DDG no-till, 0.39 for DDG tilled, and 0.35 for urea. With the nitrogen resample plot only urea could be fit to a model (Figure 16). Urea fit a linear model with a positive slope and r^2 of 0.34.

Stalk Nitrogen

Doniphan County had highly variable stalk nitrogen concentrations, so no differences were detected (Table 9). In 2008, urea had the highest stalk nitrogen concentration at 5.2 g N kg^{-1}. There was no difference between DDG no-till and tilled with a mean of 3.0 g N kg^{-1}. The char treatments had the lowest mean at 2.4 g N kg^{-1}. At Marshall County, char was the only treatment different from urea, at 2.6 g N kg^{-1} compared with 3.1 g N kg^{-1}. At Riley County in 2009, char and DDG no-till were lower than urea with, 2.9, 3.2, and 3.6 g N kg^{-1}, respectively. The DDG tilled was the same as urea, but was also not different from DDG no-till.

Only two location-years showed any response to plotting stalk nitrogen with nitrogen application. The first location was Riley County in 2008, with both char treatments not being able to be fit to any models (Figure 17). Positive linear models were fit to DDG no-till, DDG tilled fit, and urea with r^2 of 0.60, 0.46, and 0.74, respectively. Like in 2008 at Riley County, in 2009 at Marshall County only DDG no-till, DDG tilled, and urea could be fit to any model (Figure 18). All three were fit to positive linear models with r^2 for DDG no-till of 0.18, DDG tilled of 0.28, and urea of 0.60.

Stalk Phosphorus

At Doniphan County stalk samples were not tested for Phosphorus (Table 10). At Riley County in 2008 no differences were found between any of the treatments. In 2009 at Marshall County urea, DDG no-till and DDG tilled were the same with a concentration 0.58 g P kg^{-1}. The char treatments had the highest phosphorus concentration at 1.1 g P kg^{-1}. At Riley County in 2009 the char, DDG no-till, and DDG tilled treatments were higher than urea, at 1.4 g P kg^{-1}. Urea had the lowest concentration with 1.2 g P kg^{-1}.

When stalk phosphorus is plotted with applied nitrogen, two locations showed responses. At Marshall County, char no-till was the only treatment that could not be fit to a model (Figure 19). The char tilled treatment was fit to a positive linear model with r^2 of 0.21. Negative quadratic models were fit to DDG no-till, DDG tilled, and urea. They had r^2 of 0.48 for DDG no-till, 0.57 for DDG tilled, and 0.67 for urea. At Riley County in 2009 only urea was fit to a model and it was a negative linear plateau model with X_o of 66 kg N ha^{-1} and r^2 of 0.66 (Figure 20). All other treatments could not be fit to any models.

Stalk Potassium

Stalk potassium was not taken for Doniphan County (Table 11). In 2008 urea had the lowest potassium concentration with 28.7 g kg^{-1}. The char and DDG no-till treatments had the highest concentration with 32.9 g K kg^{-1}. The DDG no-till treatment had a higher potassium concentration then DDG tilled with 32.9 instead of 30.1 g kg^{-1}. In Marshall County, char had the same concentration as urea with 12.1 g K kg^{-1}. Both the DDG treatments, no-till and tilled, had higher potassium concentrations then urea with 12.8 g kg^{-1} and were not different form each other. No treatment differences were found at Riley County in 2009.

When stalk potassium was plotted with nitrogen application three locations showed responses. Riley County in 2008, only DDG no-till, DDG tilled, and urea could be fit to any models (Figure 21). They were fit to linear models all with negative slopes and r^2 of 0.24, 0.49, and 0.52, for DDG no-till, DDG tilled, and urea, respectively. At Marshall County in 2009, char no-till and DDG no-till could not be fit to a model (Figure 22). The remaining treatments, char tilled, DDG tilled, and urea were all fit to linear models with positive slopes and r^2 of 0.27, 0.41, and 0.15, respectively. At Riley County in 2009, only char tilled could not be fit to a model (Figure 23). The DDG tilled and urea were fit to linear models with positive slopes and r^2 of

0.16 and 0.26, respectively. Charcoal no-till and DDG no-till were both fit to linear plateaus with X_o of 80 and 44 kg N ha^{-1} and r ^{2} of 0.40 and 0.41, respectively.

Grain Nitrogen

There was no grain tested for nitrogen concentration in 2007. In 2008 urea was the highest, at 10.9 g N kg^{-1} (Table 12). The DDG treatments were the same at 10.0 g N kg^{-1}. Char was the lowest at 8.6 g N kg^{-1}. At Marshall County, DDG tilled had the highest nitrogen concentration, at 10.0 g N kg^{-1}. The DDG no-till treatment was the same as urea but not the same as DDG tilled. Char was lower than urea at 8.5 compared with 9.3 g N kg^{-1}. Urea had the highest nitrogen concentration at Riley County in 2009, at 9.3 g N kg^{-1}. The DDG tilled treatment was lower than urea but still higher than DDG no-till at 8.9 g N kg^{-1}. Char had lower nitrogen concentration then urea at 8.4 g N kg^{-1}.

When grain nitrogen is plotted with applied nitrogen three location-years have responses. For Riley County in 2008, both char treatments had no response so could not be fit to any models (Figure 24). No-till and tilled DDG as well as urea were all fit to linear models with r^2 of 0.64 for DDG no-till, 0.74 for DDG tilled, and 0.84 for urea. Marshall County in 2009, had the same response as 2008 with both char treatments not fitting any models and DDG no-till, DDG tilled, and urea fitting positive linear models with r^2 of 0.34, 0.73, and 0.59, respectively. Riley County had the same response as 2008 and Marshall County. Charcoal treatments showed no response to applied nitrogen and both DDG treatments and urea all being fit to positively sloped linear models. The r^2 for DDG no-till was 0.15, for DDG tilled it was 0.59, and for urea it was 0.72.

Grain Yield Correlation to Yield Components

Grain yield data from all locations were combined and correlated with yield components. There was no correlation between grain yield and ears m^{-1}. A linear model was fit to Grain weight ear^{-1} with the intercept forced through the origin, because grain yield of zero will have zero g ear^{-1} (r^2 = 0.92) (Figure 27). The grain weight ear^{-1} accounts for most of the variability in grain yield. Individual seed weight was also fit to a linear model (r^2 = 0.49). This accounted for almost half of the increase in grain yield at all locations (Figure 28). Doniphan County had erratic stalk nitrogen data and in the resample plot stalk nitrogen was not measured, so they were excluded from the grain yield correlation to stalk nitrogen model. The remaining locations were combined and were fit to a quadratic model ($r^2 = 0.13$) (Figure 29). Both stalk phosphorus and potassium could not be correlated to grain yield. The correlation with grain yield and grain nitrogen was also fit to a quadratic model ($r^2 = 0.33$) (Figure 30). This correlation is believed to be the result of grain nitrogen increasing with plant uptake of nitrogen. When grain nitrogen was compared with stalk nitrogen (plant N uptake), a linear model was fit ($r^2 = 0.33$) (Figure 31).

CHAPTER 4 - Discussion and Conclusions

Discussion

In all years and locations, except Riley County in 2009, DDGs grain yields met if not exceeded the grain yields from urea. That means that 6 out of 7 treatments were at least the same as urea. The graphs, at each location demonstrate this, with DDGs having similar yield responses as urea the majority of the time. Stalk nitrogen followed the same trend as the DDGs and urea with char having no response. Stalk phosphorus actually showed a decrease in concentration with increasing nitrogen rate. With the soil analysis it is believed that neither phosphorus nor potassium was limiting. Because this experiment was designed mainly as a nitrogen yield response study and not for observing response to phosphorus or potassium most of the results for phosphorus and potassium will be speculative. A possible explanation to the decrease of phosphorus in the plant tissue could be either a dilution effect because of the higher yielding plants biomass or it could be that the plant translocated the phosphorus to the developing grain. The phosphorus concentration of the grain was not tested, so no conclusions can be stated. Increasing stalk potassium at some locations and a decrease at other locations while being interesting are too inconclusive so that no explanation can be given.

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 would lead us to believe that the lower grain yield produced from DDG no-till at Riley County in 2009, was because of the slower mineralization of the DDGs in the no-till environment. From the soil analysis, the only factor that might be limiting is nitrogen. Nelson (2009) hypothesized and reported that DDGs mineralize and become available in a similar fashion as manure. Our results would support their findings. This slower mineralization can be seen in some of the relationships; one example is the grain yield response to residual nitrogen (resample of 2008 plot) where DDG no-till continued to contribute to the residual nitrogen available (measured by grain yield) at all rates (the linear plateau part) but the control. Also about 65% of the time the r^2 values for DDG no-till regressions were lower and a 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 (Marshal 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 nitrogen faster, especially in a year with high rainfall and no major heat stress (good 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.

The biggest limiting factor to the use of DDGs as fertilizer is not its performance, but its bulk and cost. In Table 1, the weight of DDGs needed, assuming no moisture content and total nitrogen concentration plant available, is around 22 kg to supply one kg of nitrogen, it would also take around 134 kg to supply one kg of phosphorus and 149 kg to supply one kg of potassium. Prices on the table were also calculated as cost per of nutrient (C, N, P, and K). All prices listed are for Northeastern Kansas as of 6 May 2010. For DDGs to be less expensive then urea, the price of urea would have to go up to around 1.44USD kg^{-1} N, the cost of DDGs would have to good down to around 0.05USD kg^{-1} of DDG, or some mix of the two for it to be competitive with urea.

Conversely, with charcoal, none of the locations in which char was applied, had higher grain yields than urea. Similar grain yield responses to char application in corn (no nitrogen fertilizer) were found by Gaskin (2010) and Major (2010). Stalk nitrogen in the char treatment was found to be lower than urea treatments. Similar tissue nitrogen 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 nitrogen is a way to measure plant uptake of nitrogen, this could help to explain why the char treatments had lower overall yield. In essence, the char treatments took up less nitrogen 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 nitrogen availability. The lower individual seed weights for the char treatments also help to explain this. The growth stage at which nitrogen uptake is the most limiting is during the grain filing stages of corn development. Char treatments also appear to not have yields much higher than the control across all rates. The regression analysis validates this with the char having a slope of zero (non-significant lines). The stable or almost unaffected stalk phosphorus and potassium levels could be a sign that char helps to improve availability of these nutrients. Of course it is hard to known because they were the same as the control in almost all the relationships. So, the stability could be because the corn was not limited or did not need the phosphorus or potassium because it lacked nitrogen. Grain nitrogen follows the same trend as yield; so as to fortify the notion that nitrogen was the biggest limiting factor for the char treated corn. It would be of interest to this author to see more research done on char as a soil amendment.

Table 13 contains the analysis of yield components and their contribution to yield. When location-years are analyzed separately grain weight ear^{-1} contributes the most to grain yield with ears m^{-2} being additive. Individual seed weight was still important at two of the four location-years but grain weight ear^{-1} had the large r^2. When all locations are combined, including the resample of the 2008 plot, individual seed weight becomes the largest contributor to yield, with grain weight ear^{-1} and ears m^2 being additive.

Conclusions

The application of DDGs produced the same yields and similar nitrogen responses as urea, in 6 out of 7 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 as urea. The DDG tilled treatments usually produced more consistent grain yields because of faster/increased mineralization.

Inversely the char treatments always had lower grain yields than urea. Although not directly compared by any orthogonal contrasts, regression analysis validated through the nitrogen response curves that the char treatments did not increase yield any more than the control treatments but also it did not decrease yields either.

The char did tend to act like a more stable source of phosphorus and potassium. With phosphorus and potassium the char treatments either non significant (zero slope) or slightly increased. The response (or lack of) could just be caused by phosphorus and potassium not being limiting. Because no grain samples were tested for phosphorus or potassium we don’t know if the depression in stalk phosphorus and potassium was because of the lack of availability or nutrient translocation to grain.

With these results, DDG could function as a replacement for urea and perform as well. Both materials can also be a source of phosphorus and potassium if available. Bulk and price are the biggest limitation to future use as a fertilizer. Both DDGs and char have to be applied at high rates (22 and 55 kg kg^{-1} N) to achieve the same amount of total nitrogen 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.

Land application does seem to have potential merit for disposal and/or nutrient cycling of DDGs and char, with DDGs being preferred because of its nitrogen contribution. Char may contribute phosphorus and potassium as well as micronutrients to the soil. Unfortunately that is outside the scope of this experiment. This experiment was not designed to observe/comment on any of the long term effects of DDGs and char on soil organic matter, microbiological activity, and physical properties, but form some of the observations and chemical analysis both materials are high in carbon and seem to decompose slowly, char being the slower of the two. Charcoal may have benefits when it comes to storing carbon or adding CEC to soils but neither was observed.

Table 1. The concentration, weight, and price of char and DDGs compared with urea, diammonium phosphate (DAP), and potassium chloride (KCl); per kg of carbon, nitrogen, phosphorus, and potassium, for 2007, 2008, and 2009, in Kansas.

Source and Year	Carbon	Nitrogen	Phosphorus	Potassium
Nutrient Concentrations				
Char	- - - - - - - - - -	- - - - - - - - - -	$g\ kg^{-1}$ - - - - - - - - - -	- - - - - - - - - -
2008	589.4	18.5	28.5	42.4
2009	392.0	18.2	1.7	15.3
DDG				
2007	430.9	41.0	7.8	9.0
2008	432.8	46.5	7.5	5.4
2009	431.5	47.3	7.2	6.7
Weight per kg of nutrient	- - - - - - - - - -	- - - - - - - - - -	$kg\ kg^{-1}$ - - - - - - - - - -	- - - - - - - - - -
Char	2.12	54.50	311.66	44.47
DDG	2.32	22.35	133.48	148.52
Price per kg of nutrient*	- - - - - - - - - -	- - - - - - - - - -	$USD\ kg^{-1}$ - - - - - - - - - -	- - - - - - - - - -
Char at 0.11USD kg^{-1}	0.23	5.99	34.28	4.89
DDG at 0.14USD kg^{-1}	0.32	3.13	18.69	20.79
Urea at 0.50USD kg^{-1}	-	1.09	-	-
DAP at 0.45USD kg^{-1}	-	4.52	3.07	-
KCl at 0.55USD kg^{-1}	-	-	-	1.11

*Based on prices in Northeastern Kansas, 6 May 2010 (char price is an estimate)

Table 2. Soil test values for nitrogen, phosphorus, potassium, organic matter, and pH, Doniphan County in 2007, Riley County in 2008, Marshall County in 2009, and Riley County in 2009, Kansas.

Location-year	Ammonium	Nitrate	Phosphorus	Potassium	Organic Matter	pH
	ppm	ppm	ppm	ppm	%	
Doniphan County 2007	4.3	9.1	52.0	260	2.4	6.6
Riley County 2008	3.5	7.3	48.0	246	1.0	7.2
Marshall County 2009	2.1	6.6	20.1	268	1.4	5.9
Riley County 2009	3.2	8.1	51.4	230	1.3	7.7

Table 3. The average monthly high temperature (°C) and precipitation (cm) for April through October at Doniphan County in 2007, Riley County in 2008, Marshall County in 2009, and Riley County in 2009, in Kansas.

Location-years	April	May	June	July	August	September	October	Average or Total
	- - - - - - - - - - - - - - - - -		Average high temperature (°C)			- - - - - - - - - - - - - - - - -		
Doniphan in 2007	16.2	24.3	28.1	30.6	32.7	27.0	21.3	25.7
Riley in 2008	16.4	24.5	30.7	31.7	30.4	26.1	20.5	25.8
Marshall in 2009	17.0	23.7	28.9	28.8	29.1	24.7	14.1	23.7
Riley in 2009	17.9	24.7	30.9	29.9	30.2	25.5	15.6	25.0
	- - - - - - - - - - - - - - - - -			Precipitation (cm)		- - - - - - - - - - - - - - - - -		
Doniphan in 2007	7.4	23.8	4.0	1.4	26.1	5.5	12.1	80.2
Riley in 2008	5.7	12.6	29.0	12.0	13.4	13.8	7.1	93.6
Marshall in 2009	10.0	6.0	15.9	7.1	9.6	3.6	8.8	60.9
Riley in 2009	13.3	2.5	21.5	16.6	11.4	5.2	10.2	80.7

Table 4. The grain yield and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Treatment	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - - -	Mg ha^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	7.9	6.2	7.6
Char tilled	-	7.6	5.7	6.6
DDG no-till	10.6	10.2	8.7	10.9
DDG tilled	11.0	10.2	9.2	12.2
Urea	11.0	10.6	8.5	12.4
Orthogonal Contrasts	- - - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	<.0001	<.0001	<.0001
Urea vs. DDG no-till	0.0746	0.1797	0.7162	0.0073
Urea vs. DDG tilled	0.3496	0.2408	0.0339	0.7315
DDG no-till vs. tilled	0.3786	0.8625	0.0758	0.0178

Table 5. Yield components and contrast probabilities for char, DDG, and urea for the residual nitrogen resample plot at Ashland Bottoms, Manhattan, KS.

Treatment	Grain Yield	Seed weight	Ears per m^2	Ear weight
Means	Mg ha^{-1}	mg seed^{-1}	ears m^{-2}	g ear^{-1}
Char no-till	4.6	230	7.84	59
Char tilled	4.4	236	7.89	56
DDG no-till	6.1	240	7.90	77
DDG tilled	5.5	237	7.95	70
Urea	5.9	246	7.83	75
		236	*7.36*	
Orthogonal Contrasts	- - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	0.1186	0.6362	0.0303	0.0336
Urea vs. DDG no-till	0.5071	0.0870	0.7023	0.7594
Urea vs. DDG tilled	0.4124	0.0092	0.5352	0.3660
DDG no-till vs. tilled	0.1416	0.3362	0.8112	0.2283

* The mean for urea at which it and char were compared *

Table 6. Corn ears m^{-2} and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Treatment	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - - -	ears m^{-2}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	5.9	6.9	6.7
Char tilled	-	6.1	6.8	6.9
DDG no-till	7.9	5.8	7.2	7.6
DDG tilled	7.9	5.7	7.1	7.1
Urea	8.0	5.6	7.1	6.9
Orthogonal Contrasts	- - - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	0.2173	0.0383	0.8036
Urea vs. DDG no-till	0.6003	0.1524	0.5176	0.0247
Urea vs. DDG tilled	0.6003	0.5430	0.9631	0.4327
DDG no-till vs. tilled	1.0000	0.4037	0.4883	0.1349

Table 7. Grain weight ear^{-1} and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Treatment	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - - -	g ear^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	135	106	114
Char tilled	-	125	107	143
DDG no-till	134	176	105	122
DDG tilled	139	180	107	146
Urea	143	188	109	147
Orthogonal Contrasts	- - - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	<.0001	0.7390	0.1363
Urea vs. DDG no-till	0.1152	0.0351	0.6788	0.0720
Urea vs. DDG tilled	0.5055	0.1805	0.8416	0.9185
DDG no-till vs. tilled	0.3517	0.4211	0.8301	0.0890

Table 8. Individual seed weight and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Treatment	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - - -	mg seed^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	240	252	262
Char tilled	-	246	247	261
DDG no-till	276	281	264	270
DDG tilled	275	285	261	276
Urea	284	303	251	265
Orthogonal Contrasts	- - - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	<.0001	0.5798	0.4038
Urea vs. DDG no-till	0.1416	<.0001	0.0010	0.3090
Urea vs. DDG tilled	0.0916	0.0001	0.0137	0.0256
DDG no-till vs. tilled	0.1844	0.3108	0.3588	0.2108

Table 9. Stalk nitrogen and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Stalk Nitrogen	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - -	g kg^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	2.575	2.681	3.006
Char tilled	-	2.213	2.613	2.853
DDG no-till	0.004	2.906	3.056	3.206
DDG tilled	0.139	3.094	3.319	3.331
Urea	0.020	5.200	3.131	3.600
Orthogonal Contrasts	- - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	0.0017	0.0001	<.0001
Urea vs. DDG no-till	0.8707	<.0001	0.5835	0.0204
Urea vs. DDG tilled	0.2307	<.0001	0.1734	0.1092
DDG no-till vs. tilled	0.1790	0.4917	0.0586	0.4523

Table 10. Stalk phosphorus and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Stalk Phosphorus	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - -	g kg^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	0.8	1.2	1.5
Char tilled	-	1.0	1.0	1.4
DDG no-till	-	1.0	0.6	1.4
DDG tilled	-	1.0	0.5	1.2
Urea	-	0.8	0.6	1.2
Orthogonal Contrasts	- - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	0.3629	<.0001	<.0001
Urea vs. DDG no-till	-	0.1083	0.0010	0.0012
Urea vs. DDG tilled	-	0.0885	0.0137	0.0427
DDG no-till vs. tilled	-	0.9190	0.3588	0.1905

Table 11. Stalk potassium and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

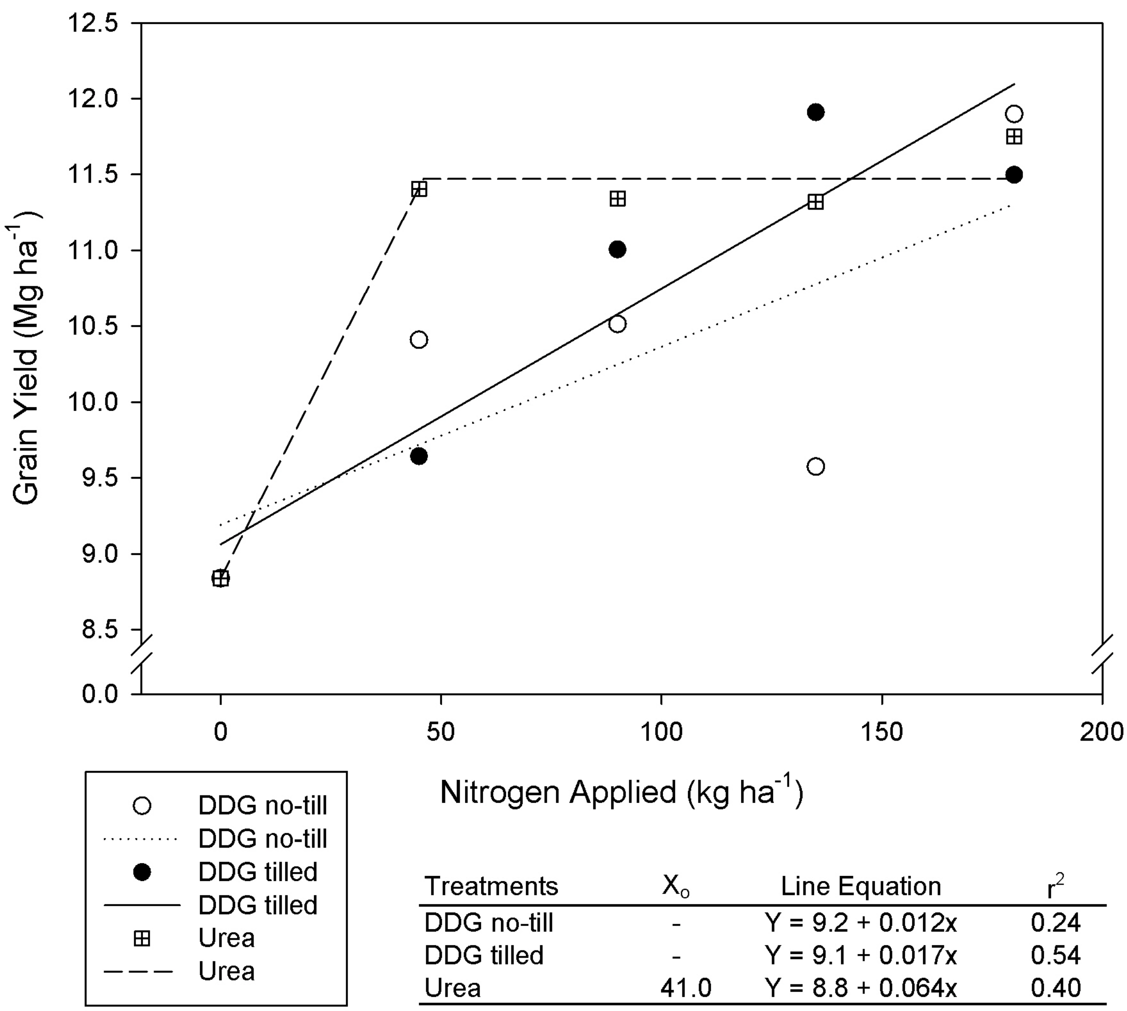
Stalk Potassium	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - -	g kg^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	33.1	12.4	17.1
Char tilled	-	32.7	12.0	16.0
DDG no-till	-	32.9	12.8	17.7
DDG tilled	-	30.1	12.8	17.1
Urea	-	28.7	11.9	16.1
Orthogonal Contrasts	- - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	0.0219	0.2082	0.9504
Urea vs. DDG no-till	-	<.0001	0.0372	0.2801
Urea vs. DDG tilled	-	0.0436	0.0335	0.6919
DDG no-till vs. tilled	-	0.0436	0.9650	0.4920

Table 12. Grain nitrogen and contrast probabilities for char, DDG, and urea at all four location-years in Kansas.

Grain Nitrogen	Doniphan County 2007	Riley County 2008	Marshall County 2009	Riley County 2009
Means	- - - - - - - - - - - - - - - -	g kg^{-1}	- - - - - - - - - - - - - - - - - -	
Char no-till	-	8.5	8.5	8.5
Char tilled	-	8.7	8.4	8.3
DDG no-till	-	9.8	9.2	8.5
DDG tilled	-	10.1	10.0	8.9
Urea	-	10.9	9.3	9.3
Orthogonal Contrasts	- - - - - - - - - - - - - - - -	Pr>F	- - - - - - - - - - - - - - - - - -	
Urea vs. Char	-	<.0001	<.0001	0.0031
Urea vs. DDG no-till	-	<.0001	0.4725	<.0001
Urea vs. DDG tilled	-	<.0001	0.0002	0.0159
DDG no-till vs. tilled	-	0.0560	<.0001	0.0284

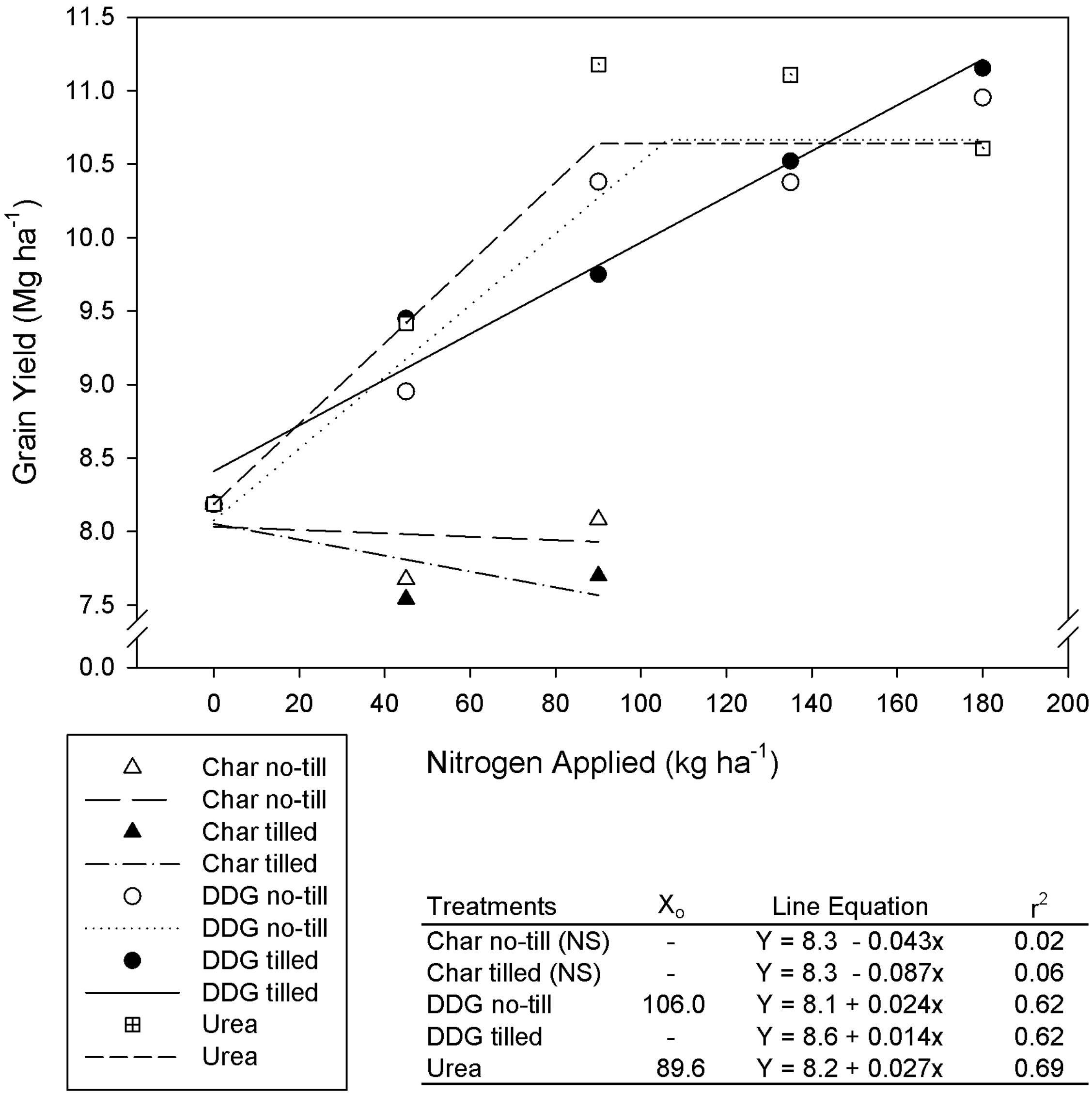
Table 13. Yield component contribution to overall grain yield at all four location-years, in Kansas.

Location-year	Yield Component	Partial r2	Model r2	Pr>F
Doniphan County 2007	Grain ear-1	0.9002	0.9002	<.0001
	Ears m-2	0.0981	0.9983	<.0001
Riley County 2008	Grain ear-1	0.8822	0.8822	<.0001
	Ears m-2	0.1116	0.9938	<.0001
Marshall County 2009	Individual seed weight	0.3144	0.3144	<.0001
	Ears m-2	0.0316	0.3460	0.0328
Riley County 2009	Individual seed weight	0.2254	0.2554	<.0001
Resample of 2008	Grain ear-1	0.8867	0.8867	<.0001
	Ears m-2	0.1040	0.9906	<.0001
Combined	Individual seed weight	0.4866	0.4866	<.0001
	Grain ear-1	0.0537	0.5403	<.0001
	Ears m-2	0.0073	0.5475	0.0090



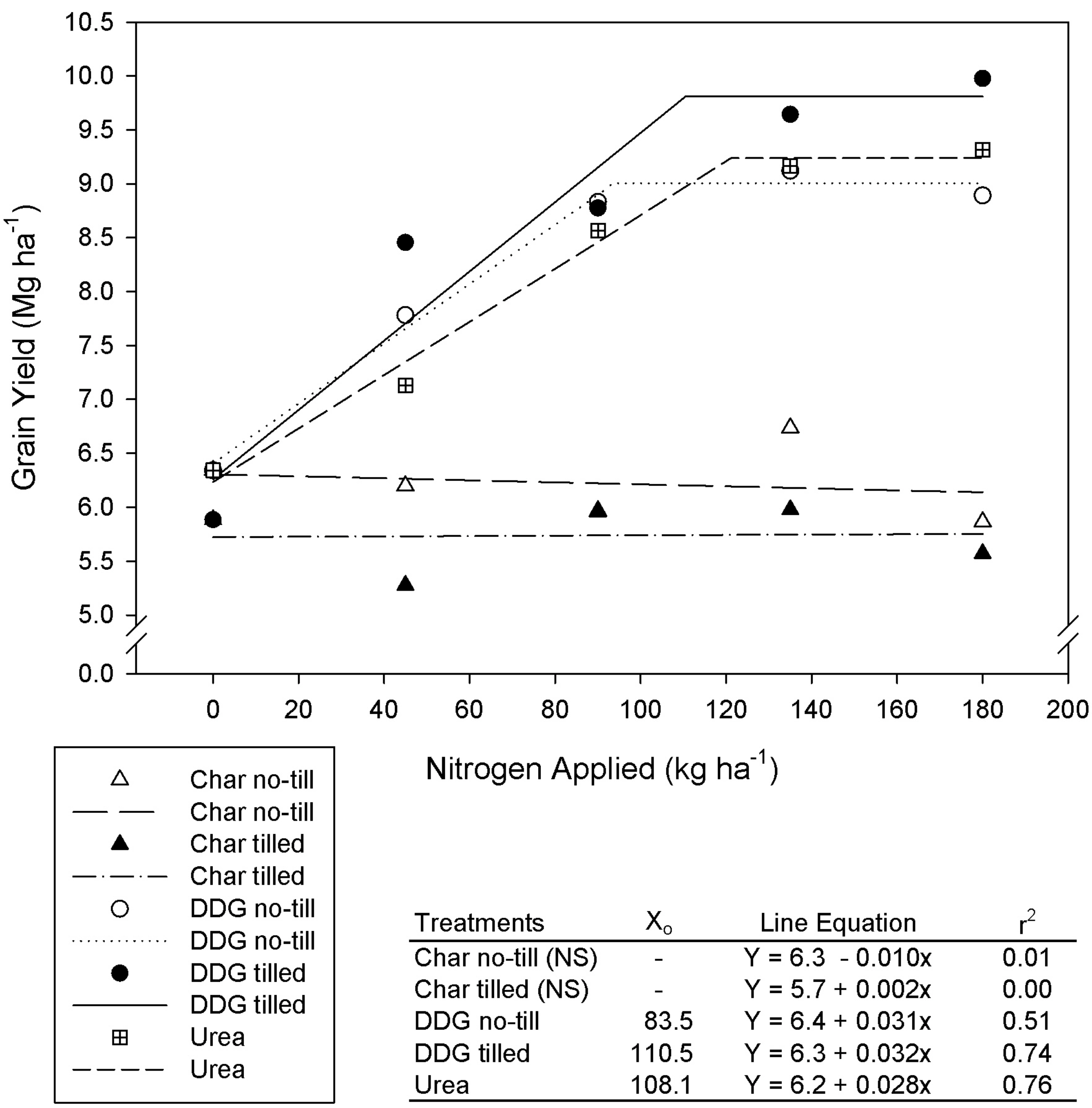
Treatments	X_o	Line Equation	r^2
DDG no-till	-	Y = 9.2 + 0.012x	0.24
DDG tilled	-	Y = 9.1 + 0.017x	0.54
Urea	41.0	Y = 8.8 + 0.064x	0.40

Figure 1. Grain yield response to DDGs and urea applied as nitrogen at Doniphan County in 2007.



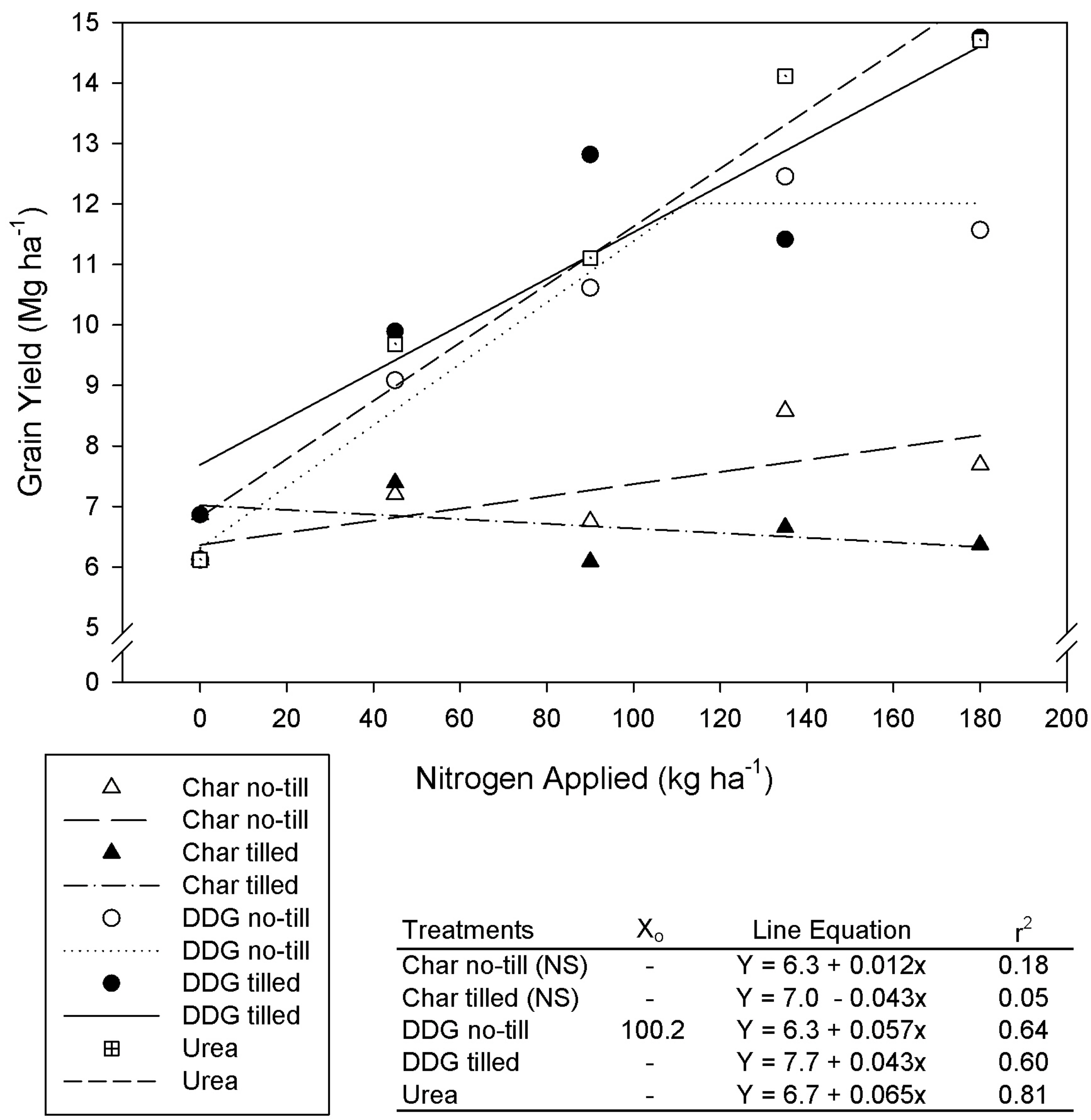
Treatments	X_o	Line Equation	r^2
Char no-till (NS)	-	Y = 8.3 - 0.043x	0.02
Char tilled (NS)	-	Y = 8.3 - 0.087x	0.06
DDG no-till	106.0	Y = 8.1 + 0.024x	0.62
DDG tilled	-	Y = 8.6 + 0.014x	0.62
Urea	89.6	Y = 8.2 + 0.027x	0.69

Figure 2. Grain yield response to char, DDGs, and urea applied as nitrogen at Riley County in 2008.



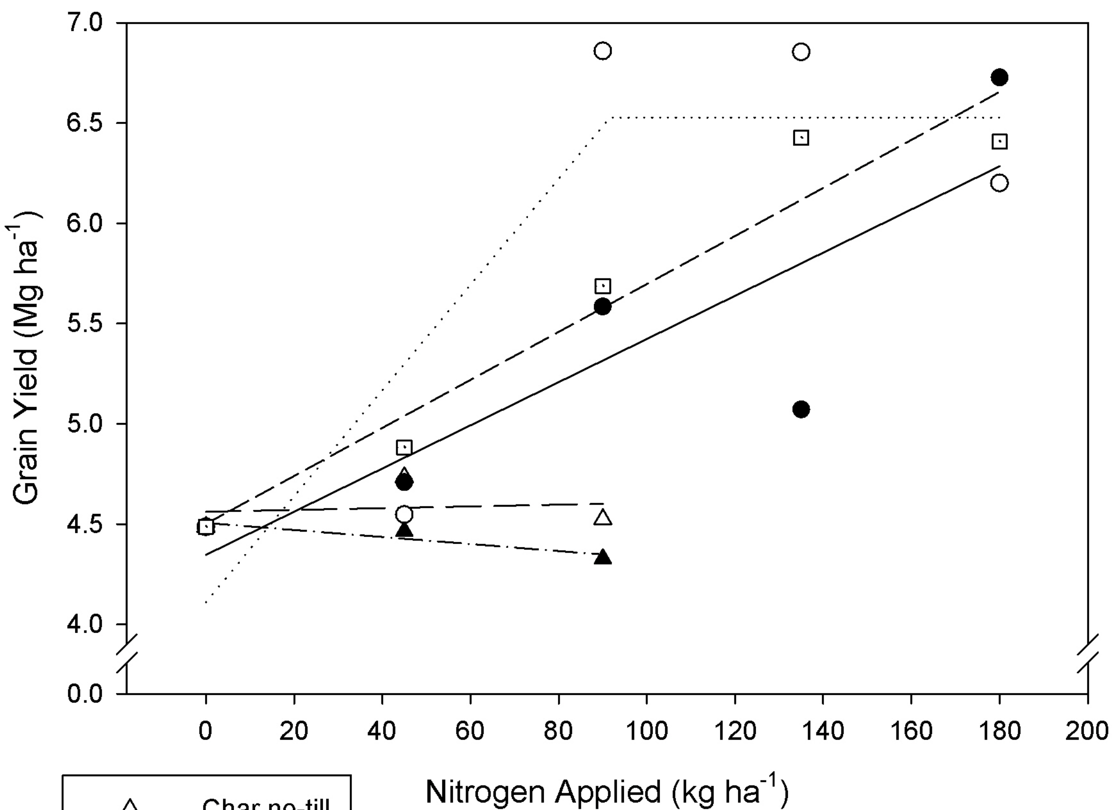
Treatments	X_o	Line Equation	r^2
Char no-till (NS)	-	Y = 6.3 - 0.010x	0.01
Char tilled (NS)	-	Y = 5.7 + 0.002x	0.00
DDG no-till	83.5	Y = 6.4 + 0.031x	0.51
DDG tilled	110.5	Y = 6.3 + 0.032x	0.74
Urea	108.1	Y = 6.2 + 0.028x	0.76

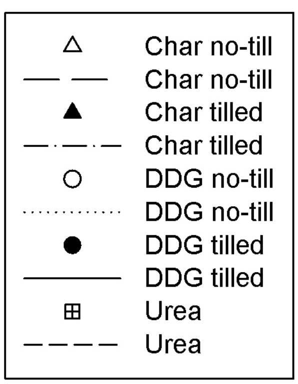
Figure 3. Grain yield response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009.



Treatments	X_o	Line Equation	r^2
Char no-till (NS)	-	Y = 6.3 + 0.012x	0.18
Char tilled (NS)	-	Y = 7.0 - 0.043x	0.05
DDG no-till	100.2	Y = 6.3 + 0.057x	0.64
DDG tilled	-	Y = 7.7 + 0.043x	0.60
Urea	-	Y = 6.7 + 0.065x	0.81

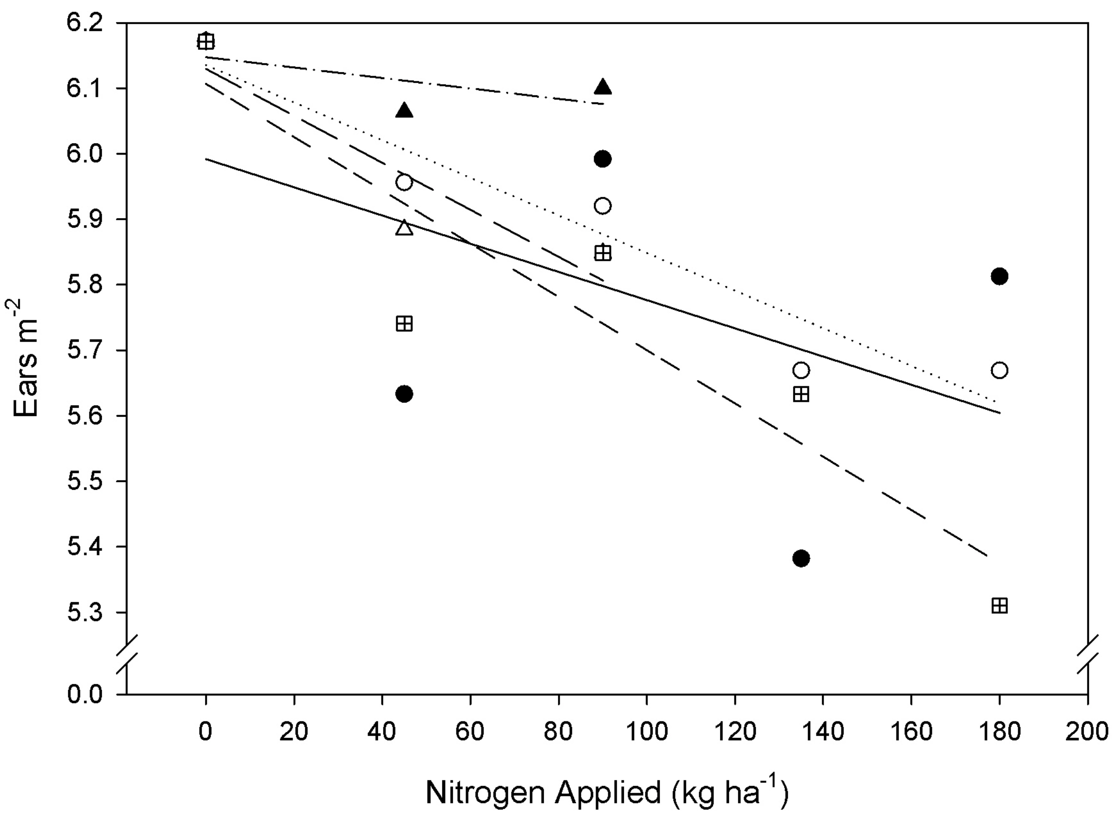
Figure 4. Grain yield response to char, DDGs, and urea applied as nitrogen at Riley County in 2009.





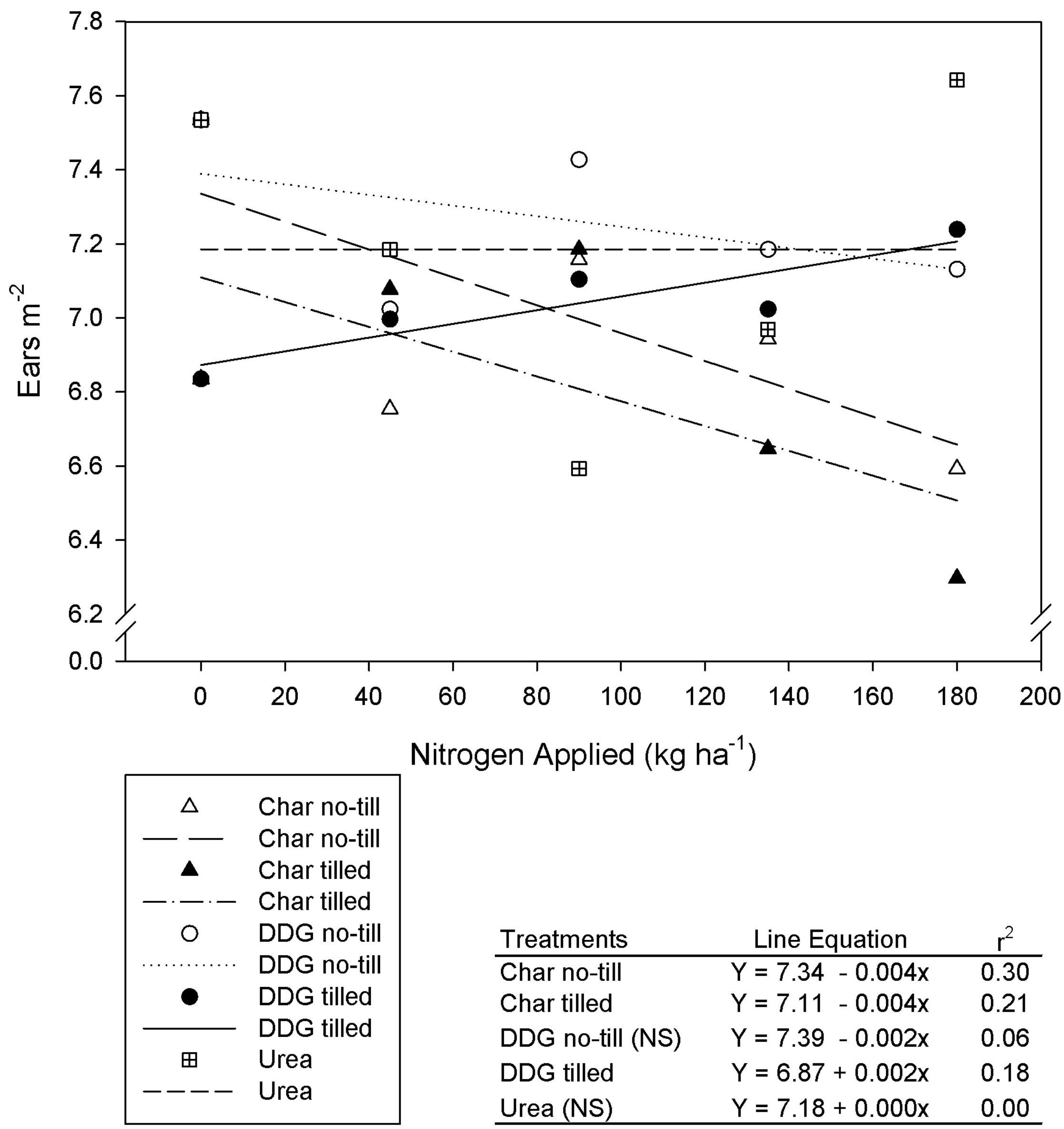
Treatments	X_o	Line Equation	r^2
Char no-till (NS)	-	Y = 4.6 + 0.004x	0.00
Char tilled (NS)	-	Y = 4.5 - 0.018x	0.01
DDG no-till	91.6	Y = 4.1 + 0.026x	0.42
DDG tilled	-	Y = 4.3 + 0.011x	0.28
Urea	-	Y = 4.5 + 0.012x	0.34

Figure 5. Grain yield response to residual nitrogen resample of 2008's application of char, DDGs, and urea at Riley County in 2009.



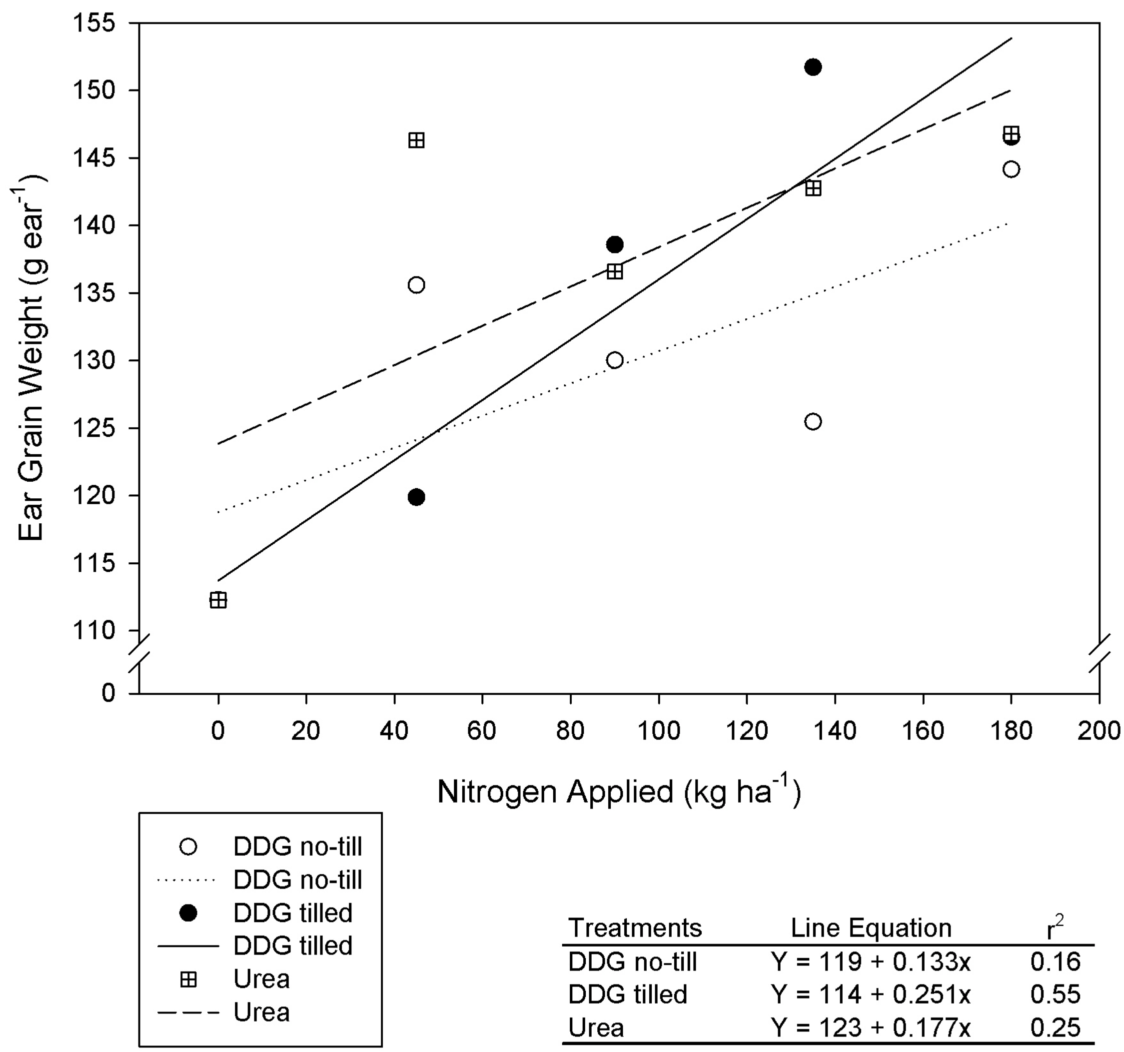
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 6.13 - 0.004x	0.14
Char tilled (NS)	Y = 6.15 - 0.001x	0.01
DDG no-till	Y = 6.14 - 0.003x	0.30
DDG tilled (NS)	Y = 5.99 - 0.002x	0.10
Urea	Y = 6.11 - 0.005x	0.51

Figure 6. Ears m^{-2} response to char, DDGs, and urea applied as nitrogen at Riley County in 2008, in Kansas.



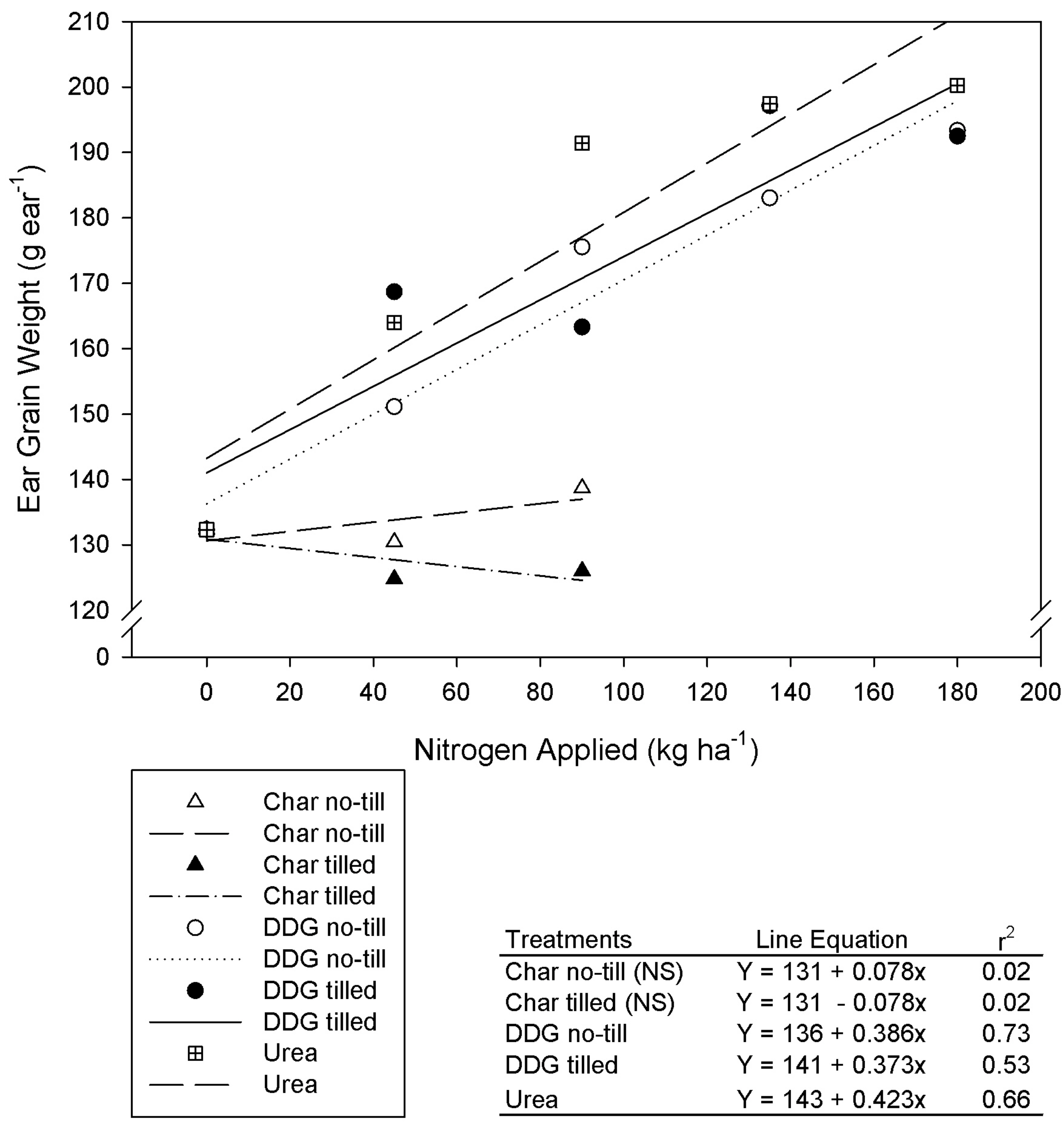
Treatments	Line Equation	r^2
Char no-till	Y = 7.34 - 0.004x	0.30
Char tilled	Y = 7.11 - 0.004x	0.21
DDG no-till (NS)	Y = 7.39 - 0.002x	0.06
DDG tilled	Y = 6.87 + 0.002x	0.18
Urea (NS)	Y = 7.18 + 0.000x	0.00

Figure 7. Ears m^{-2} response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009, in Kansas.



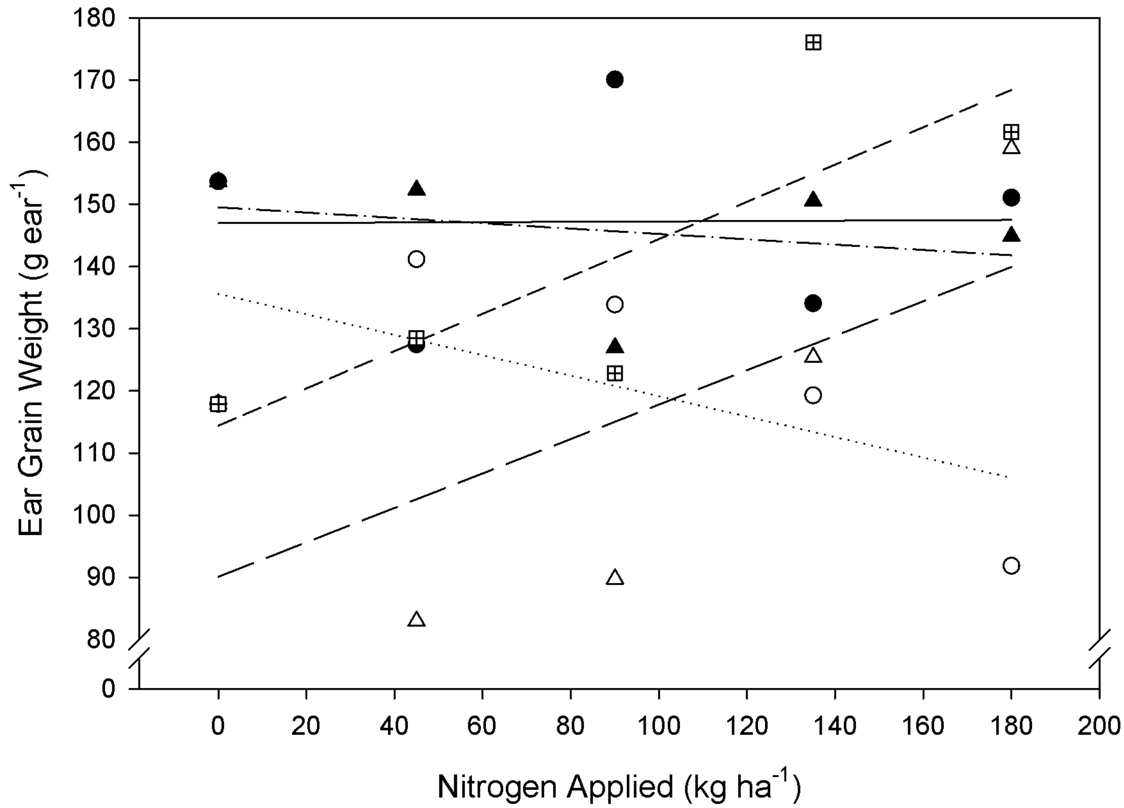
Treatments	Line Equation	r^2
DDG no-till	Y = 119 + 0.133x	0.16
DDG tilled	Y = 114 + 0.251x	0.55
Urea	Y = 123 + 0.177x	0.25

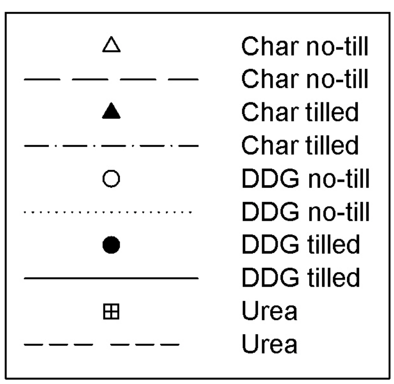
Figure 8. Grain weight ear^{-1} response to char, DDGs, and urea applied as nitrogen at Doniphan County in 2007, in Kansas.



Treatments	Line Equation	r^2
Char no-till (NS)	Y = 131 + 0.078x	0.02
Char tilled (NS)	Y = 131 - 0.078x	0.02
DDG no-till	Y = 136 + 0.386x	0.73
DDG tilled	Y = 141 + 0.373x	0.53
Urea	Y = 143 + 0.423x	0.66

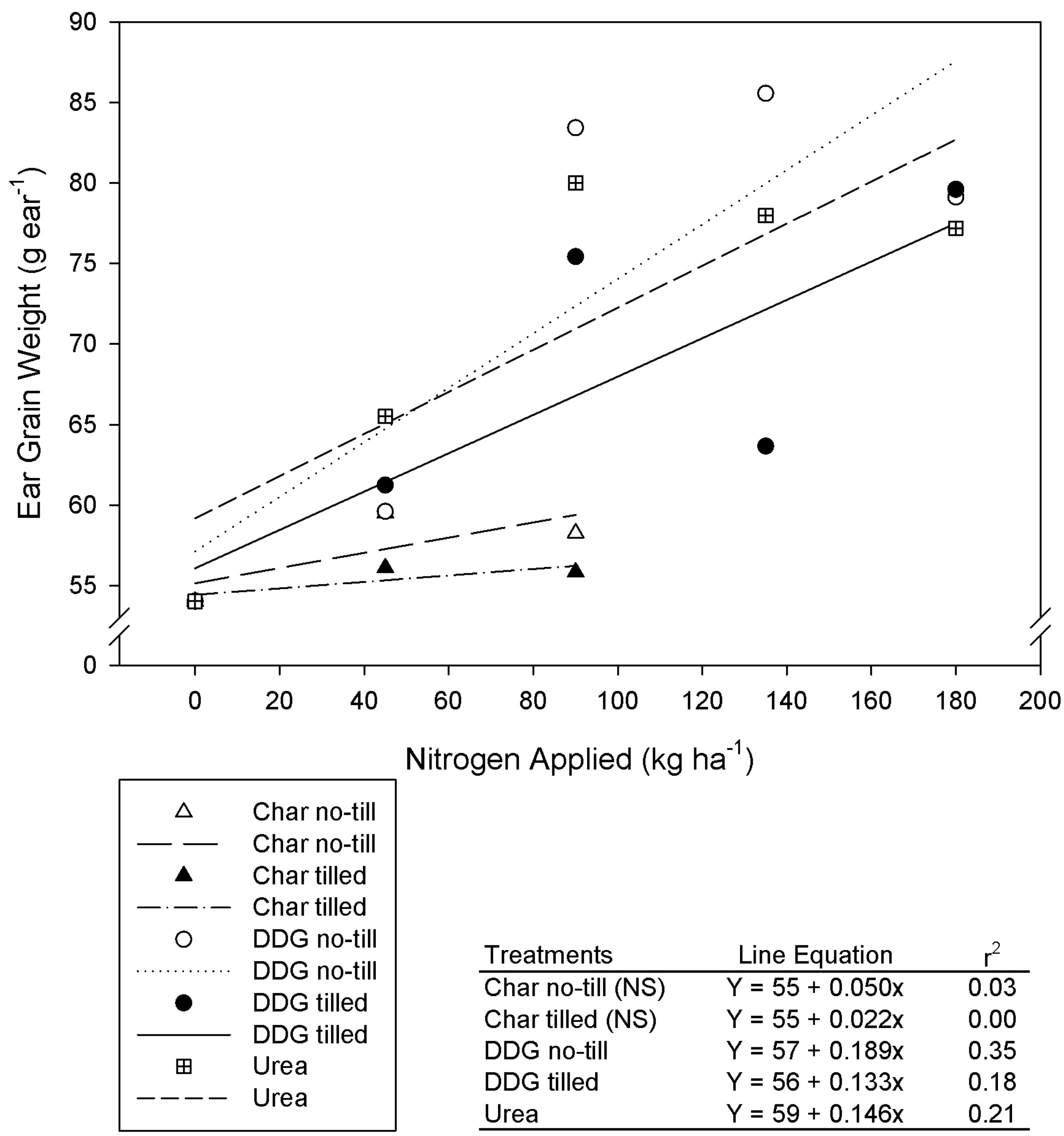
Figure 9. Grain weight ear^{-1} response to char, DDGs, and urea applied as nitrogen at Riley County in 2008, in Kansas.





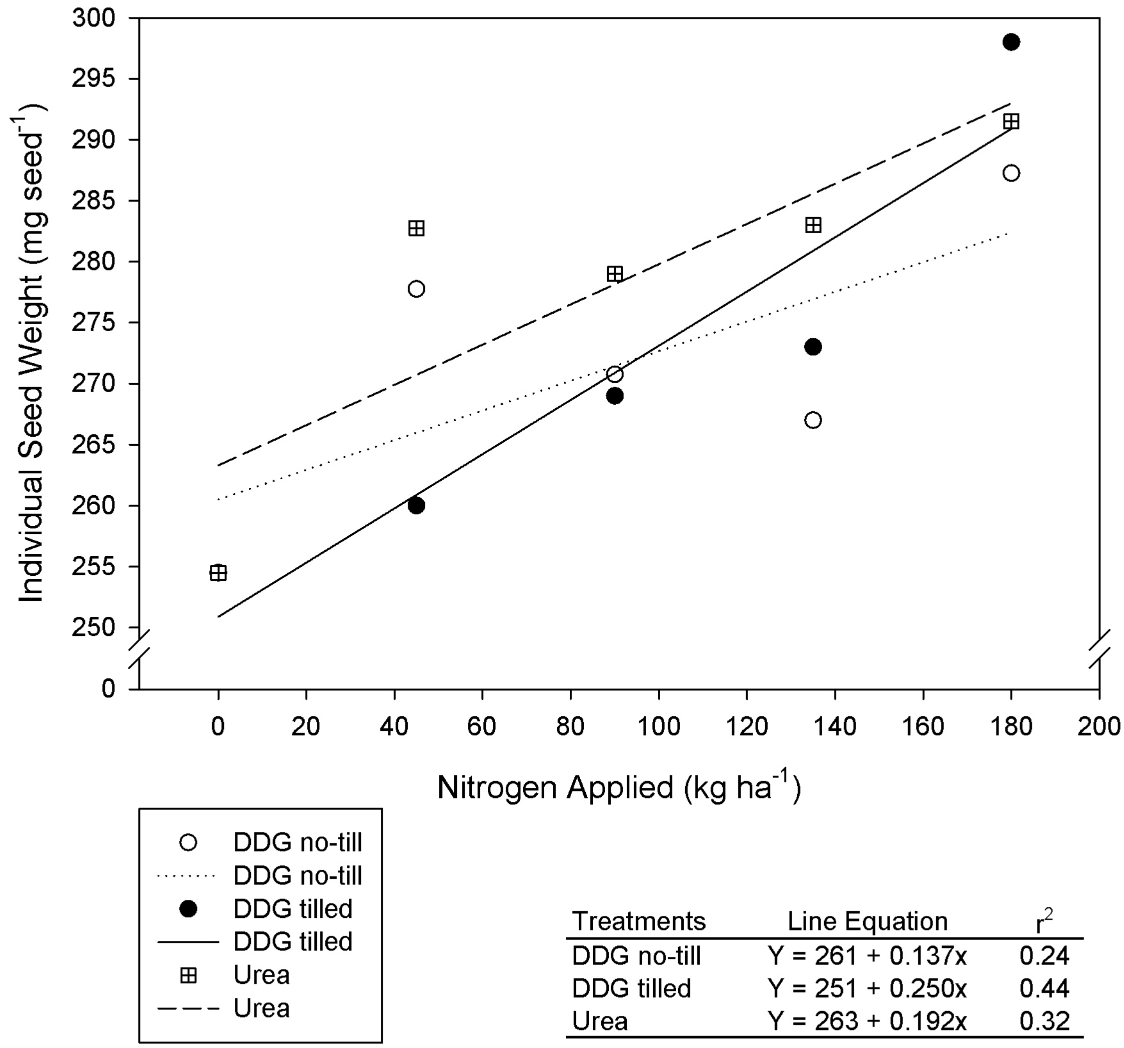
Treatments	Line Equation	r^2
Char no-till	Y = 94 + 0.282x	0.17
Char tilled (NS)	Y = 149 - 0.048x	0.00
DDG no-till (NS)	Y = 133 - 0.167x	0.09
DDG tilled (NS)	Y = 147 + 0.006x	0.00
Urea	Y = 115 + 0.332x	0.24

Figure 10. Grain weight ear^{-1} response to char, DDGs, and urea applied as nitrogen at Riley County in 2009, in Kansas.



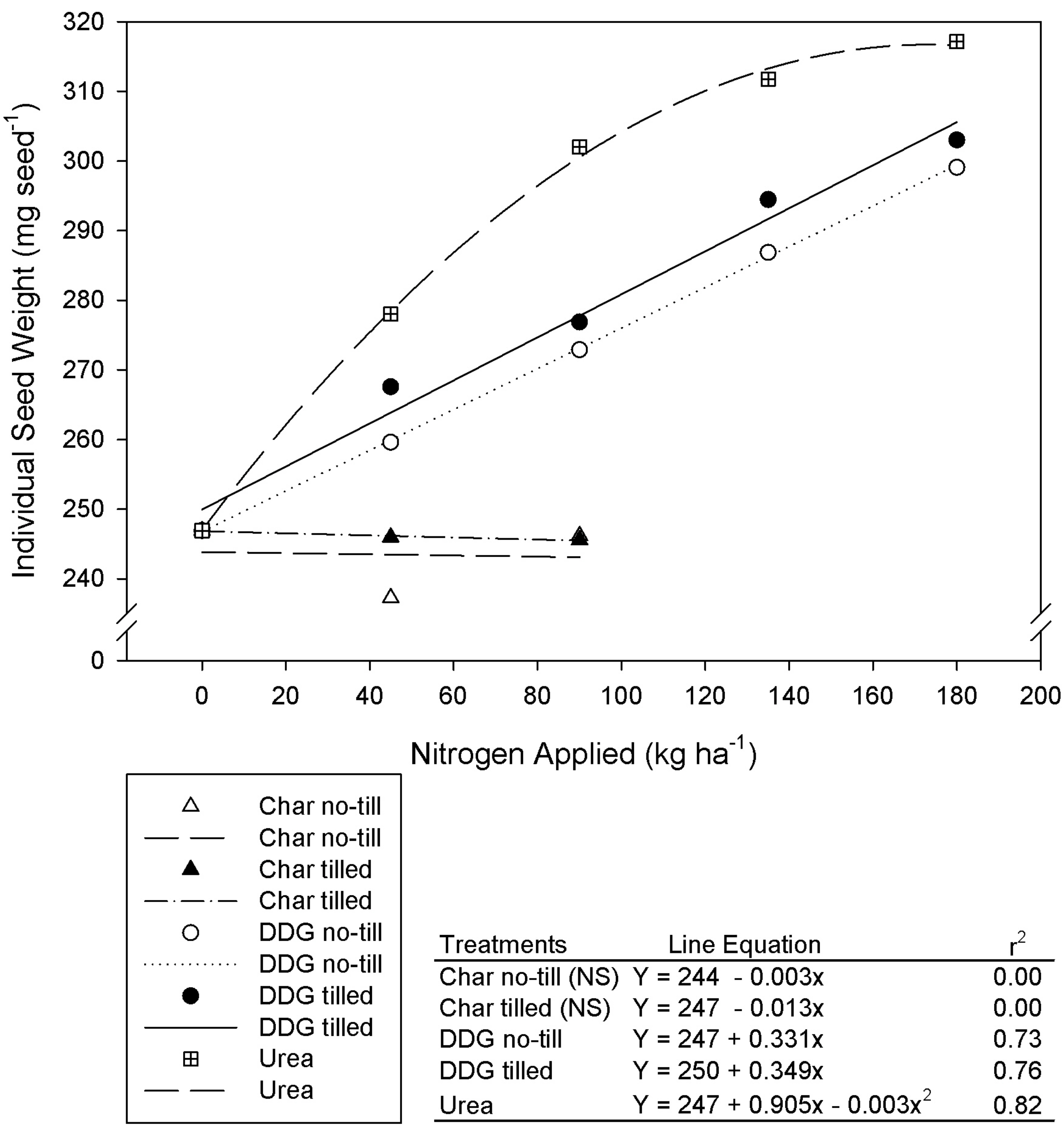
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 55 + 0.050x	0.03
Char tilled (NS)	Y = 55 + 0.022x	0.00
DDG no-till	Y = 57 + 0.189x	0.35
DDG tilled	Y = 56 + 0.133x	0.18
Urea	Y = 59 + 0.146x	0.21

Figure 11. Grain weight ear^{-1} response to residual nitrogen, resample of 2008's char, DDGs, and urea applied as nitrogen, at Riley County in 2009.



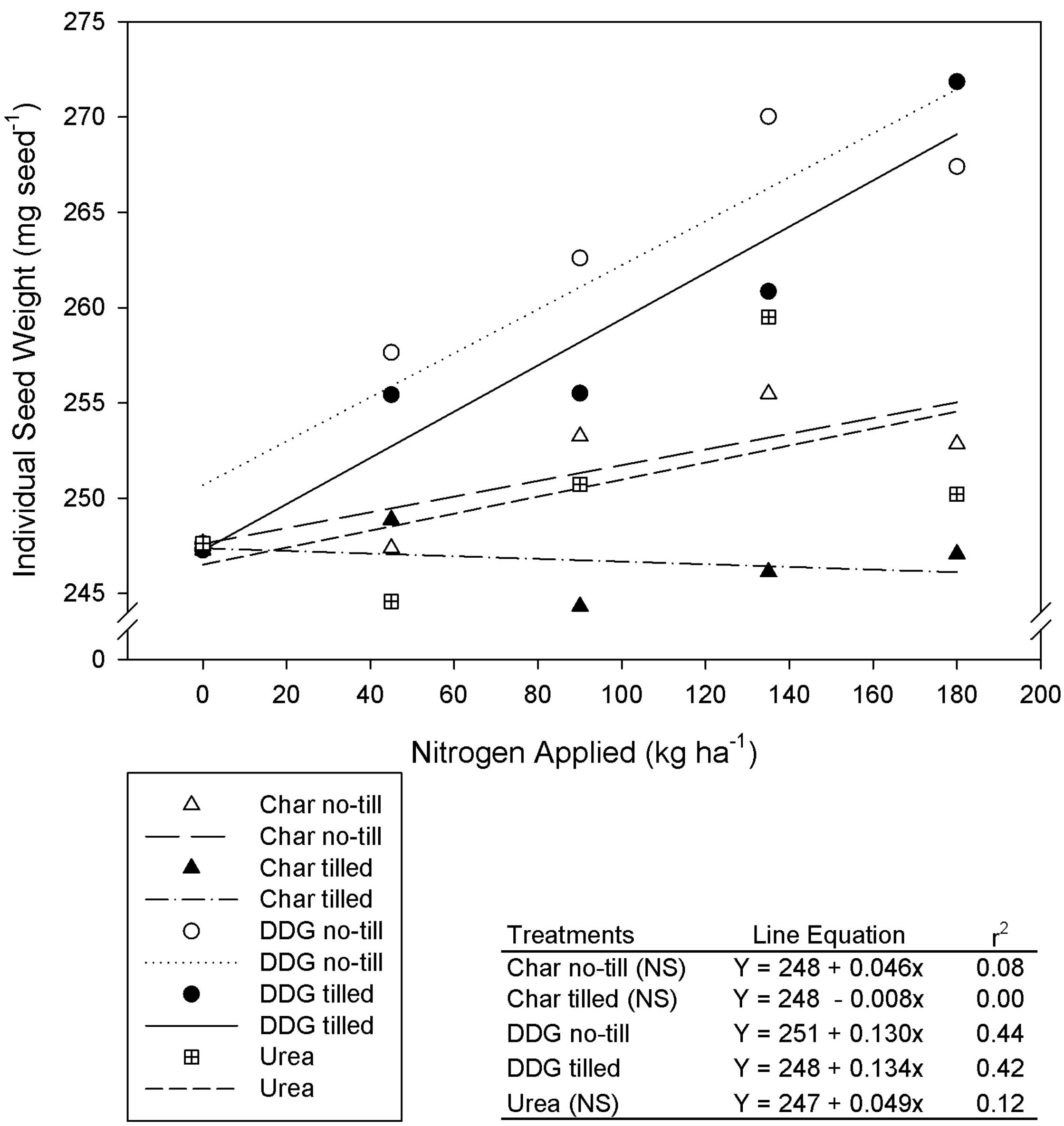
Treatments	Line Equation	r^2
DDG no-till	Y = 261 + 0.137x	0.24
DDG tilled	Y = 251 + 0.250x	0.44
Urea	Y = 263 + 0.192x	0.32

Figure 12. Seed weight response to char, DDGs, and urea applied as nitrogen at Doniphan County in 2007, in Kansas.



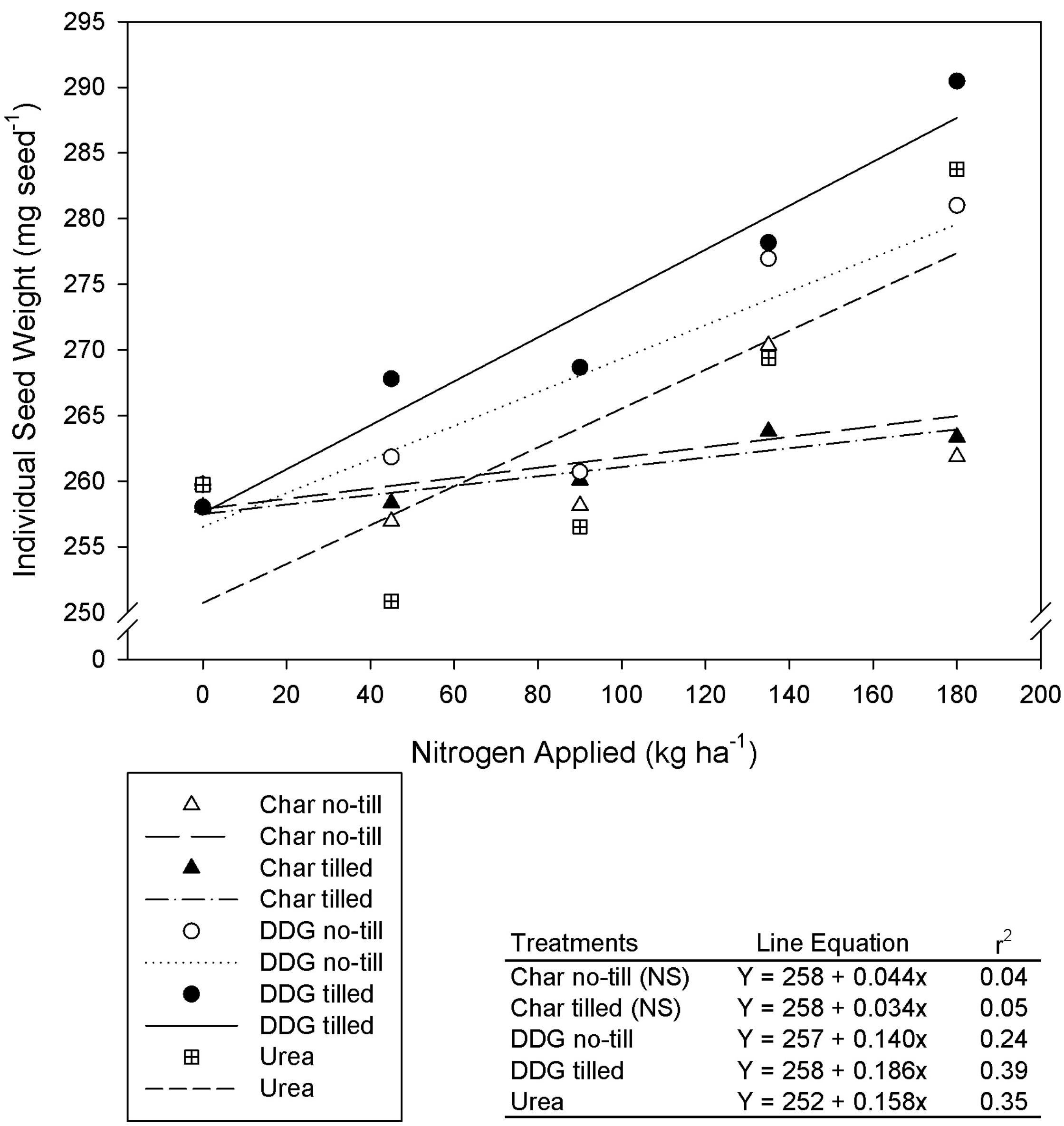
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 244 - 0.003x	0.00
Char tilled (NS)	Y = 247 - 0.013x	0.00
DDG no-till	Y = 247 + 0.331x	0.73
DDG tilled	Y = 250 + 0.349x	0.76
Urea	Y = 247 + 0.905x - 0.003x^2	0.82

Figure 13. Seed weight response to char, DDGs, and urea applied as nitrogen at Riley County in 2008, in Kansas.



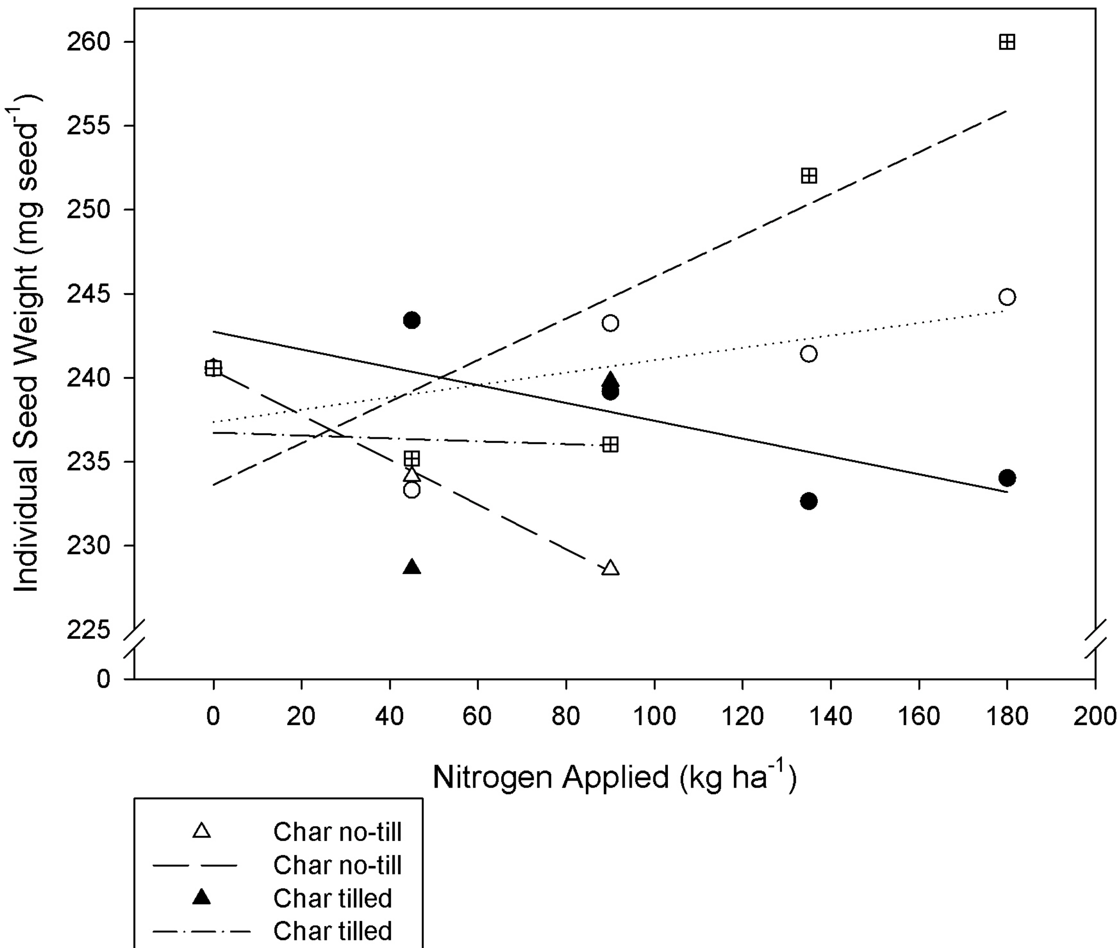
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 248 + 0.046x	0.08
Char tilled (NS)	Y = 248 - 0.008x	0.00
DDG no-till	Y = 251 + 0.130x	0.44
DDG tilled	Y = 248 + 0.134x	0.42
Urea (NS)	Y = 247 + 0.049x	0.12

Figure 14. Seed weight response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009, in Kansas.



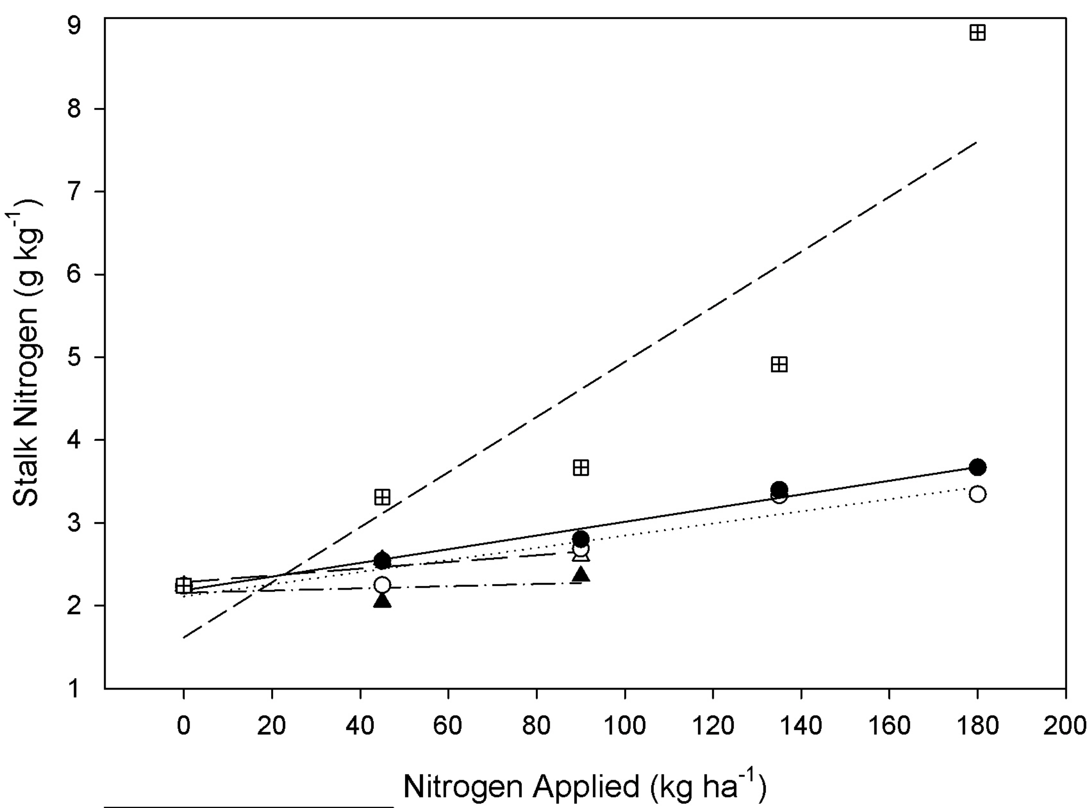
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 258 + 0.044x	0.04
Char tilled (NS)	Y = 258 + 0.034x	0.05
DDG no-till	Y = 257 + 0.140x	0.24
DDG tilled	Y = 258 + 0.186x	0.39
Urea	Y = 252 + 0.158x	0.35

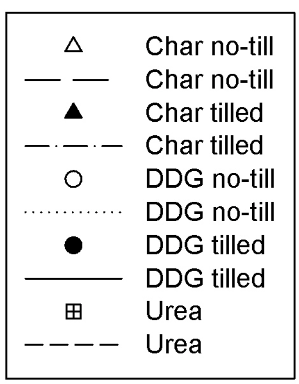
Figure 15. Seed weight response to char, DDGs, and urea applied as nitrogen at Riley County in 2009, in Kansas.



Treatments	Line Equation	r^2
Char no-till (NS)	Y = 240 - 0.147x	0.13
Char tilled (NS)	Y = 237 - 0.009x	0.00
DDG no-till (NS)	Y = 237 + 0.042x	0.05
DDG tilled (NS)	Y = 243 - 0.059x	0.12
Urea	Y = 234 + 0.139x	0.34

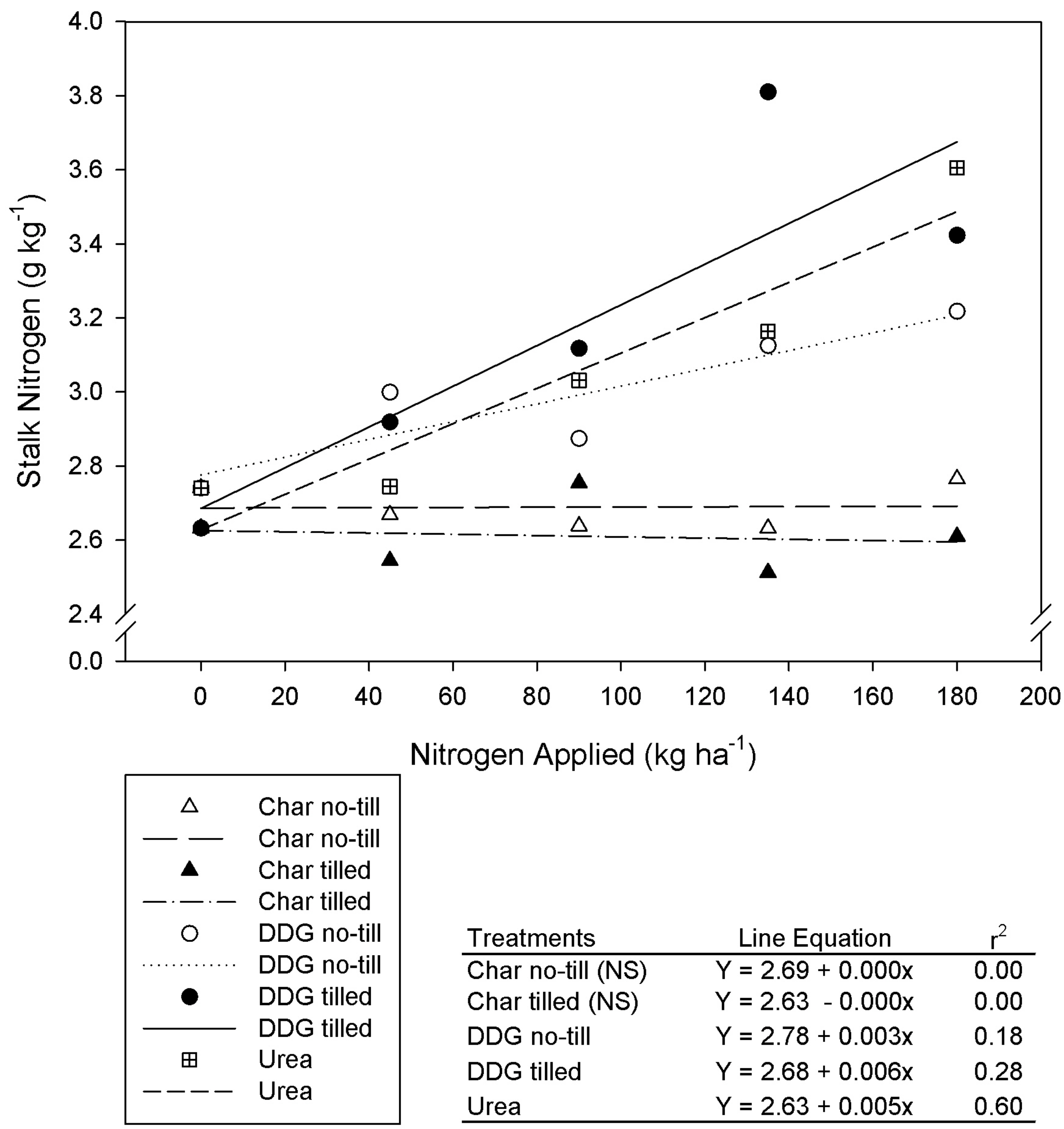
Figure 16. Seed weight response to residual nitrogen, resample of 2008's char, DDGs, and urea applied as nitrogen, at Riley County in 2009.





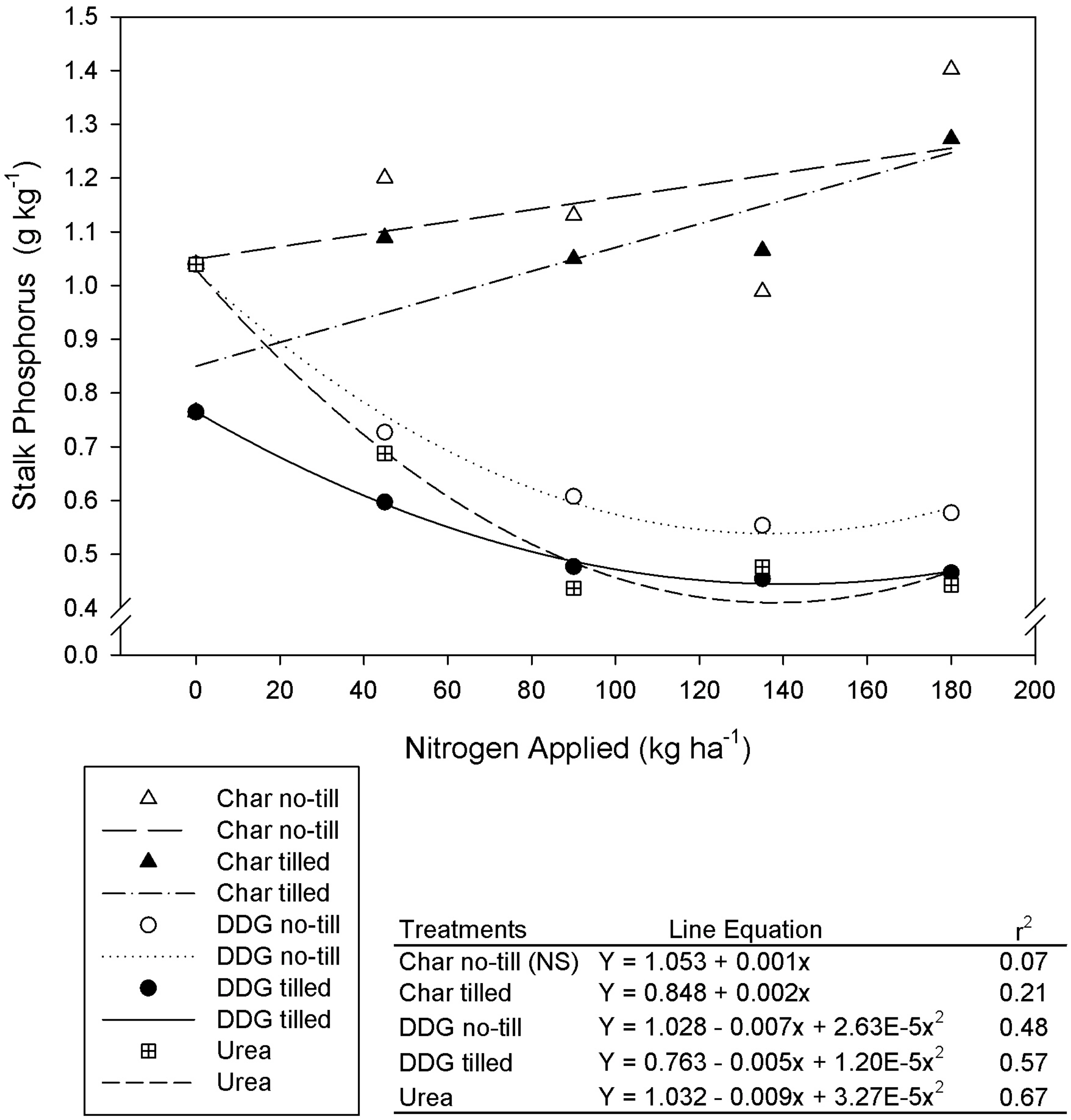
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 2.28 + 0.005x	0.05
Char tilled (NS)	Y = 2.16 + 0.001x	0.02
DDG no-till	Y = 2.11 + 0.008x	0.60
DDG tilled	Y = 2.19 + 0.009x	0.46
Urea	Y = 1.62 + 0.037x	0.74

Figure 17. Stalk nitrogen response to char, DDGs, and urea applied as nitrogen at Riley County in 2008, in Kansas.



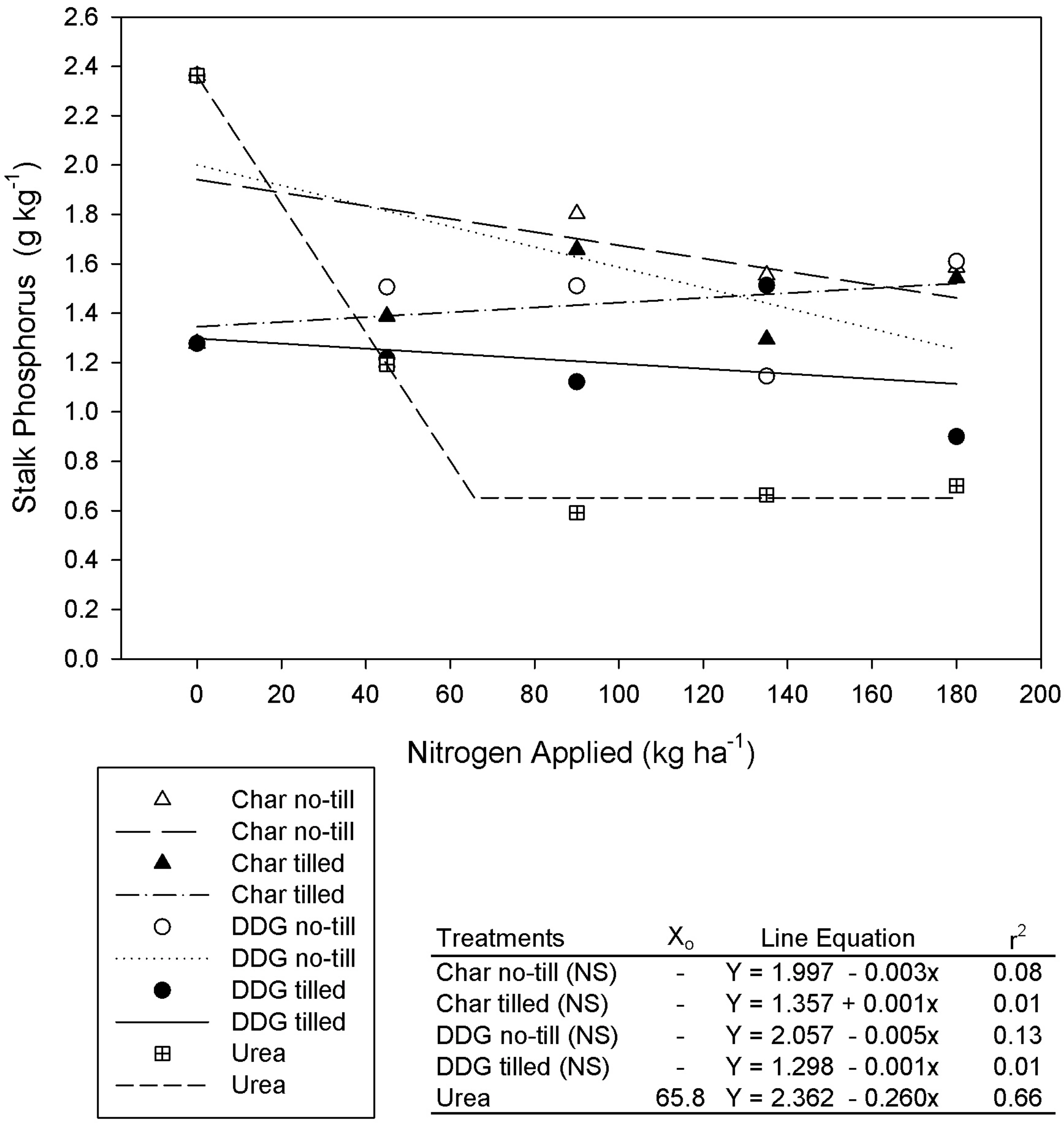
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 2.69 + 0.000x	0.00
Char tilled (NS)	Y = 2.63 - 0.000x	0.00
DDG no-till	Y = 2.78 + 0.003x	0.18
DDG tilled	Y = 2.68 + 0.006x	0.28
Urea	Y = 2.63 + 0.005x	0.60

Figure 18. Stalk nitrogen response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009, in Kansas.



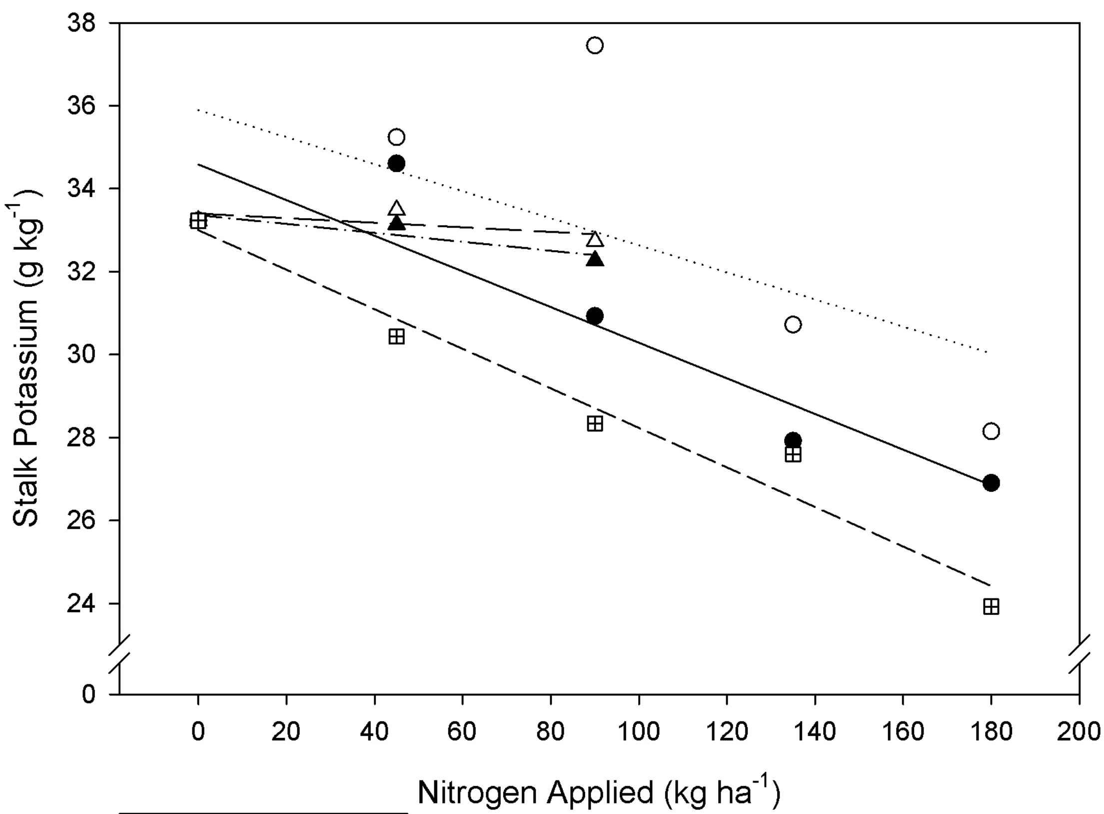
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 1.053 + 0.001x	0.07
Char tilled	Y = 0.848 + 0.002x	0.21
DDG no-till	Y = 1.028 - 0.007x + 2.63E-5x^2	0.48
DDG tilled	Y = 0.763 - 0.005x + 1.20E-5x^2	0.57
Urea	Y = 1.032 - 0.009x + 3.27E-5x^2	0.67

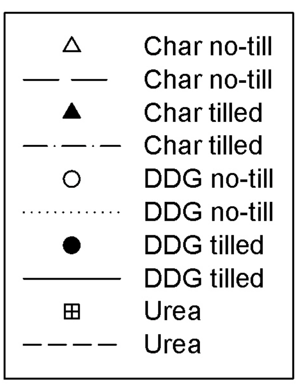
Figure 19. Stalk phosphorus response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009, in Kansas.



Treatments	X_o	Line Equation	r^2
Char no-till (NS)	-	Y = 1.997 - 0.003x	0.08
Char tilled (NS)	-	Y = 1.357 + 0.001x	0.01
DDG no-till (NS)	-	Y = 2.057 - 0.005x	0.13
DDG tilled (NS)	-	Y = 1.298 - 0.001x	0.01
Urea	65.8	Y = 2.362 - 0.260x	0.66

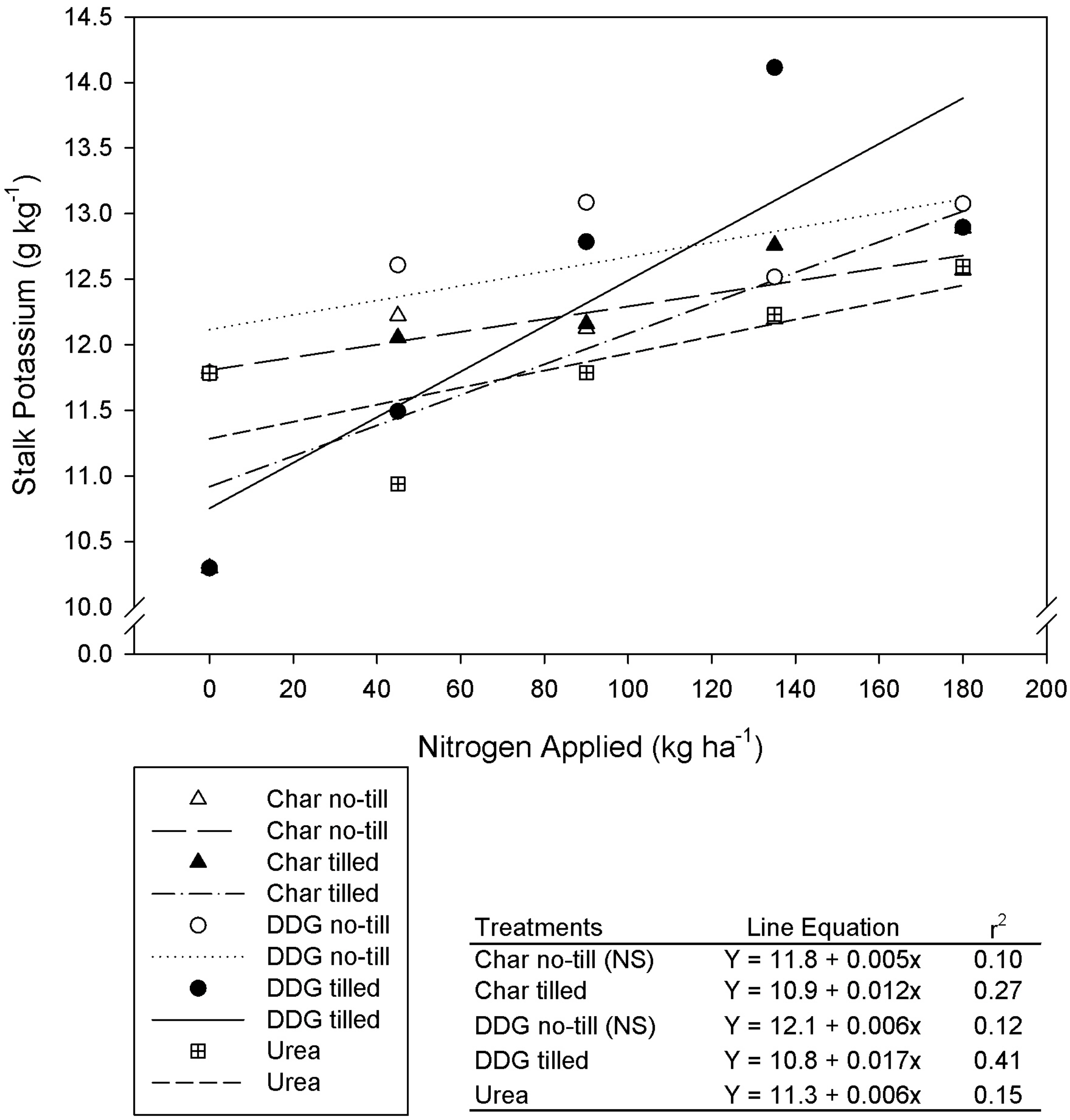
Figure 20. Stalk phosphorus response to char, DDGs, and urea applied as nitrogen at Riley County in 2009, in Kansas.





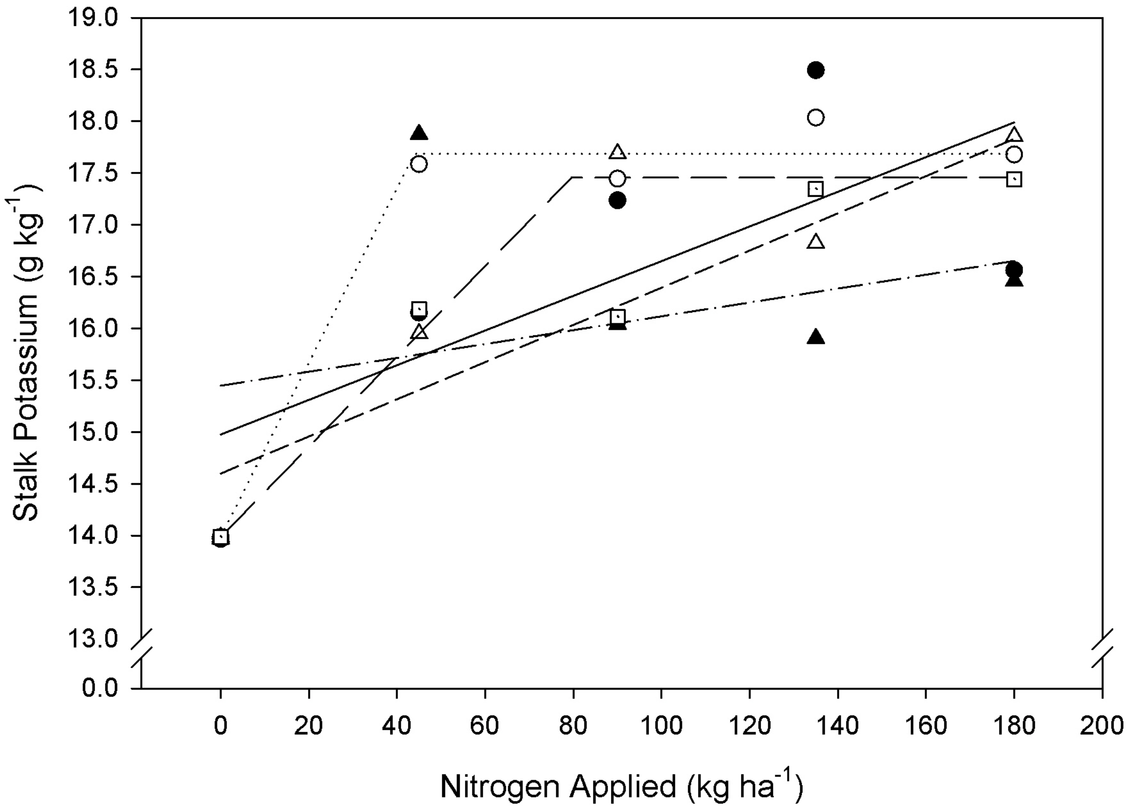
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 33.4 - 0.006x	0.00
Char tilled (NS)	Y = 33.4 - 0.011x	0.01
DDG no-till	Y = 35.9 - 0.033x	0.24
DDG tilled	Y = 34.6 - 0.043x	0.49
Urea	Y = 33.0 - 0.048x	0.52

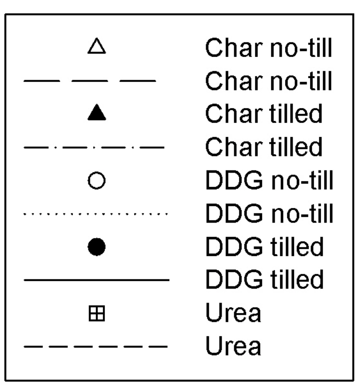
Figure 21. Stalk potassium response to char, DDGs, and urea applied as nitrogen at Riley County in 2008, in Kansas.



Treatments	Line Equation	r^2
Char no-till (NS)	Y = 11.8 + 0.005x	0.10
Char tilled	Y = 10.9 + 0.012x	0.27
DDG no-till (NS)	Y = 12.1 + 0.006x	0.12
DDG tilled	Y = 10.8 + 0.017x	0.41
Urea	Y = 11.3 + 0.006x	0.15

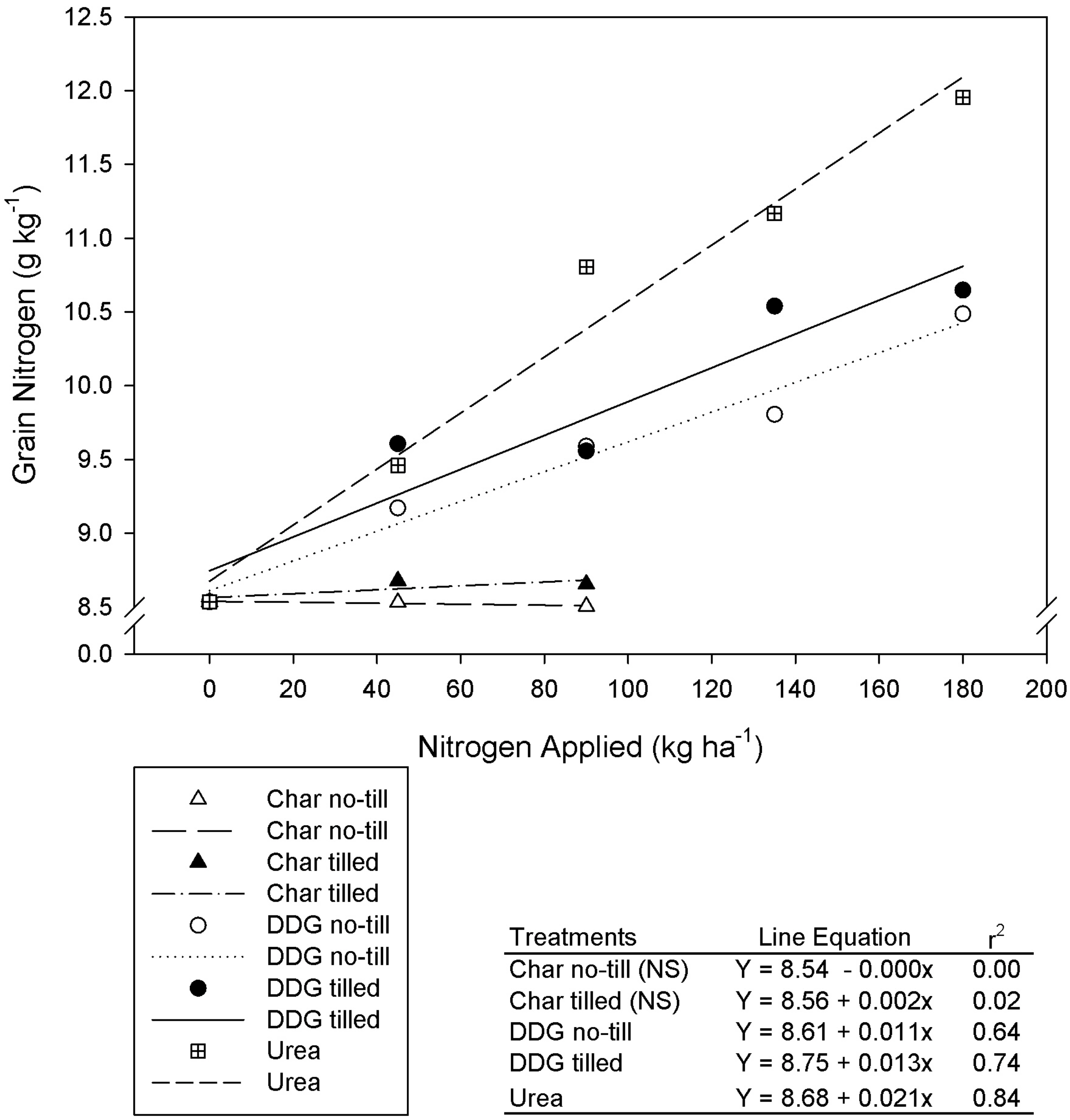
Figure 22. Stalk potassium response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009, in Kansas.





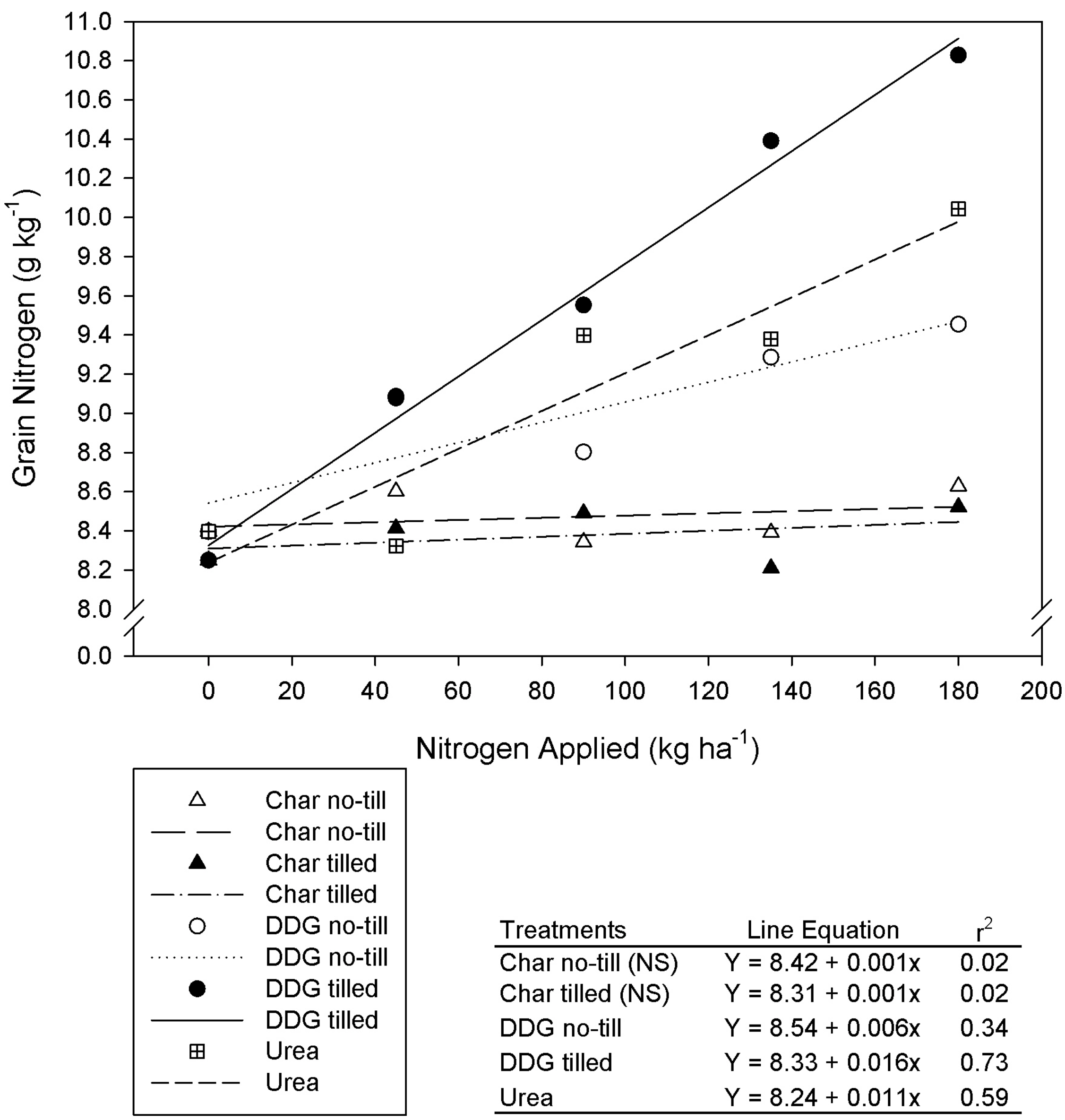
Treatments	X_o	Line Equation	r^2
Char no-till	79.6	Y = 14.0 + 0.044x	0.40
Char tilled (NS)	-	Y = 15.4 + 0.007x	0.03
DDG no-till	44.0	Y = 14.0 + 0.084x	0.41
DDG tilled	-	Y = 15.0 + 0.017x	0.16
Urea	-	Y = 14.5 + 0.019x	0.26

Figure 23. Stalk potassium response to char, DDGs, and urea applied as nitrogen at Riley County in 2009, in Kansas.



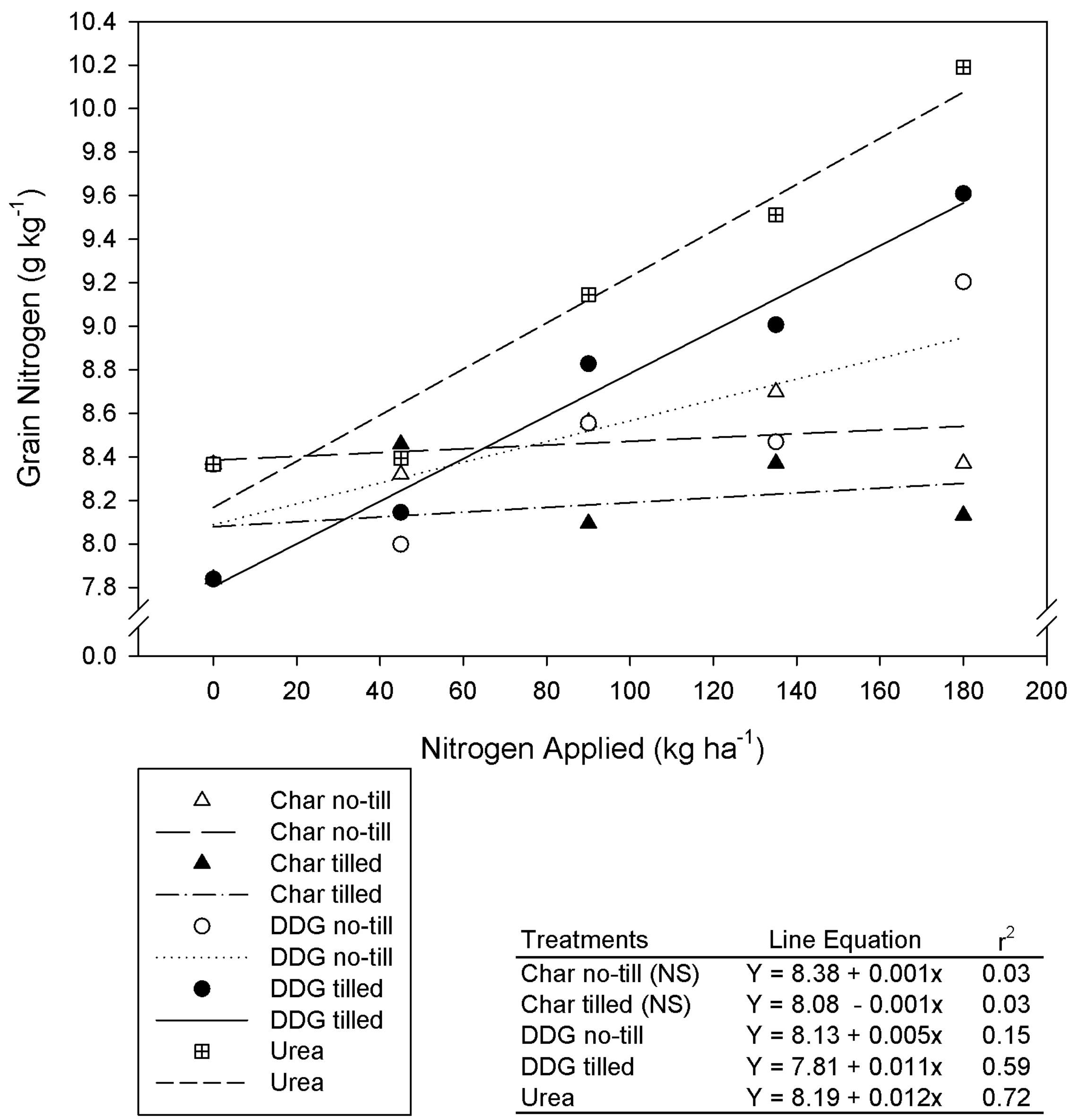
Treatments	Line Equation	r^2
Char no-till (NS)	Y = 8.54 - 0.000x	0.00
Char tilled (NS)	Y = 8.56 + 0.002x	0.02
DDG no-till	Y = 8.61 + 0.011x	0.64
DDG tilled	Y = 8.75 + 0.013x	0.74
Urea	Y = 8.68 + 0.021x	0.84

Figure 24. Grain nitrogen response to char, DDGs, and urea applied as nitrogen at Riley County in 2008, in Kansas.



Treatments	Line Equation	r^2
Char no-till (NS)	Y = 8.42 + 0.001x	0.02
Char tilled (NS)	Y = 8.31 + 0.001x	0.02
DDG no-till	Y = 8.54 + 0.006x	0.34
DDG tilled	Y = 8.33 + 0.016x	0.73
Urea	Y = 8.24 + 0.011x	0.59

Figure 25. Grain nitrogen response to char, DDGs, and urea applied as nitrogen at Marshall County in 2009, in Kansas.



Treatments	Line Equation	r^2
Char no-till (NS)	Y = 8.38 + 0.001x	0.03
Char tilled (NS)	Y = 8.08 - 0.001x	0.03
DDG no-till	Y = 8.13 + 0.005x	0.15
DDG tilled	Y = 7.81 + 0.011x	0.59
Urea	Y = 8.19 + 0.012x	0.72

Figure 26. Grain nitrogen response to char, DDGs, and urea applied as nitrogen at Riley County in 2009, in Kansas.

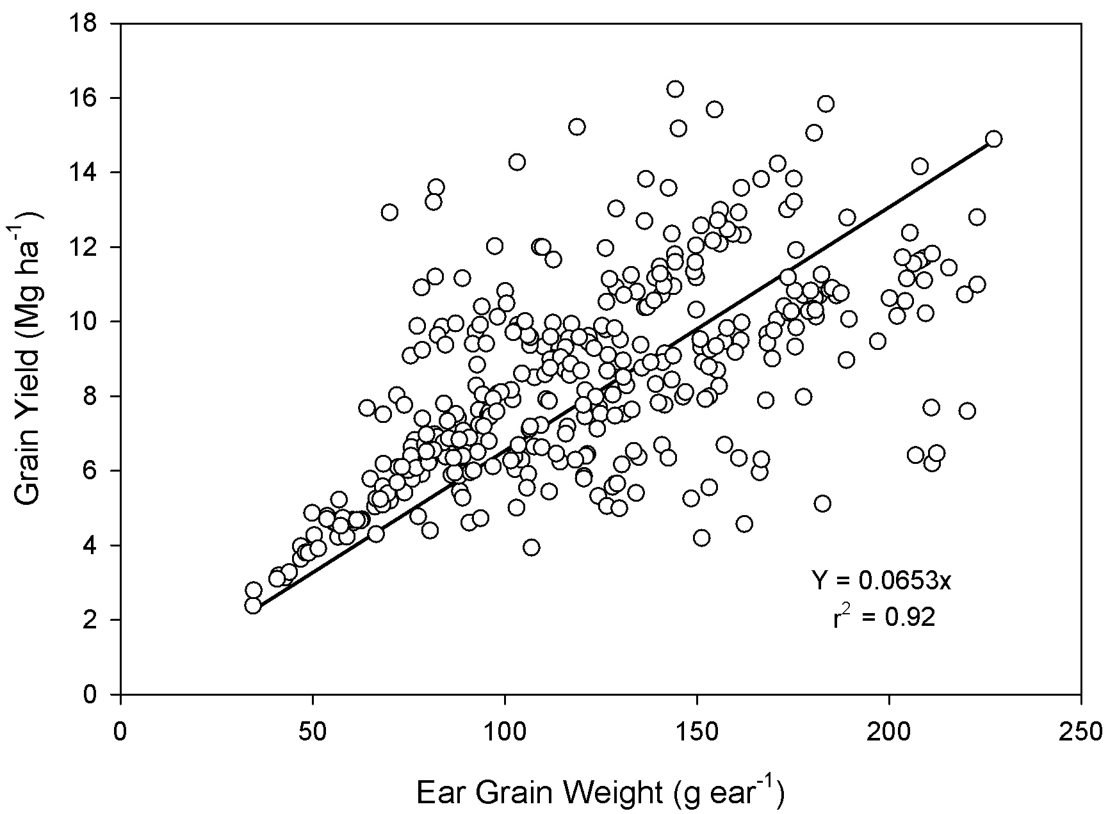


Figure 27. Grain yield as a function of to grain weight per ear, at all locations and years.

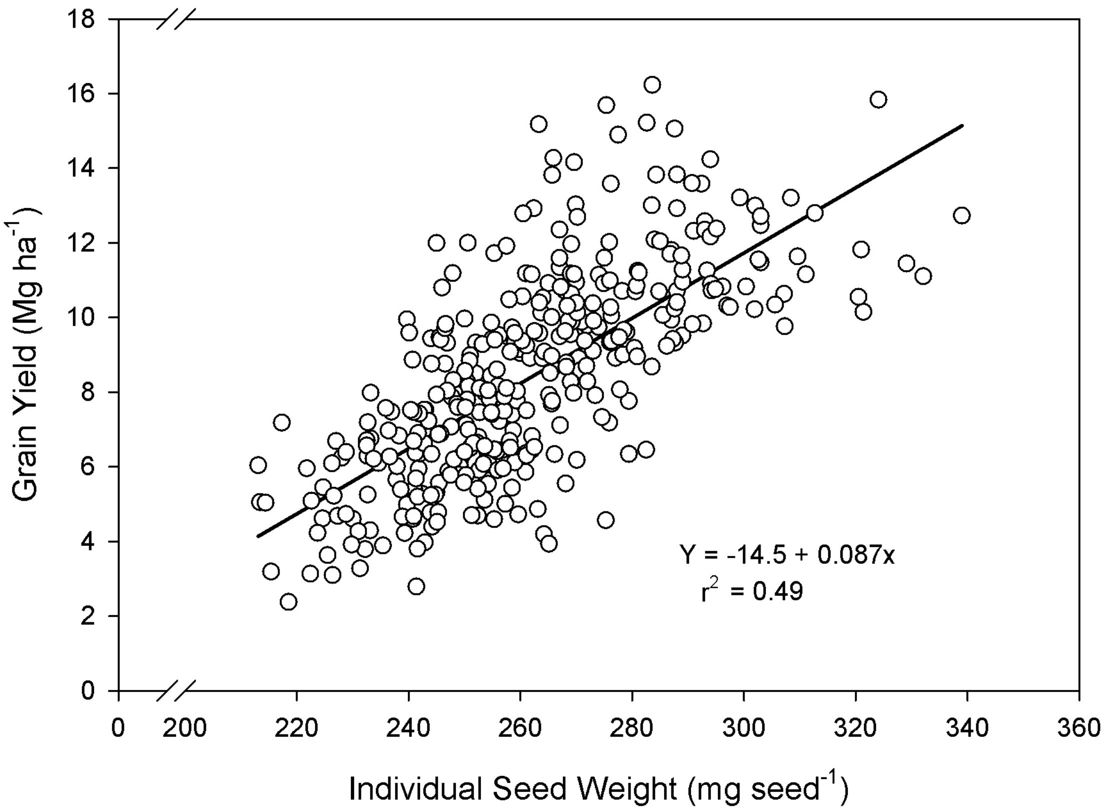


Figure 28. Grain yield as a function of dry seed weight, at all locations and years.

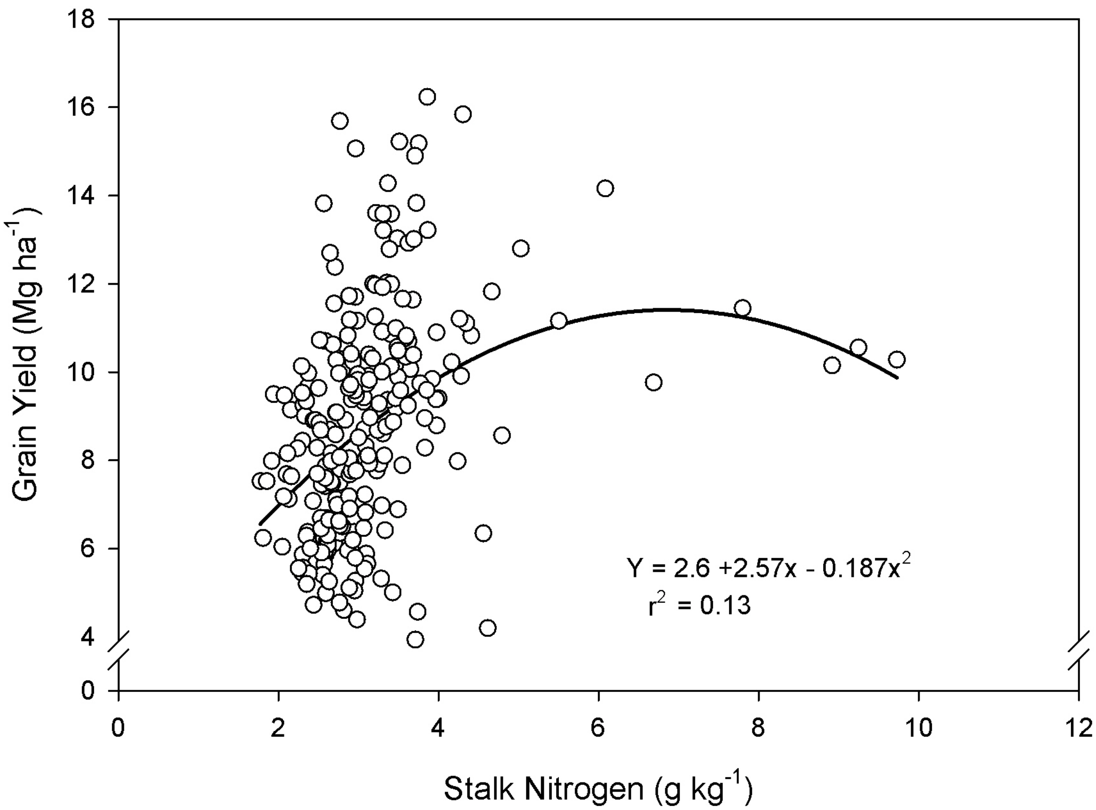


Figure 29. Grain yield as a function of to stalk nitrogen, at locations in 2008 and 2009.

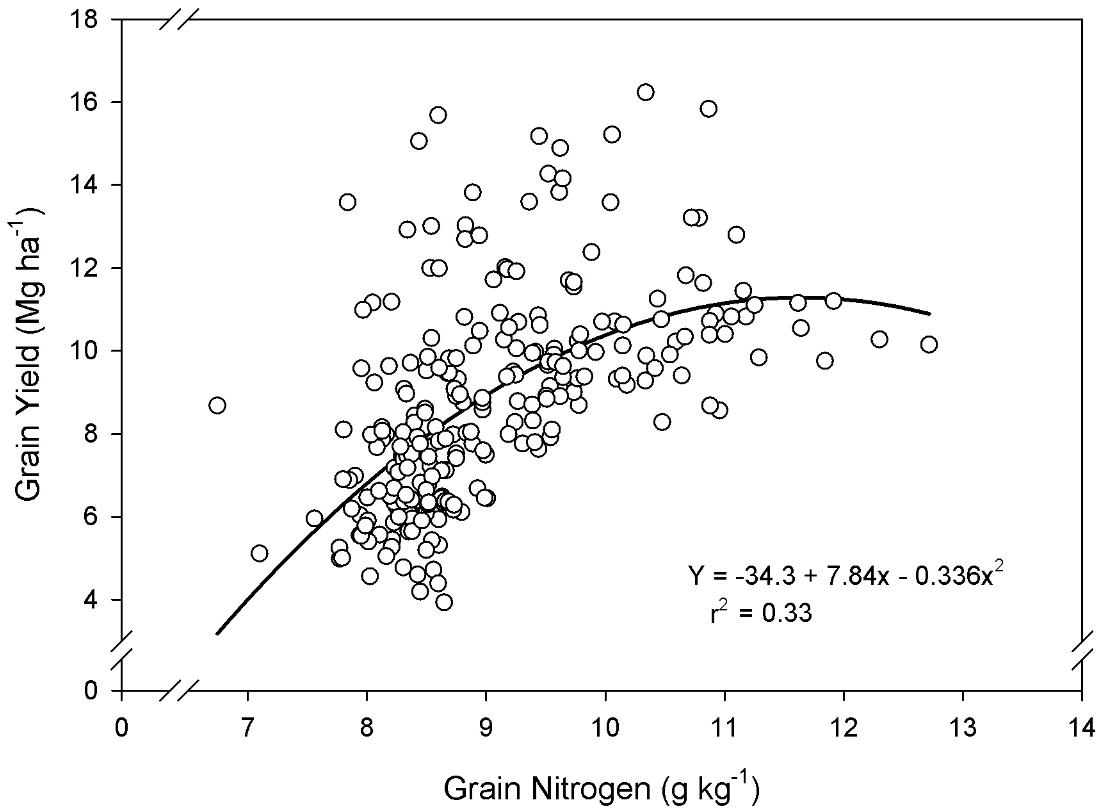


Figure 30. Grain yield as a function of grain nitrogen, at locations in 2008 and 2009.

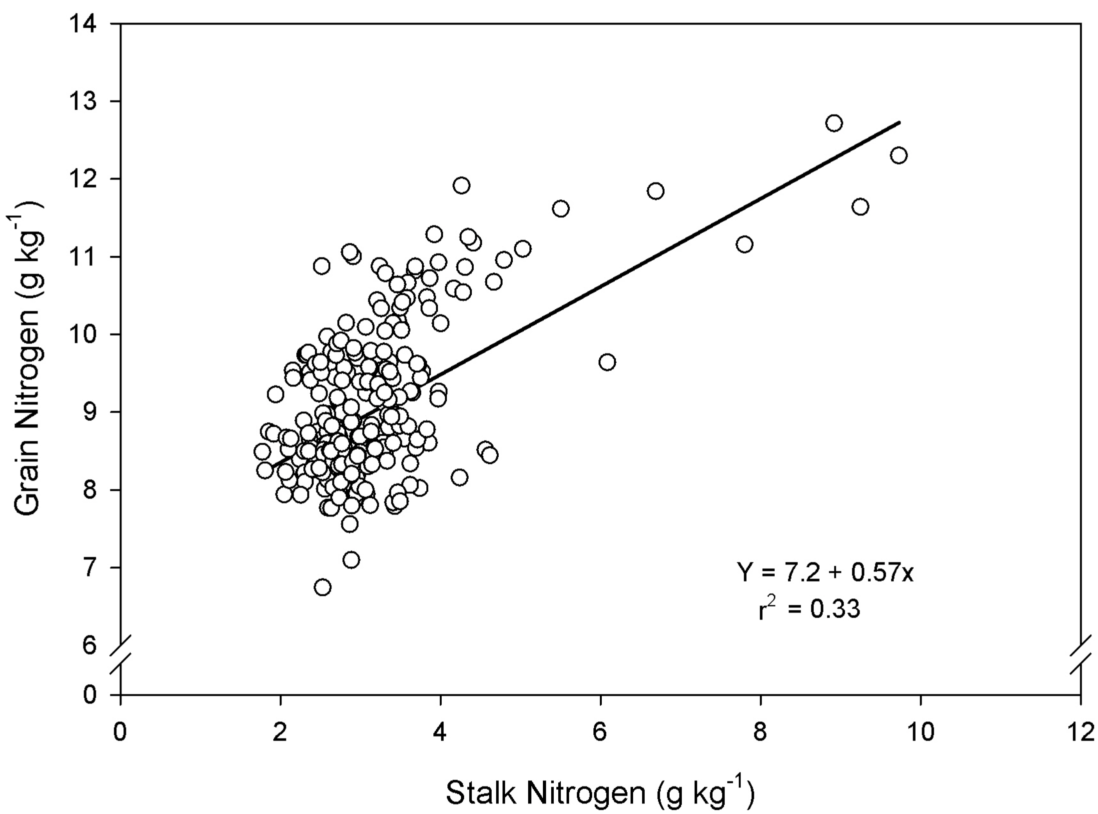


Figure 31. Grain nitrogen as a function of stalk nitrogen, at locations in 2008 and 2009.

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Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Doniphan	2007	40	11.5	303.0	8.2	140.3	0.00	.	.	.
2	Doniphan	2007	40	11.2	261.0	7.5	149.8	0.00	.	.	.
3	Doniphan	2007	40	9.5	258.0	7.8	122.1	3.18	.	.	.
4	Doniphan	2007	40	9.5	289.0	7.3	130.0	3.18	.	.	.
1	Doniphan	2007	80	12.1	284.0	7.8	156.0	0.00	.	.	.
2	Doniphan	2007	80	10.9	265.0	8.5	129.0	0.00	.	.	.
3	Doniphan	2007	80	9.6	279.0	7.9	121.8	13.22	.	.	.
4	Doniphan	2007	80	9.4	255.0	8.3	113.3	2.35	.	.	.
1	Doniphan	2007	120	10.9	270.0	7.6	143.9	0.00	.	.	.
2	Doniphan	2007	120	10.5	264.0	8.3	126.5	0.00	.	.	.
3	Doniphan	2007	120	7.9	257.0	7.8	102.1	2.81	.	.	.
4	Doniphan	2007	120	8.9	277.0	6.9	129.4	3.64	.	.	.
1	Doniphan	2007	160	12.6	293.0	8.3	151.1	0.00	.	.	.
2	Doniphan	2007	160	13.8	288.0	7.9	175.2	0.00	.	.	.
3	Doniphan	2007	160	9.9	287.0	8.5	117.4	3.62	.	.	.
4	Doniphan	2007	160	11.3	281.0	8.5	132.9	2.36	.	.	.
1	Doniphan	2007	40	9.3	252.0	8.5	110.1	0.00	.	.	.
2	Doniphan	2007	40	9.0	251.0	8.0	111.8	0.00	.	.	.
3	Doniphan	2007	40	9.5	269.0	8.2	116.7	5.21	.	.	.
4	Doniphan	2007	40	10.7	268.0	7.6	140.8	17.06	.	.	.
1	Doniphan	2007	80	11.1	274.0	8.8	127.3	0.00	.	.	.
2	Doniphan	2007	80	11.3	267.0	7.6	149.2	0.00	.	.	.
3	Doniphan	2007	80	11.2	262.0	7.9	141.3	8.73	.	.	.
4	Doniphan	2007	80	10.4	273.0	7.6	136.4	4.44	.	.	.
1	Doniphan	2007	120	11.6	267.0	7.8	149.6	0.00	.	.	.
2	Doniphan	2007	120	10.8	246.0	8.0	134.4	0.00	.	.	.
3	Doniphan	2007	120	12.9	288.0	8.0	160.8	914.60	.	.	.
4	Doniphan	2007	120	12.3	291.0	7.6	162.0	3.60	.	.	.
1	Doniphan	2007	160	11.8	287.0	8.2	144.3	0.00	.	.	.
2	Doniphan	2007	160	9.1	273.0	7.2	126.9	0.00	.	.	.
3	Doniphan	2007	160	12.4	293.0	7.8	159.4	23.80	.	.	.
4	Doniphan	2007	160	12.7	339.0	8.2	155.6	135.76	.	.	.
1	Doniphan	2007	0	9.8	272.0	7.8	126.3	0.00	.	.	.
2	Doniphan	2007	0	9.4	244.0	7.8	121.8	0.00	.	.	.
3	Doniphan	2007	0	7.6	250.0	8.2	93.2	3.19	.	.	.
4	Doniphan	2007	0	8.5	252.0	7.9	107.7	2.39	.	.	.

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Doniphan	2007	40	14.2	294.0	8.3	171.0	0.00	.	.	.
2	Doniphan	2007	40	9.9	271.0	7.9	125.3	0.00	.	.	.
3	Doniphan	2007	40	10.3	297.0	6.9	149.8	38.46	.	.	.
4	Doniphan	2007	40	11.2	269.0	8.0	139.1	2.01	.	.	.
1	Doniphan	2007	80	12.4	267.0	8.6	143.5	0.00	.	.	.
2	Doniphan	2007	80	13.0	302.0	8.3	156.1	0.00	.	.	.
3	Doniphan	2007	80	9.3	259.0	8.0	115.8	4.04	.	.	.
4	Doniphan	2007	80	10.7	288.0	8.2	131.0	44.19	.	.	.
1	Doniphan	2007	120	9.0	260.0	7.9	114.6	0.00	.	.	.
2	Doniphan	2007	120	11.6	275.0	8.0	144.3	0.00	.	.	.
3	Doniphan	2007	120	12.2	294.0	7.9	154.2	26.47	.	.	.
4	Doniphan	2007	120	12.5	303.0	7.9	158.0	3.58	.	.	.
1	Doniphan	2007	160	12.0	285.0	8.0	149.8	0.00	.	.	.
2	Doniphan	2009	160	12.7	303.0	8.2	155.4	0.00	.	.	.
3	Doniphan	2008	160	11.0	289.0	7.8	141.4	2.40	.	.	.
4	Doniphan	2008	160	11.3	289.0	8.0	140.4	38.42	.	.	.
1	Riley	2008	40	7.5	243.0	5.7	131.1	0.18	0.849	0.557	34.639
2	Riley	2008	40	9.1	259.8	6.5	141.6	0.22	0.954	1.445	39.749
3	Riley	2008	40	6.0	213.1	5.9	102.7	0.20	0.794	0.594	29.819
4	Riley	2008	40	8.0	233.2	5.5	146.4	0.42	0.816	0.536	29.745
1	Riley	2008	80	8.4	254.7	5.9	143.5	0.23	0.840	0.406	30.284
2	Riley	2008	80	9.3	246.9	6.2	151.1	0.35	0.876	0.863	34.081
3	Riley	2008	80	6.3	232.6	6.0	104.4	0.24	0.846	1.022	27.720
4	Riley	2008	80	8.3	250.5	5.3	155.8	0.22	0.840	0.780	38.845
1	Riley	2008	40	9.5	267.0	5.9	161.4	0.19	0.923	0.987	38.624
2	Riley	2008	40	7.7	249.4	6.2	124.6	0.21	0.852	1.492	35.889
3	Riley	2008	40	5.5	224.7	6.2	88.3	0.23	0.821	0.649	27.936
4	Riley	2008	40	7.5	242.8	6.0	124.9	0.19	0.875	0.676	30.120
1	Riley	2008	80	7.6	257.1	5.7	133.1	0.22	0.944	1.338	33.664
2	Riley	2008	80	8.2	250.7	6.7	120.9	0.21	0.813	1.258	37.227
3	Riley	2008	80	6.2	228.0	5.5	114.4	0.18	0.825	0.547	31.008
4	Riley	2008	80	8.8	246.5	6.5	135.7	0.34	0.881	0.852	27.167
1	Riley	2008	40	9.7	278.5	5.7	168.3	0.24	0.951	0.720	36.095
2	Riley	2008	40	8.7	266.2	5.6	155.3	0.26	0.978	2.295	36.109
3	Riley	2008	40	8.0	248.2	6.5	123.7	0.19	0.872	0.642	29.842
4	Riley	2008	40	9.5	245.5	6.0	157.1	0.21	0.867	0.546	38.912

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Riley	2008	80	10.7	278.2	6.0	177.7	0.35	1.008	0.998	34.988
2	Riley	2008	80	10.7	280.6	5.9	181.9	0.26	0.997	1.398	35.285
3	Riley	2008	80	10.0	269.1	6.2	161.6	0.24	0.941	1.124	41.735
4	Riley	2008	80	10.1	263.7	5.6	181.0	0.23	0.889	1.647	37.794
1	Riley	2008	120	11.3	293.4	6.2	182.4	0.32	1.044	0.946	30.278
2	Riley	2008	120	9.3	287.7	5.3	175.6	0.31	1.010	0.684	31.485
3	Riley	2008	120	10.9	280.8	5.9	184.5	0.34	0.944	0.673	32.508
4	Riley	2008	120	10.1	285.5	5.3	189.6	0.36	0.925	0.579	28.623
1	Riley	2008	160	10.6	307.2	5.9	180.7	0.28	1.015	0.675	29.063
2	Riley	2008	160	9.8	292.7	5.6	175.8	0.39	1.129	1.500	27.203
3	Riley	2008	160	11.7	286.8	5.6	209.0	0.30	0.969	0.550	26.525
4	Riley	2008	160	11.6	309.6	5.6	207.9	0.37	1.082	0.797	29.808
1	Riley	2008	40	8.9	261.7	5.9	151.5	0.28	0.951	0.874	33.375
2	Riley	2008	40	9.3	261.1	6.0	153.5	0.23	0.974	0.920	36.349
3	Riley	2008	40	9.0	278.4	5.3	169.6	0.23	0.974	1.224	36.890
4	Riley	2008	40	10.6	269.1	5.3	200.1	0.27	0.945	0.632	31.820
1	Riley	2008	80	9.3	276.0	6.0	155.0	0.23	0.977	1.822	32.794
2	Riley	2008	80	8.9	270.4	6.3	141.1	0.24	0.962	0.624	28.007
3	Riley	2008	80	10.7	284.8	5.7	186.3	0.36	0.927	1.297	33.590
4	Riley	2008	80	10.1	276.3	5.9	170.8	0.28	0.957	0.719	29.326
1	Riley	2008	120	10.9	294.1	5.9	185.2	0.40	1.093	1.222	24.990
2	Riley	2008	120	10.2	287.6	5.9	174.0	0.29	0.977	0.857	30.473
3	Riley	2008	120	10.2	301.9	4.9	209.5	0.42	1.059	1.287	27.167
4	Riley	2008	120	10.7	294.2	4.9	219.7	0.25	1.088	0.765	29.048
1	Riley	2008	160	10.8	300.4	6.0	179.6	0.44	1.118	1.190	25.720
2	Riley	2008	160	10.4	288.0	6.0	172.7	0.29	1.100	0.821	24.445
3	Riley	2008	160	11.6	302.6	5.6	206.4	0.27	0.973	0.891	30.808
4	Riley	2008	160	11.8	321.0	5.6	211.2	0.47	1.068	0.799	26.653
1	Riley	2008	0	8.9	263.9	6.5	138.0	0.25	0.875	0.487	30.353
2	Riley	2008	0	9.5	256.2	6.3	150.9	0.23	0.850	1.160	31.145
3	Riley	2008	0	7.1	250.3	5.7	124.1	0.21	0.866	0.850	39.386
4	Riley	2008	0	7.2	217.3	6.2	116.3	0.21	0.823	0.557	32.036
1	Riley	2008	40	9.4	287.3	5.6	168.4	0.31	0.925	0.648	27.372
2	Riley	2008	40	9.2	280.4	5.7	160.0	0.35	1.018	0.698	27.940
3	Riley	2008	40	8.8	268.2	5.7	153.1	0.40	0.926	1.078	30.633
4	Riley	2008	40	10.3	276.1	5.9	174.6	0.27	0.915	0.638	35.805

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Riley	2008	80	11.2	311.1	5.5	204.6	0.55	1.162	1.234	24.180
2	Riley	2008	80	10.8	296.2	6.2	175.5	0.29	1.106	0.844	31.447
3	Riley	2008	80	10.3	305.6	5.7	180.2	0.36	1.067	0.513	29.631
4	Riley	2008	80	12.4	295.1	6.0	205.4	0.27	0.988	0.435	28.122
1	Riley	2008	120	10.8	294.9	5.7	187.5	0.36	1.047	1.048	25.031
2	Riley	2008	120	9.8	307.3	5.7	170.0	0.67	1.184	1.139	27.392
3	Riley	2008	120	11.1	332.1	5.3	209.2	0.43	1.125	0.567	26.273
4	Riley	2008	120	12.8	312.7	5.7	222.9	0.50	1.110	0.752	31.682
1	Riley	2008	160	10.2	321.4	5.0	202.1	0.89	1.272	0.677	21.400
2	Riley	2009	160	10.3	297.5	5.7	179.1	0.97	1.230	1.115	22.960
3	Riley	2009	160	10.6	320.5	5.2	204.2	0.92	1.164	0.783	26.793
4	Riley	2009	160	11.4	329.1	5.3	215.6	0.78	1.116	0.496	24.559
1	Marshall	2009	40	5.3	242.4	6.9	89.0	0.30	0.821	1.228	10.980
2	Marshall	2009	40	6.3	266.1	7.1	160.9	0.24	0.864	1.105	10.964
3	Marshall	2009	40	6.5	254.0	6.8	76.5	0.27	0.863	1.428	13.049
4	Marshall	2009	40	6.7	227.0	7.5	140.9	0.26	0.893	1.039	13.894
1	Marshall	2009	80	5.9	247.1	7.3	86.1	0.31	0.831	1.267	11.633
2	Marshall	2009	80	5.9	248.6	7.0	120.6	0.26	0.835	1.046	12.084
3	Marshall	2009	80	6.2	256.4	6.7	80.4	0.26	0.849	1.050	11.352
4	Marshall	2009	80	5.9	260.9	7.1	88.1	0.23	0.822	1.161	13.435
1	Marshall	2009	120	6.4	256.7	7.3	121.5	0.26	0.862	0.739	10.330
2	Marshall	2009	120	5.6	254.0	6.7	128.7	0.26	0.835	1.232	12.471
3	Marshall	2009	120	7.5	252.7	7.0	87.1	0.26	0.829	0.972	12.730
4	Marshall	2009	120	7.4	258.5	7.2	78.6	0.27	0.830	1.014	13.251
1	Marshall	2009	160	6.5	262.0	7.1	85.8	0.28	0.901	0.962	12.700
2	Marshall	2009	160	5.3	245.0	6.9	124.3	0.33	0.861	1.916	12.292
3	Marshall	2009	160	5.6	245.4	7.1	128.0	0.23	0.811	1.442	12.643
4	Marshall	2009	160	6.1	259.0	6.7	96.9	0.27	0.879	1.291	13.922
1	Marshall	2009	0	5.9	252.6	6.9	78.4	0.29	0.801	0.733	9.437
2	Marshall	2009	0	5.3	232.7	6.8	148.5	0.26	0.777	0.980	10.661
3	Marshall	2009	0	6.3	249.5	7.2	118.4	0.24	0.873	0.623	9.578
4	Marshall	2009	0	6.1	254.3	6.4	72.2	0.26	0.850	0.723	11.513
1	Marshall	2009	40	5.4	241.0	6.9	134.2	0.26	0.801	1.687	12.178
2	Marshall	2009	40	4.6	240.8	6.6	90.8	0.28	0.842	0.752	12.271
3	Marshall	2009	40	4.7	259.6	6.6	93.7	0.24	0.856	1.084	12.431
4	Marshall	2009	40	6.4	254.1	6.8	84.6	0.24	0.866	0.832	11.338

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Marshall	2009	80	5.1	213.4	7.0	126.6	0.29	0.816	1.248	12.095
2	Marshall	2009	80	6.2	249.2	6.8	130.5	0.26	0.873	0.934	12.336
3	Marshall	2009	80	7.2	256.2	7.1	109.4	0.31	0.853	1.162	12.487
4	Marshall	2009	80	5.4	258.5	6.5	111.6	0.24	0.854	0.855	11.725
1	Marshall	2009	120	5.0	239.7	6.4	129.8	0.26	0.777	1.701	14.068
2	Marshall	2009	120	6.0	221.8	6.8	91.0	0.26	0.838	0.615	13.388
3	Marshall	2009	120	7.4	254.9	7.2	87.9	0.26	0.875	1.015	13.019
4	Marshall	2009	120	5.6	268.1	6.6	153.2	0.23	0.794	0.930	10.563
1	Marshall	2009	160	5.9	241.8	6.1	87.0	0.26	0.860	1.399	10.321
2	Marshall	2009	160	4.8	243.9	5.5	77.5	0.28	0.831	1.096	11.531
3	Marshall	2009	160	6.4	261.0	6.9	134.9	0.27	0.868	1.412	15.323
4	Marshall	2009	160	5.2	241.6	6.9	70.2	0.24	0.850	1.186	13.101
1	Marshall	2009	40	6.4	254.4	7.4	121.1	0.28	0.843	0.932	12.186
2	Marshall	2009	40	7.1	247.6	7.6	89.2	0.24	0.826	0.872	11.339
3	Marshall	2009	40	9.9	269.2	7.2	77.2	0.35	1.034	0.434	13.774
4	Marshall	2009	40	7.8	259.4	7.3	141.6	0.32	0.931	0.670	13.132
1	Marshall	2009	80	9.9	254.8	7.0	83.7	0.30	0.851	0.496	13.731
2	Marshall	2009	80	8.6	255.8	7.1	104.5	0.33	0.849	0.742	10.727
3	Marshall	2009	80	8.6	270.8	7.8	110.5	0.27	0.897	0.579	14.453
4	Marshall	2009	80	8.3	269.0	7.4	92.6	0.25	0.924	0.615	13.429
1	Marshall	2009	120	10.9	274.9	6.8	78.4	0.33	0.912	0.789	12.150
2	Marshall	2009	120	8.7	271.8	6.7	115.6	0.31	0.939	0.414	11.573
3	Marshall	2009	120	7.5	257.1	7.6	95.6	0.28	0.900	0.478	12.341
4	Marshall	2009	120	9.4	276.3	7.8	106.6	0.34	0.965	0.535	14.004
1	Marshall	2009	160	7.9	273.4	6.6	110.8	0.33	0.954	0.388	13.110
2	Marshall	2009	160	9.9	268.6	7.0	103.4	0.31	0.957	0.450	12.311
3	Marshall	2009	160	8.0	253.6	7.1	153.2	0.27	0.919	0.757	13.233
4	Marshall	2009	160	9.7	274.0	7.5	102.8	0.38	0.952	0.714	13.647
1	Marshall	2009	40	8.2	256.0	6.6	101.7	0.27	0.858	0.540	10.858
2	Marshall	2009	40	8.1	252.7	6.2	147.0	0.33	0.955	0.427	12.343
3	Marshall	2009	40	9.7	258.5	6.4	92.4	0.31	0.958	0.704	12.261
4	Marshall	2009	40	7.8	254.5	7.0	140.0	0.26	0.860	0.718	10.508
1	Marshall	2009	80	8.0	259.4	6.8	71.9	0.31	0.883	0.597	12.263
2	Marshall	2009	80	8.3	272.0	7.4	131.7	0.38	1.048	0.432	13.399
3	Marshall	2009	80	9.9	239.7	7.1	87.2	0.30	0.939	0.492	13.043
4	Marshall	2009	80	8.8	250.9	6.4	92.8	0.25	0.951	0.388	12.438

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Marshall	2009	120	9.9	273.1	6.7	93.6	0.43	1.054	0.486	14.270
2	Marshall	2009	120	8.6	250.1	6.4	116.9	0.48	1.096	0.521	16.763
3	Marshall	2009	120	10.1	270.2	6.9	98.1	0.34	1.015	0.455	12.693
4	Marshall	2009	120	10.0	250.0	7.8	112.5	0.28	0.992	0.356	12.730
1	Marshall	2009	160	8.7	268.2	6.8	126.7	0.32	1.088	0.487	11.382
2	Marshall	2009	160	10.4	270.0	6.8	137.1	0.37	1.087	0.381	12.896
3	Marshall	2009	160	9.6	268.0	7.3	82.5	0.25	0.965	0.619	12.043
4	Marshall	2009	160	11.2	281.2	6.7	81.9	0.43	1.192	0.376	15.261
1	Marshall	2009	0	5.7	237.8	6.4	129.3	0.31	0.838	1.440	11.338
2	Marshall	2009	0	6.4	242.0	6.8	88.8	0.28	0.823	1.187	12.185
3	Marshall	2009	0	7.5	254.8	7.2	120.9	0.25	0.852	0.815	11.665
4	Marshall	2009	0	5.9	255.9	7.2	106.1	0.25	0.846	0.715	11.945
1	Marshall	2009	40	6.4	241.2	7.3	102.6	0.29	0.831	0.769	11.813
2	Marshall	2009	40	7.9	247.7	7.5	111.5	0.26	0.813	0.834	11.771
3	Marshall	2009	40	6.8	252.5	7.3	95.9	0.28	0.852	0.494	9.174
4	Marshall	2009	40	7.5	236.9	7.9	128.7	0.27	0.834	0.653	10.997
1	Marshall	2009	80	8.8	244.1	7.2	111.8	0.33	0.897	0.490	10.825
2	Marshall	2009	80	8.3	248.0	7.5	139.3	0.31	0.939	0.465	12.560
3	Marshall	2009	80	7.8	250.5	6.7	84.2	0.28	0.941	0.367	12.591
4	Marshall	2009	80	9.4	260.3	7.9	84.6	0.29	0.982	0.427	11.176
1	Marshall	2009	120	10.4	263.4	7.8	94.0	0.31	0.979	0.540	11.980
2	Marshall	2009	120	7.9	257.1	7.2	167.9	0.35	0.866	0.467	12.669
3	Marshall	2009	120	9.1	264.3	7.9	75.5	0.27	0.874	0.611	13.013
4	Marshall	2009	120	9.3	253.2	7.5	123.2	0.33	1.033	0.289	11.265
1	Marshall	2009	160	8.9	240.7	6.9	117.1	0.34	0.897	0.365	12.989
2	Marshall	2009	160	9.4	255.4	7.4	91.7	0.40	1.014	0.372	14.519
3	Marshall	2009	160	9.4	245.7	7.4	95.2	0.35	1.064	0.489	11.832
4	Marshall	2009	160	9.6	259.0	8.2	119.4	0.35	1.042	0.547	11.057
1	Riley	2009	40	7.5	261.1	7.1	68.4	0.27	0.838	1.209	15.782
2	Riley	2009	40	7.1	267.1	6.7	106.4	0.27	0.863	1.250	15.364
3	Riley	2009	40	6.5	251.0	6.7	93.0	0.28	0.819	0.811	13.281
4	Riley	2009	40	7.7	248.6	7.6	64.2	0.29	0.808	1.536	19.370
1	Riley	2009	80	6.8	262.1	6.9	76.6	0.31	0.845	1.936	15.809
2	Riley	2009	80	4.4	244.2	3.9	80.6	0.30	0.860	1.531	18.742
3	Riley	2009	80	7.8	279.4	6.9	73.9	0.29	0.888	1.779	16.049
4	Riley	2009	80	8.0	246.9	7.3	128.1	0.31	0.831	1.966	20.148

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
1	Riley	2009	120	9.5	277.7	7.0	197.1	0.30	0.869	1.794	18.787
2	Riley	2009	120	7.0	258.7	7.1	81.7	0.33	0.855	1.675	18.447
3	Riley	2009	120	9.8	290.8	6.9	128.6	0.30	0.869	1.659	16.955
4	Riley	2009	120	8.0	254.2	7.6	94.2	0.29	0.887	1.089	13.097
1	Riley	2009	160	8.0	269.5	6.9	177.8	0.27	0.803	1.374	19.423
2	Riley	2009	160	7.0	250.7	6.8	115.9	0.27	0.790	1.220	14.793
3	Riley	2009	160	6.4	255.8	7.2	206.9	0.33	0.837	1.111	19.159
4	Riley	2009	160	9.4	271.5	6.5	135.4	0.40	0.917	2.639	18.041
1	Riley	2009	0	5.1	253.6	6.4	182.7	0.29	0.710	2.004	16.592
2	Riley	2009	0	8.1	257.5	7.4	99.0	0.31	0.781	1.147	12.027
3	Riley	2009	0	7.8	265.7	7.3	120.4	0.30	0.845	0.879	15.215
4	Riley	2009	0	6.5	255.3	6.5	212.4	0.31	0.800	1.080	12.031
1	Riley	2009	40	5.5	254.2	6.8	105.8	0.31	0.795	1.766	13.362
2	Riley	2009	40	8.5	265.3	7.1	130.9	0.30	0.849	1.180	16.613
3	Riley	2009	40	7.9	265.1	7.8	152.2	0.31	0.842	1.261	19.936
4	Riley	2009	40	7.6	248.8	7.1	220.4	0.26	0.898	1.346	21.588
1	Riley	2009	80	5.0	257.3	6.8	103.1	0.34	0.779	3.109	15.698
2	Riley	2009	80	7.2	275.9	6.7	106.6	0.29	0.834	1.509	18.464
3	Riley	2009	80	6.0	256.9	8.5	166.3	0.29	0.756	1.045	15.631
3	Riley	2009	80	6.0	249.2	7.6	91.9	0.24	0.827	1.170	14.281
4	Riley	2009	80	6.3	261.1	7.6	166.8	0.26	0.851	1.459	16.129
1	Riley	2009	120	6.7	258.1	7.1	157.2	0.25	0.823	0.781	11.782
2	Riley	2009	120	7.7	265.6	7.2	211.0	0.25	0.828	1.395	16.201
3	Riley	2009	120	5.8	249.0	7.1	120.6	0.30	0.799	1.541	18.197
4	Riley	2009	120	6.5	282.5	4.1	113.4	0.25	0.899	1.462	17.432
1	Riley	2009	160	4.6	275.3	3.6	162.4	0.37	0.802	1.937	15.516
2	Riley	2009	160	8.1	277.8	7.2	98.2	0.28	0.813	1.642	15.410
3	Riley	2009	160	6.2	248.1	7.5	211.2	0.29	0.787	1.284	16.213
4	Riley	2009	160	6.6	252.2	7.3	107.6	0.26	0.850	1.311	18.693
1	Riley	2009	40	8.7	283.5	7.2	119.8	0.25	0.675	0.766	14.338
2	Riley	2009	40	9.1	258.2	7.5	143.8	0.27	0.831	1.166	15.885
3	Riley	2009	40	9.0	265.6	7.1	188.9	0.31	0.833	1.643	17.695
4	Riley	2009	40	9.6	240.1	8.1	111.9	0.39	0.861	2.450	22.427
1	Riley	2009	80	9.6	263.4	7.3	106.7	0.30	0.795	1.172	16.616
2	Riley	2009	80	10.3	268.4	7.4	180.8	0.32	0.854	1.145	16.667
3	Riley	2009	80	12.0	250.6	7.4	109.1	0.32	0.853	1.093	14.667

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
4	Riley	2009	80	10.6	260.4	7.3	138.8	0.35	0.919	2.634	21.832
1	Riley	2009	120	13.6	292.4	6.6	161.6	0.34	0.784	1.087	17.795
2	Riley	2009	120	11.2	269.6	7.1	89.0	0.30	0.805	0.939	14.490
3	Riley	2009	120	12.0	275.9	7.2	97.4	0.34	0.916	0.864	18.911
4	Riley	2009	120	13.0	269.9	6.9	129.0	0.35	0.883	1.690	20.945
1	Riley	2009	160	6.5	262.5	6.1	133.6	0.28	0.833	2.720	17.334
2	Riley	2009	160	12.9	262.4	7.8	70.1	0.36	0.834	1.279	16.995
3	Riley	2009	160	13.6	290.7	7.5	82.2	0.32	0.936	1.071	17.599
4	Riley	2009	160	13.2	308.4	5.8	81.5	0.33	1.079	1.370	18.782
1	Riley	2009	40	9.2	286.2	7.2	78.5	0.36	0.806	1.664	15.454
2	Riley	2009	40	11.0	276.0	7.6	223.0	0.35	0.797	1.765	17.106
3	Riley	2009	40	9.6	262.5	7.2	106.0	0.29	0.819	0.582	14.094
4	Riley	2009	40	9.7	246.5	7.4	102.2	0.29	0.837	0.851	17.951
1	Riley	2009	80	13.0	283.5	7.3	173.5	0.37	0.854	0.947	16.454
2	Riley	2009	80	13.8	265.7	7.6	166.7	0.26	0.889	0.707	14.931
3	Riley	2009	80	12.7	270.2	7.3	136.4	0.26	0.882	1.582	20.215
4	Riley	2009	80	11.7	255.3	7.8	203.5	0.29	0.906	1.253	17.341
1	Riley	2009	120	6.3	279.4	8.3	142.6	0.46	0.852	3.160	14.601
2	Riley	2009	120	15.7	275.4	7.4	154.6	0.28	0.860	0.903	17.815
3	Riley	2009	120	11.7	288.8	6.4	112.7	0.36	0.974	1.246	22.744
4	Riley	2009	120	12.0	269.1	6.9	126.2	0.32	0.918	0.742	18.811
1	Riley	2009	160	15.1	287.6	7.6	180.5	0.30	0.844	0.662	12.928
2	Riley	2009	160	13.8	284.3	7.3	136.7	0.37	0.961	1.320	17.195
3	Riley	2009	160	15.8	324.1	7.1	183.6	0.43	1.087	0.714	16.236
4	Riley	2009	160	14.3	265.9	13.0	103.2	0.34	0.952	0.904	19.890
1	Riley	2009	0	4.2	264.2	6.1	151.3	0.46	0.845	3.652	13.384
1	Riley	2009	0	3.9	265.1	6.1	107.0	0.37	0.865	3.004	14.555
2	Riley	2009	0	6.6	242.8	7.2	109.6	0.28	0.810	1.049	12.400
3	Riley	2009	0	9.0	280.9	6.6	130.8	0.38	0.878	2.521	15.230
4	Riley	2009	0	6.9	245.7	6.7	90.8	0.35	0.785	1.586	14.356
1	Riley	2009	40	6.9	241.7	7.4	82.5	0.29	0.780	1.479	13.815
2	Riley	2009	40	11.2	247.9	6.9	173.7	0.29	0.821	0.819	15.822
3	Riley	2009	40	10.8	267.2	7.0	100.1	0.36	0.882	1.096	16.852
4	Riley	2009	40	9.8	246.6	6.9	157.8	0.31	0.875	1.372	18.241
1	Riley	2009	80	10.5	258.0	6.9	100.5	0.35	0.895	0.745	17.851
2	Riley	2009	80	12.0	245.0	7.2	109.9	0.34	0.860	0.497	13.751

Appendix Table 1. All data for Urea, DDG, and char applications at four location years

Replication	Location	Year	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt	Stalk N	Kernel N	Stalk P	Stalk K
			kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}	ppm	ppm	ppm	ppm
3	Riley	2009	80	10.0	265.6	7.3	105.3	0.33	0.978	0.392	16.147
4	Riley	2009	80	11.9	257.5	6.8	175.8	0.33	0.925	0.737	16.694
1	Riley	2009	120	12.8	260.5	7.0	189.1	0.34	0.894	0.645	20.616
2	Riley	2009	120	15.2	263.3	6.9	145.2	0.38	0.944	0.511	18.164
3	Riley	2009	120	14.9	277.5	7.3	227.3	0.37	0.962	0.892	17.530
4	Riley	2009	120	13.6	276.2	7.8	142.6	0.33	1.004	0.609	13.072
1	Riley	2009	160	16.2	283.6	7.6	144.4	0.39	1.034	0.462	19.017
2	Riley	2009	160	15.2	282.6	7.2	118.8	0.35	1.006	0.380	17.311
3	Riley	2009	160	14.2	269.6	11.0	208.1	0.61	0.964	1.211	13.177
4	Riley	2009	160	13.2	299.3	6.4	175.3	0.39	1.072	0.750	20.256

Appendix Table 2. All data for Urea, DDG, and char applications from the 2008 residual plots planted and harvested in 2009 at Riley

Replication	Location	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt
		kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}
1	Ashnotill	40	4.2	239.3	7.5	56.6
2	Ashnotill	40	5.8	247.5	8.9	65.0
3	Ashnotill	40	5.0	214.4	7.6	66.2
4	Ashnotill	40	3.9	235.4	7.8	50.2
1	Ashnotill	80	4.6	224.6	8.3	55.5
2	Ashnotill	80	5.3	244.8	7.9	66.6
3	Ashnotill	80	3.1	222.4	7.3	42.8
4	Ashnotill	80	5.1	222.6	7.5	68.2
1	Ashtill	40	6.1	226.3	8.0	75.8
2	Ashtill	40	4.0	242.9	8.5	46.9
3	Ashtill	40	3.2	215.4	7.8	41.2
4	Ashtill	40	4.6	230.0	7.6	60.5
1	Ashtill	80	4.8	245.3	8.9	53.8
2	Ashtill	80	4.6	255.3	8.2	56.1
3	Ashtill	80	3.6	225.5	7.8	46.9
4	Ashtill	80	4.3	233.1	6.5	66.5
1	DDGnotill	40	6.8	233.2	8.0	84.0
2	DDGnotill	40	5.8	250.3	7.6	75.9
3	DDGnotill	40	2.4	218.5	6.9	34.5
4	DDGnotill	40	3.3	231.3	7.5	43.9
1	DDGnotill	80	7.2	243.6	7.8	93.3
2	DDGnotill	80	6.6	251.6	8.8	75.7
3	DDGnotill	80	6.7	232.5	8.5	79.2
4	DDGnotill	80	6.9	245.3	8.0	85.4
1	DDGnotill	120	7.6	235.9	7.9	96.0
2	DDGnotill	120	6.4	250.0	8.5	75.6
3	DDGnotill	120	7.4	241.9	7.8	95.8
4	DDGnotill	120	6.0	237.9	8.0	74.8
1	DDGnotill	160	7.5	240.9	7.8	96.3
2	DDGnotill	160	6.1	253.4	7.9	77.0
3	DDGnotill	160	4.7	252.4	7.5	62.9
4	DDGnotill	160	6.6	232.5	8.2	80.3
1	DDGtill	40	3.8	241.6	7.9	48.2
2	DDGtill	40	2.8	241.4	8.0	34.7
3	DDGtill	40	5.4	252.4	7.3	73.9
4	DDGtill	40	6.8	238.3	7.8	88.2
1	DDGtill	80	5.6	249.9	8.2	68.2
2	DDGtill	80	4.7	227.3	7.8	60.4
3	DDGtill	80	5.4	238.6	7.8	69.6
4	DDGtill	80	6.7	240.9	6.5	103.6
1	DDGtill	120	6.1	234.6	8.3	73.3
2	DDGtill	120	4.2	223.7	7.2	58.9
3	DDGtill	120	5.7	241.3	7.9	72.0
4	DDGtill	120	4.3	231.0	8.5	50.4
1	DDGtill	160	7.5	240.4	8.6	87.3
2	DDGtill	160	5.2	226.6	9.2	56.9
3	DDGtill	160	7.0	236.4	8.8	79.6
4	DDGtill	160	7.2	232.7	7.6	94.5
1	Fert	0	4.7	228.8	8.2	57.9

Appendix Table 2. All data for Urea, DDG, and char applications from the 2008 residual plots planted and harvested in 2009 at Riley

Replication	Location	N Rate	Grain Yield	Kernel Weight	Ear No	Ear Wt
		kg ha^{-1}	Mg ha^{-1}	mg seed	Ear m^{-2}	g ear^{-1}
2	Fert	0	4.9	263.1	9.8	49.9
3	Fert	0	5.2	244.0	7.8	67.6
4	Fert	0	3.1	226.4	7.6	40.8
1	Fert	40	4.7	238.9	7.5	62.5
2	Fert	40	4.7	240.9	7.6	61.5
3	Fert	40	6.4	228.8	7.2	89.1
4	Fert	40	3.8	232.2	7.8	48.9
1	Fert	80	6.2	233.7	7.8	80.2
2	Fert	80	6.3	244.1	7.3	86.7
3	Fert	80	6.3	236.6	6.2	101.6
4	Fert	80	3.9	229.8	7.6	51.5
1	Fert	120	7.9	245.0	8.2	97.0
2	Fert	120	6.6	253.6	8.0	81.5
3	Fert	120	4.7	251.3	8.8	53.7
4	Fert	120	6.5	258.2	8.2	79.6
1	Fert	160	7.6	250.2	7.8	97.9
2	Fert	160	7.3	274.6	8.6	85.1
3	Fert	160	6.2	270.1	9.0	68.4
4	Fert	160	4.5	245.1	7.9	57.3