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Comparison of ESN, urea, and aqua ammonia as sources of nitrogen for corn production in Iowa

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Comparison of ESN, urea, and aqua ammonia as sources of nitrogen for corn production in Iowa

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TO:

My family and friends who have always supported me.

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Comparison of ESN and aqua ammonia applied in the spring as sources of nitrogen for corn production in Iowa

Abstract

Three nitrogen response studies were conducted in Iowa to compare the effect of a controlled release fertilizer, ESN, to urea and aqua ammonia (AA), on corn grain yields, biomass yields, and soil nitrate (NO_3^--N) and ammonium (NH_4^+-N) concentrations. Experiments were conducted at two sites from 2003 through 2007 for the spring-applied ESN/urea study, two sites from 2006 through 2007 for the fall and spring-applied ESN/AA study, and one site from 2006 through 2007 for the spring applied ESN/AA study. N rates in the studies were 0-202 kg ha^{-1} in 34 kg N ha^{-1} increments in the ESN/urea study and 0-202 kg N ha^{-1} in 67 kg N ha^{-1} increments in the fall and spring-applied ESN/AA studies. Four of nine site-years in the ESN/urea study had significantly higher corn grain yields due to ESN. One of four site-years in the fall and spring-applied study had higher grain yields to either fall or spring application of ESN. Neither year of the spring-applied ESN/AA study had significantly higher grain yields due to ESN. Biomass yields, the above ground portion of the plant minus the ear, were also collected at physiological maturity. None of the nine site-years in the ESN/urea study had a positive response to ESN. One of the four site-years in the fall and spring-applied ESN/AA study had a positive response to spring-applied ESN. Neither year of the spring-applied ESN/AA study had a positive response to ESN. Soil samples were taken to measure NH_4^+-N and NO_3^--N concentrations at the V-6, V-15 growth stages, and also post-harvest at a depth of 0-30 cm. A 31-60 cm soil sample was also taken at post harvest. Throughout all of the studies, ESN treatments usually had higher concentrations of soil NH_4^+-N and NO_3^--N. Higher concentrations of residual N left in the soil after harvest can be subject to loss overwinter.

General Introduction

Nitrogen (N) fertilization is one of the most important aspects to corn production. In the past, as well as now, producers would often over-apply N to compensate for the risk of running short of N during the growing season thus risking yield losses. Increasing environmental concerns about nitrate leaching into ground water, runoff into surface water, and the rising cost of N fertilizer have led researchers and producers to look at different N management strategies which can help to reduce N loss and increase economic return to the producer.

Timing of N fertilizer application can affect the efficiency of N, primarily because of the time between the application and uptake by the crop. If nitrogen is applied well before crop uptake, it can be lost by leaching or denitrification (Bundy, 1986). Leaching losses tend to occur more often on well-drained soils while denitrification happens primarily on poorly drained soils in the presence of warmer temperatures. Excess precipitation can increase the losses of N through these two processes (Randall and Schmitt, 1998). Most N application in the northern part of the Corn Belt is typically done by producers in the fall because there is more time and field conditions are better suited for application compared to the spring (Bundy and Sawyer, 2005). Also, N application in the fall by producers has other advantages such as better distribution of labor and equipment demands, time savings during the busy planting season, and the cost of N is usually cheaper in the fall compared to the spring (Bundy, 1986; Randall and Schmitt, 1998).

Even though nitrogen gas (N_2) makes up 78 percent of the atmosphere, it is one of the most limiting elements for plant growth because it is not available until it is combined with hydrogen or oxygen (Troeh and Thompson, 1993). Nitrogen is required for formation of enzymes, to make lignin in cell walls, and is needed in about twenty amino acids to form protein through peptide linkages. Nitrogen is also a component of chlorophyll; it is used in the formation of purine and pyrimidine in DNA and RNA. Because N is required in such large amounts, it can be reasoned that a deficiency will be detrimental to producing high yields in crops. Plants tend to take up nitrate (NO_3^-) in the largest amount followed by ammonium (NH_4^+). Nitrate is the only inorganic form of nitrogen that can and will accumulate in plants in significant quantities (Black, 1968).

One type of management strategy currently being evaluated is the use of controlled and slow-release N fertilizers. There are no official definitions of slow and controlled release, but Trenkel (1997) suggests that a slow release fertilizer is insoluble and requires microbial decomposition to release the fertilizer material, while a controlled release fertilizer refers to a material which is coated or encapsulated by an insoluble material. This encapsulation (water insoluble, semi-permeable or impermeable with pores) slows down the release of the fertilizer. The general idea behind these N fertilizers is to slowly provide N or other nutrients to plants throughout the growing season. The idea behind slow and controlled release N products began as early as 1907 when a United States patent was granted for an impregnating and coating process to be used in the production of a slow-release fertilizer (Powell, 1968). Controlled-release fertilizers have been shown to increase yields in crops such as potatoes (Zvomuya and Rosen, 2001) and barley (Nyborg et al., 1999).

ESN is a controlled-release N product (44% N) developed by Agrium, Inc. Nitrogen is released through the organic, biodegradable, polymer coating which is composed of castor oil, polymeric diphenylmethane diisocyanate, and wax. After the prills come in contact with soil moisture, they absorb water and liquefy the urea inside the coating. The urea solution will then diffuse into the soil solution though the coating over the growing season. The diffusion rate is based on temperature with higher temperatures leading to increased diffusion rates. After all of the urea solution is released, the coating will be broken down by microbial action over time.

The use of slow and controlled release N fertilizers has some advantages because the release of the product isn't affected by certain soil properties such as pH, soil texture, microbial activity, soil salinity, and other factors. This property of the coating makes it possible to predict release rates over time (Trenkel, 1997). Other advantages include reduced passes over the field which can aid in preventing compaction and reduce labor costs. Plant injury from contact with high concentrations of soluble fertilizer can also be reduced (Powell, 1968). Currently, slow and controlled release fertilizers are predominately used in the turf grass and horticultural industries because of their higher costs when compared to conventional N fertilizers (Hauck, 1985). Trenkel (1997) states that unless the cost of controlled release fertilizers can be significantly lowered, they will not gain wide use on low value agricultural crops such as corn. Also, special care must be taken when handling controlled release fertilizers in order not to scratch or break the coating. If this happens, the granules will lose their controlled release properties. Controlled release fertilizers such as ESN, and slow release N fertilizers have potential for generating greater corn yields and reduced losses of nitrate compared with urea, especially in situations where N loss potential is high (sandy soils, plentiful spring rainfall, fall application, etc.) (Randall and Sawyer, 2005).

The environment could also benefit from the increased use of controlled release fertilizers. Hypoxia (low concentrations of dissolved oxygen in water, generally less than 2 mg/L) has been a persistent problem in the Gulf of Mexico. The hypoxia is most widespread in June, July, and August and the size of the zone varies from year to year (Mitsch et al., 2001). If laws are passed to restrict nitrogen application to certain times of the year or on farmland where there is a possibility of polluting groundwater, rivers, and lakes, producers may be forced to give a preference to these types of nitrogen fertilizers (Trenkel, 1997). Delaying N applications until plants are able to effectively utilize N may substantially increase N use efficiency (Olson and Kurtz, 1982).

The objectives of these papers were to: 1) compare the effects of spring-applied ESN and urea on corn grain yields; 2) compare the effects of ESN and aqua ammonia applied in the fall and spring on corn grain yields and 3) compare soil NH_4^+-N and soil NO_3^--N concentrations at three times during the year, the V-6 growth stage, the V-15 growth stage, and at post-harvest.

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Thesis Organization

This thesis is organized with a general introduction, three papers that will be submitted to *Communications in Soil Science and Plant Analysis* and a general conclusion. Each individual paper has an abstract, introduction, materials and methods, results and discussion, and summary and conclusions.

Comparison of ESN and urea applied in spring as sources of nitrogen for corn production in Iowa

A paper to be submitted to *Communications in Soil Science and Plant Analysis*

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Abstract

Controlled-release nitrogen (N) fertilizers are an alternative to using conventional N fertilizers in corn production. A five year (2003-2007) field study at two locations in Iowa was conducted to evaluate the effect of a controlled-release N fertilizer, ESN, and urea on corn grain and biomass yields, N uptake, and soil N concentrations. Fertilizer rates from 0 to 202 kg N ha^{-1} in 34 kg N ha^{-1} increments were spring-applied. The addition of fertilizer N increased biomass yields at four of nine site-years and biomass N uptake at seven of nine site-years. Corn grain yields increased with the addition of N at all site-years and grain N uptake at eight of nine site-years. Corn grain yields were increased by the use of ESN at four of nine site-years. Soil nitrate-N (NO_3^- -N) and ammonium-N (NH_4^+-N) concentrations were measured three times each season in 2005-2007. ESN treatments usually had slightly higher concentrations of residual NO_3^--N and NH_4^+-N after harvest. These residual amounts of N from inorganic fertilizers could have negative consequences for crop producers because nitrate is easily leached from the soil profile if excess water is present. We did not observe a negative response from the use of ESN at any time during the duration of the study.

Introduction

The use of nitrogen (N) fertilizer to obtain high corn grain yields is very common in Iowa. Proper N fertilization is a difficult challenge facing today's crop producers. Rising costs of N fertilizer encourage producers to look for ways to increase yields and recover applied N while keeping costs at a minimum.

Nitrogen is subject to physical and biological processes in the soil which can influence the amount of N that is available for plant uptake (Gonzalez, 2005). Urea ($CO(NH_2)_2$) is one of the most common N fertilizers used in the United States today. When urea is applied to soils, it is hydrolyzed rapidly by an enzyme, urease, to form ammonium (NH_4^+) and is then converted to nitrate (NO_3^-) by a process called nitrification. Leaching of applied N fertilizer results in reduced uptake efficiency by the target crop and is an agricultural problem that crop producers have to deal with (Wang and Alva, 1996). The dominant form of N in well-aerated soils is NO_3^--N, which is easily lost to leaching when water passes through the soil profile (Allen, 1985).

ESN is a controlled-release N product (44% N) developed by Agrium, Inc. When ESN comes in contact with soil moisture, it absorbs water and liquefies the urea inside of the coating. ESN releases liquid urea through its polymer coating during the growing season. As temperature increases, the rate of release of the urea into the soil solution increases.

Slow and controlled-release fertilizers are predominately used in the turf grass and horticultural industries because of their higher cost when compared to conventional fertilizers (Hauck, 1985). The use of controlled-release fertilizers offers advantages such as reduced passes over the field, a decrease in plant injury, and soil properties (pH, soil texture, microbial activity, etc) don't affect release rates of the fertilizer (Trenkel, 1997). Currently the cost of the fertilizer is prohibiting its use in lower value crops such as corn. Handling of the product is also an issue. Care must be taken not to compromise the integrity of the coating which can make the fertilizer lose its controlled release characteristics. To date, little research has been published comparing ESN with urea for application to corn.

The objectives of this study were to: 1) compare the effects of spring-applied ESN and urea on corn grain and biomass yields and 2) compare the effects of spring-applied ESN and urea on soil NH_4^+-N and soil NO_3^--N concentrations at three times during the year: the V-6 growth stage, the V-15 growth stage, and at post-harvest.

Materials and Methods

The study was conducted over five growing seasons at two locations in Iowa: the Northern Research and Demonstration Farm (KNW) at Kanawha (2003-2007) and the Northwest Research and Demonstration Farm (NW) at Sutherland (2003, 2005-2007). The 2004 location at Sutherland received heavy hail damage so no data were collected. The soil types for the experiments at Kanawha and Sutherland are listed in Table 1, while cultural practices are listed in Table 2, and baseline soil data are listed in Table 3.

Treatments were arranged as a factorial in a randomized complete block design with four replications. Each experimental plot measured 4.6 m by 12.2 m at KNW and contained six rows of corn spaced 76 cm apart. The experimental plots at NW measured 3.05 m by 12.2 m. These plots contained 4 rows of corn spaced 76 cm apart. The ESN (44% N) and urea (46% N) were hand applied in the spring before the corn was planted and incorporated within twenty-four hours of application to reduce N loss due to volatilization. Nitrogen application rates for all sites in all years were: 0, 34, 67, 101, 134, 168, and 202 kg N ha^{-1}. The corn plots followed soybeans in all years of the study at both locations.

The corn was scouted several times throughout the growing season to evaluate overall plant health and possible damage due to insects, disease, and weather related events.

Grain Yield and Analysis

The center rows of each plot were harvested (three rows at Kanawha and two rows at Sutherland) with a combine. The weight of the grain in each plot and moisture content were recorded when harvested by the combine. A sub-sample of the grain was collected, weighed, and dried at 60° C. The sub-sample was used to determine grain moisture of the plot. Corn grain yield was adjusted to reflect a moisture content of 155 g kg^{-1}.

Chemical analysis of the grain was conducted as follows: A 0.25g sub-sample of grain was ground, dried for a minimum of twenty-four hours, and was digested using the Hach Digesdahl® Digestion Apparatus, and the Hach Plant Tissue and Tissue Analysis System (Hach Company, 1988), with concentrated sulfuric acid (18 *M* H_2SO_4) and 50% hydrogen peroxide (H_2O_2). The digested product was then used to determine percent N by using a modified Nessler Method test and a Hach DR/3000 Spectrophotometer (DR/3000 Procedure Code N.10) as described in the method for Nitrogen Analysis in Total Plant Tissue (Hach Company, 1988). Nitrogen uptake was calculated by multiplying the grain yield by the percent of N in the grain.

Plant Biomass Production and Analysis

Whole plant samples were collected when the plants reached physiological maturity. The entire above-ground portion of six plants, minus the ears of corn were selected from the center two rows (three plants from each row) of each plot. The first plant in the row was skipped because it was generally larger due to more light interception. The plant samples were chopped and weighed. A sub-sample was taken, weighed, then dried at 60° C for a minimum of forty-eight hours, weighed again, and ground. Total nitrogen content and N uptake of the biomass was determined by using the same procedure that was used to determine the total nitrogen content of the grain. The dry weight of the sub-sample was used to determine total above ground biomass produced per hectare. N uptake was calculated by multiplying the dry weight of the biomass by the percent N in the biomass sample.

Soil Sampling and Analysis

Soil samples were collected three times a year at each site and year in 2005-2007. The soil samples were taken at the V-6 growth stage, the V-15 growth stage, and after harvest was completed. Three cores were randomly taken to a depth of 30 cm between the center two rows of the plot and combined to form the sample. The post harvest sample included samples collected from a depth of 31-60 cm.

The soil samples were dried at 60° C for a minimum of twenty-four hours and ground to pass through a 2 mm sieve. A 10 g sub-sample was weighed and extracted with 50 ml of 2 *M* KCl solution. The extract was filtered and analyzed for NO_3^--N and NH_4^+-N using a QuikChem 8000 Automated Ion Analyzer by the QuikChem Method 12-107-04-1-B (Lachat Instruments, 1992) for the NO_3^--N and QuikChem Method 12-107-06-2-A (Lachat Instruments, 1993) for NH_4^+-N.

Data Analysis

Statistix 8 (Analytical Software, 2003) was used to analyze the data. The analyses for each combination of site and year were done separately. Nitrate-N and NH_4^+-N content for all soil sampling times were also analyzed separately. Differences at the $p>F = 0.05$ level or less were considered significant. Outliers in all of the data, except for corn grain yield, were identified by using residual graphs and were determined to be non-representative if they were greater than three standard deviations from the experiment mean.

Results and Discussion

Kanawha location

Biomass production

Biomass yields increased with N rate in 2005 (p>F = 0.0003) and 2007 (p>F = 0.0001) but were non significant every other year (Table 4). The difference between the two materials was not significant any year of the study. The interaction between material and N rate was significant in 2006 (p>F = 0.0325) (Table 4). Average biomass yields were greater for ESN treatments than urea treatments in 2004 and 2007. Averaged over site-years at Kanawha, urea treatments yielded 8.08 Mg ha^{-1} while ESN treatments yielded 8.04 Mg ha^{-1}. Biomass yields displayed a large amount of variability over the site-years at Kanawha. Since six plants per plot were collected to determine biomass yield, it is possible that the samples weren't always representative of the plots.

Biomass N uptake was significantly increased by N rate in 2003, 2005 (p>F = <0.0001), 2006, and 2007 (p>F = 0.0005) (Table 4). The difference between the two materials was higher for ESN treatments in 2005 (p>F = 0.0050) (Table 4). The interaction between material and N rate was not significant any year of the study. ESN treatments had higher average N uptakes in 2003-2005 and 2007 (Table 4). This could be due to the protective coating on the ESN. Because N is released at a slower rate compared to urea, it is likely that more N was taken up by the corn than lost to leaching or other factors.

Grain Production

Corn grain yield increased with N rate each year of the study (p>F = <0.0001) (Table 5). The difference between the two materials in 2003, 2006, and 2007 were not statistically significant. In 2004 and 2005, there was no response to material (p>F = 0.0646) and (p>F = 0.0671) (Figures 1, 2) (Table 5), but there was a trend for ESN to out-yield urea treatments (Figures 1, 2). The interaction between material and N rate was not significant in any year of the study. In 2007, ESN treatments had a higher average grain yield than urea treatments. Over the five site-years, there was variability in the grain yields. We think that this could be due to different weather and soil conditions over the site-years.

Grain N uptake increased with N rate was applied (p>F = <0.0001) in 2003-2005 and 2007 (Table 5). The difference between materials was greatest for ESN treatments in 2005 (p>F = 0.0066) but not significant every other year at KNW (Table 5). In 2004, the ESN treatments had a higher N uptake than the urea treatments. The interaction between material and N rate was not significant in any year of the study. There was also a large amount of variability in grain N uptake in the ESN and urea treatments over the five site-years. Soil conditions, weather, and the coating of the ESN could have influenced N uptake.

2005-2007 Soil analysis

Soil NH_4^+-N concentrations were not affected by N rate at the V-6 sample time in any year of the study at KNW. The difference between the two materials was significantly higher for ESN only in 2005 (p>F = 0.0007) (Table 6). The interaction between N rate and material was not significant any year of the study at the V-6 sampling time. In 2006 and 2007, the ESN treatments had higher concentrations of soil NH_4^+-N. We would not expect the ESN treatments to have higher NH_4^+-N concentrations at this time because of the release properties of the ESN. Since ESN should be released at a slower rate throughout the season, we would predict that there would be less N available at the V-6 growth stage when compared to the urea treatments.

Soil NH_4^+-N concentrations at V-15 were increased by the addition of N in 2005 and 2007 (p>F = 0.0017 and 0.0516) (Tables 6, 8). The difference between the two materials was significantly higher for ESN treatments in 2005 and 2007 (p>F = 0.0172 and 0.0224) (Tables 6, 8). The interaction between the two materials was only significant in 2005 (p>F = 0.0194) (Table 6). The average concentrations of soil NH_4^+-N at this time were higher each year for the ESN treatments compared to the urea treatments. We would expect this to happen because a good portion of the N should still be releasing from the ESN and available for plant uptake.

Post harvest soil NH_4^+-N concentrations at the 0-30 cm depth were not affected by any of the factors tested in 2005-2007. Soil NH_4^+-N concentrations at the post harvest sampling time at the 31-60 cm depth were slightly increased with the addition of N in 2007 (p>F = 0.0636) (Table 8).

Soil NO_3^--N concentrations at the V-6 sampling time increased with the addition of N every year of the study (p>F = 0.0001, <0.0001, and <0.0001 respectively) (Tables 6, 7, 8). The difference between the two materials was also significantly higher in the urea treatments each year of the study (p>F = 0.0008, <0.0001, and <0.0001) (Tables 6, 7, 8). The interaction between the two materials at the V-6 sampling time was significant in 2006 and 2007 (p>F = 0.0068 and 0.0475) (Tables 7, 8). We expected soil NO_3^--N concentrations from urea to be higher due to the fact that urea generally hydrolyzes rapidly in soils in the

Midwest (Kissel, 1988). Obviously conditions such as temperature, moisture, soil pH and other factors play a role in how fast N from urea becomes plant available.

At the V-15 sampling time, NO_3-N concentrations increased with the addition of fertilizer N every year of the study (p>F = 0.0025, 0.0052, and <0.0001 respectively) (Tables 6, 7, 8). The difference between the two materials was higher for ESN treatments in 2005 (p>F = 0.0001) (Table 6). The interaction between N rate and material was significant in 2005 and 2007 (p>F = 0.0202 and 0.0043) (Tables 6, 8). The average concentrations of soil NO_3-N from urea were only slightly higher than soil NO_3-N from the ESN treatments in 2006. Generally, this would be expected because N from urea quickly becomes plant available.

Post harvest soil NO_3^--N concentrations at the 0-30 cm depth increased with N rate in 2006 (p>F = <0.0001) (Table 7). No other factors at this depth were affected over the duration of the study. At the 31-60 cm depth, soil NO_3^--N concentrations increased with the addition of N in 2005 and 2007 (p>F = 0.0007 and 0.0009) (Tables 6, 8). The difference between the two materials was higher for ESN treatments in 2005 (p>F = 0.0014) (Table 6). The interaction between material and N rate was significant in 2005 (p>F = 0.0060) (Table 6).

Results and Discussion

Sutherland location

Biomass production

Biomass yields increased with increased N rates in 2006 (p>F = 0.0343) and 2007 (p>F = 0.0066) (Table 9). The difference between fertilizer materials and the interaction between material and N rate were not significant in any year of the study. Averaged over site-years at Sutherland, biomass yields from urea treatments were 7.28 Mg ha^{-1} and 7.14 Mg ha^{-1} from ESN treatments. Biomass yields varied greatly over the four site-years at Sutherland. This is more than likely due to different rainfall amounts over the length of the study. The variation could also be due to not getting a representative sample to determine biomass yield.

Biomass N uptake increased with N rate in 2003 (p>F = 0.0053), 2005 (p>F = 0.0001), and 2007 (p>F = <0.0001) (Table 9). The difference between the fertilizer materials and the interaction between material and N rate were not significant in any year of the study. Average biomass N uptake varied throughout the study, but when compared by year, the source of N, ESN or urea, didn't have much of an effect on N uptake. This could be because environmental conditions were not ideal for the loss of N. The soils in this part of Iowa tend to retain more NO_3^--N than in central Iowa which could also affect N availability.

Grain production

Corn grain yields increased as N rates increased each year of the study (p>F = <0.0001) (Table 10). The difference between the two fertilizer materials was not significant in 2003, 2006, and 2007 but in 2003 (p>F = 0.0885) there was a trend for ESN to yield higher than urea treatments (Figure 3). In 2005, ESN treatments yielded higher than urea treatments (p>F = <0.0001) (Table 10). Corn yields over the four site-years were variable just as at Kanawha. In 2003 and 2006, average corn yields were higher from ESN treatments compared to urea treatments. The higher average ESN yields could be attributed to the coating on the ESN, which can help to prevent loss of N due to leaching out of the soil profile. The interaction between material and N rate was significant in 2005 (p>F = 0.0191) and 2007 (p>F = 0.0214) (Table 10).

Grain N uptake increased with the addition of N in 2003 (p>F = <0.0001), 2006 (p>F = 0.001), and 2007 (p>F = <0.0001) (Table 10). Nitrogen uptake was not significant in 2005 (p>F = 0.0761) but there was a trend for ESN to have greater N uptake than the urea treatments (Figure 4). ESN treatments had significantly higher N uptake than urea treatments in 2005 (p>F = 0.0215) (Table 10). In 2003 and 2006, average N uptake from ESN treatments was slightly higher than urea treatments. This could be possibly due to the coating on the ESN.

2005-2007 Soil Analysis

Soil NH_4^+-N concentrations at the V-6 sampling time increased with N rate each year of the study (p>F = <0.0001, 0.0036, and 0.0048 respectively) (Tables 11, 12, 13). Soil NH_4^+-N concentrations were higher for urea treatments in 2006 and ESN treatments in 2007 (p>F = 0.0345 and <0.0001) (Tables 12, 13). Greater concentrations of NH_4^+-N from urea would be expected this early in the growing season.

When soil samples were collected at the V-15 growth stage, soil NH_4^+-N concentrations increased with the addition of N during each year of the study (p>F = 0.0093, 0.0054, and <0.0001) (Tables 11, 12, 13). The ESN treatments had higher concentrations of soil NH_4^+-N each year of the study (p>F = 0.0192, 0.0085, and <0.0001) (Tables 11, 12, 13).

Post harvest concentrations of NH_4^+-N at the 0-30 cm depth were not affected by N rate, but in 2007 ESN treatments had slightly higher soil NH_4^+-N concentrations (p> F = 0.0759) (Table 13). None of the factors tested in the 31-60 cm depth were affected by N rate or materials.

Soil NO_3^--N concentrations increased with N rate in every year of the study (p>F = <0.0001, 0.0009, and <0.0001) when taken at the V-6 growth stage (Tables 11, 12, 13). The differences in soil NO_3^--N concentrations between materials were higher for urea treatments in every year of the study (p>F = <0.0001, 0.0001, and 0.0025) (Tables 11, 12, 13). The interaction between N rate and material was significant at the V-6 sampling time each year of the study (p>F = <0.0001, 0.0434, and 0.0058) (Tables 11, 12, 13).

Soil NO_3^--N concentrations increased as N rates increased at the V-15 sampling time every year of the study (p>F = <0.0001, 0.0040, and <0.0001) (Tables 11, 12, 13). Using ESN fertilizer resulted in higher NO_3^- -N concentrations in 2005 (p>F = 0.0019) (Table 11). In 2006 and 2007, soil NO_3-N concentrations were higher in the urea treatments compared to ESN treatments. The interaction between N rate and material was significant in 2005 (p>F = 0.0042) (Table 11).

Post harvest soil NO_3^--N concentrations increased with N rate every year (p>F = <0.0001) (Tables 11, 12, 13). In 2005, there was a trend for ESN treatments to have higher concentrations of soil NO_3^- -N (p>F = 0.0682) (Figure 4) (Table 11), while ESN treatments had a higher concentration of soil NO_3^--N than urea treatments (p>F = 0.0003) (Table 13) in 2007. Concentrations of soil NO_3^- -N at the 31-60 cm depth increased with N rate throughout the study (p>F = <0.0001, 0.0037, and <0.0001) (Tables 11, 12, 13). In 2007, concentrations of NO_3^- -N were higher in ESN treatments than urea treatments (p>F = <0.0001) (Table 13). The interaction between material and N rate was significant in 2007 (p>F = 0.0286) (Table 13).

Summary and Conclusions

The addition of fertilizer N increased biomass yields at four of nine site-years. Biomass yields were not affected by material at any of the site-years. When looking at corn yields, the results obtained from these field studies conducted for spring-applied ESN and urea only show a clear statistical advantage for using ESN at one of the nine site-years. However, three of the nine site-years showed a trend in which ESN treatments out-yielded urea treatments. Grain yields were affected by N rates every site-year. N uptake for biomass and corn grain was not generally affected by fertilizer material.

Soil NH_4^+-N concentrations were usually higher for ESN treatments compared to urea at the V-6 and V-15 sampling times. While this was not expected because of the time release properties of the ESN, we can speculate that the ESN was still releasing N while NH_4^+-N in the urea treatments had probably already converted to nitrate. Post harvest soil samples were generally higher in both nitrate and ammonium from the ESN treatments. It is reasonable to assume that a good portion of this residual N was lost over winter.

There were large differences among the years and locations in the study when comparing biomass yield, corn grain, yield and N uptake in the biomass and grain. There could be many reasons for the large amount of variability in biomass and grain yields such as adverse weather conditions that can favor denitrification and leaching or possibly inhibit the release of N from the ESN granules. Soil conditions throughout the studies could have also been a factor in the inconsistent yields. Conditions that favor N loss could have existed in various years throughout this study.

We did not observe any negative yield responses from the use of ESN; however ESN did not consistently result in higher corn grain and biomass yields. The data suggest that slightly higher concentrations of NO_3^--N and NH_4^+-N from ESN treatments were left behind in the soil after the corn was harvested. These residual amounts of N could have negative consequences to crop producers due to the fact that nitrate is easily lost from the soil profile if leaching occurs.

We believe that this product has the potential to increase corn grain yields in certain situations while preventing N loss (sandy soils, high rainfall locations, etc). Currently the cost of this product and the unpredictability of positive yield responses for ESN make it difficult to recommend ESN to producers as an alternative fertilizer to urea in Iowa.

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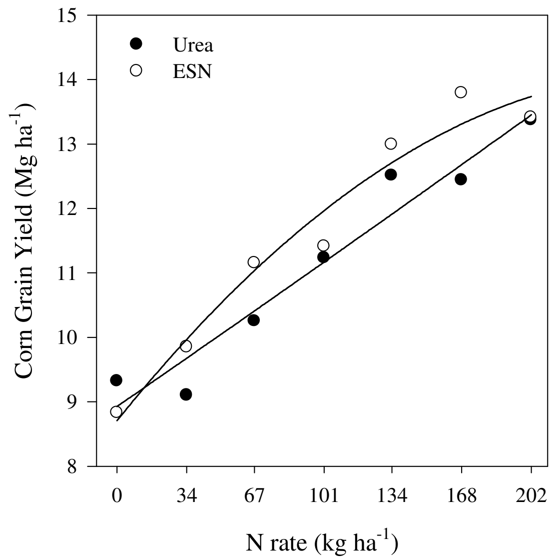

Figure 1. Relationship between N rate and corn grain yield at Kanawha, 2004.

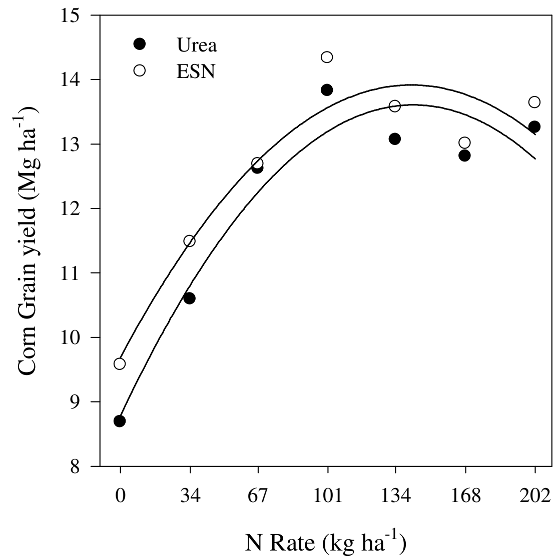

Figure 2. Relationship between N rate and corn grain yield at Kanawha, 2005.

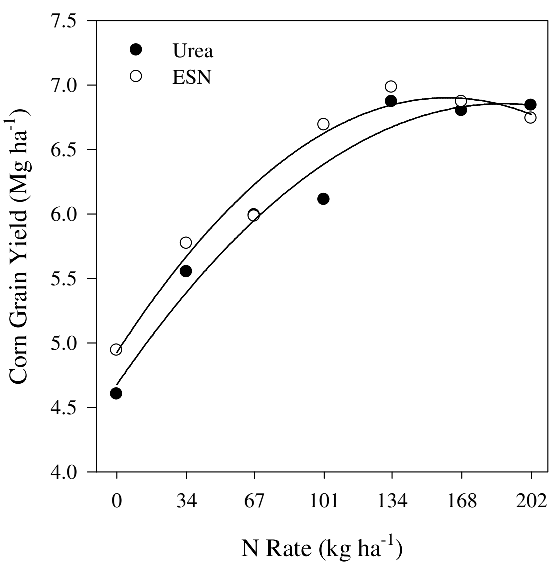

Figure 3. Relationship between N rate and corn grain yield at Sutherland, 2003.

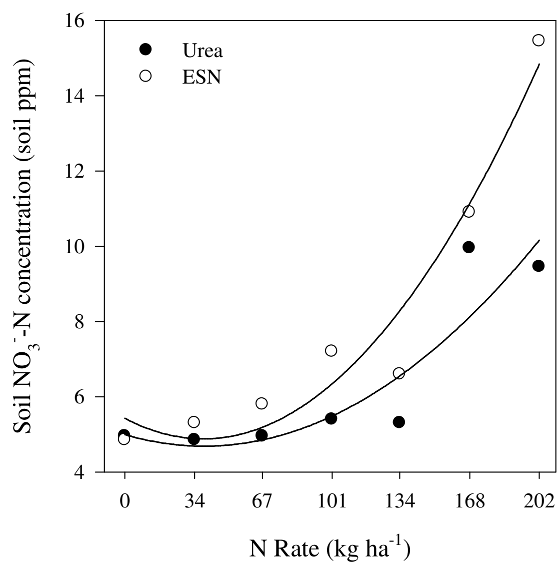

Figure 4. Relationship between N rate and post harvest soil NO_3^--N concentrations at Sutherland, 2005.

Table 1. Soil types for all years in the spring-applied ESN/urea studies at Kanawha and Sutherland.

Site	Year	Soil type	Soil series description
Kanawha	2003	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludoll
		Canisteo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll
	2004	Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludoll
	2005	Webster	Fine-loamy, mixed, superactive, mesic Typic Endoaquall
		Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludoll
	2006	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludoll
		Canisteo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll
	2007	Webster	Fine-loamy, mixed, superactive, mesic Typic Endoaquoll
		Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludoll
Sutherland	2003-2007	Primghar	Fine-silty, mixed, superactive, mesic Aquic Hapludoll
		Marcus	Fine-silty, mixed, superactive, mesic Typic Endoaquoll

Table 2. Cultural practices for all locations and years in the spring-applied ESN/urea studies at Kanawha and Sutherland.

Site / Year	Planting date	Hybrid	Population seeds/ha	Harvest date
2003				
Kanawha	April 26	DeKalb 53-32 Bt	74,133	October 18
Sutherland	May 7	DeKalb 46-28	75,368	October 16
2004				
Kanawha	April 28	DeKalb 53-32 Bt	79,040	October 16
2005				
Kanawha	April 30	DeKalb 53-32 Bt	74,100	October 15
Sutherland	May 4	FC 7515R	79,040	October 19
2006				
Kanawha	May 22	DeKalb 53-32 Bt	81,510	October 24
Sutherland	May 12	Pioneer 35Y61	79,040	October 24
2007				
Kanawha	May 10	Pioneer 36W69	81,510	October 6
Sutherland	May 2	Kruger 8602 HX	79,040	October 11

Table 3. Soil chemical properties at the 0-15 cm depth at Kanawha and Sutherland, 2003-2007.

Location	**Year**	**OM**[a]	**pH**[b]	**P**[c]	**K**[d]
		$g\ kg^{-1}$		----------------mg kg^{-1}	---------------
Kanawha	2003	49	6.2	21	109
Kanawha	2004	61	5.6	50	191
Kanawha	2005	57	5.8	44	145
Kanawha	2006	51	5.6	34	227
Kanawha	2007	53	5.9	32	255
Sutherland	2003	47	6.3	12	132
Sutherland	2005	46	6.5	11	161
Sutherland	2006	46	6.3	15	168
Sutherland	2007	47	6.3	12	155

[a] organic matter

[b] 1:1 H_2O

[c] Bray P-1

[d] Ammonium Acetate

Table 4. Corn biomass response to spring-applied urea fertilizers at Kanawha, 2003-2007.

N Material	N rate	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]
		2003		2004		2005		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Urea	0	7.10	38	3.42	18	7.53	30	8.98	49	8.60	34
	34	7.04	38	3.90	20	8.05	41	8.40	49	7.81	29
	67	9.07	59	4.09	21	7.80	41	10.05	65	10.26	48
	101	6.80	39	3.32	15	9.48	50	9.28	60	9.75	43
	134	7.84	60	4.00	22	9.30	56	10.30	76	9.69	46
	168	9.02	79	4.61	27	9.95	46	11.60	79	9.60	49
	202	8.92	71	4.59	31	10.30	58	11.08	86	11.06	73
Average		**7.97**	**55**	**3.99**	**22**	**8.92**	**46**	**9.96**	**66**	**9.54**	**46**
ESN	0	6.98	40	3.50	16	7.28	27	9.81	56	7.52	32
	34	7.89	52	3.91	20	8.85	49	10.05	56	7.87	32
	67	8.49	62	4.08	19	8.75	51	8.83	54	9.55	40
	101	8.10	49	4.51	27	9.08	49	9.03	53	11.21	60
	134	7.01	49	5.65	33	9.23	60	9.83	69	9.94	50
	168	7.46	61	4.48	23	9.00	61	8.90	59	9.61	52
	202	8.10	79	4.86	27	9.93	78	10.45	79	11.67	92
Average		**7.72**	**56**	**4.43**	**24**	**8.87**	**54**	**9.56**	**61**	**9.62**	**51**
Statistics		p > F									
N rate		NS	<0.0001	NS	NS	0.0003	<0.0001	NS	0.0005	0.0001	0.0005
Material		NS	NS	NS	NS	NS	0.0050	NS	NS	NS	NS
*N rate*Material*		NS	NS	NS	NS	NS	NS	0.0325	NS	NS	NS

[a] dry weight

Table 5. Corn grain response to spring applied urea and ESN fertilizers at Kanawha, 2003-2007.

N Material	N Rate	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]
		2003		2004		2005		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Urea	0	7.15	55	9.32	89	8.69	87	9.07	92	6.70	62
	34	8.85	72	9.10	87	10.59	100	10.91	105	7.88	73
	67	10.85	96	10.25	99	12.62	130	11.54	128	10.12	104
	101	10.77	98	11.23	117	13.82	154	11.86	122	10.85	115
	134	11.60	107	12.51	125	13.07	136	12.69	133	12.11	124
	168	10.98	106	12.44	143	12.80	140	13.25	141	12.15	134
	202	11.29	112	13.37	146	13.25	143	13.01	143	12.18	139
Average		**10.21**	**92**	**11.17**	**115**	**12.12**	**127**	**11.76**	**123**	**10.28**	**107**
ESN	0	6.99	52	8.83	84	9.57	96	8.44	85	6.24	58
	34	9.33	74	9.85	90	11.48	121	10.59	108	8.86	88
	67	10.57	90	11.15	112	12.69	136	11.80	124	10.07	99
	101	11.46	101	11.41	117	14.33	154	12.62	126	11.20	114
	134	10.96	102	12.99	136	13.57	151	13.12	145	12.08	123
	168	10.98	108	13.79	157	13.01	151	12.62	135	11.86	122
	202	10.59	108	13.41	151	13.63	154	12.69	128	12.08	128
Average		**10.13**	**91**	**11.63**	**121**	**12.61**	**138**	**11.70**	**122**	**10.34**	**105**
Statistics		---p>F---									
N rate		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.0001	<0.0001
Material		NS	NS	0.0646	NS	0.0671	0.0066	NS	NS	NS	NS
*N rate*Material*		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] 155 g kg^{-1}

[b] dry weight

Table 6. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Kanawha, 2005.

		NH_4^+				NO_3^-			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30 cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	--------------------------mg kg^{-1}------------------------				-------------------------mg kg^{-1}-------------------------			
Urea	0	7.65	4.00	8.00	4.60	5.50	1.85	5.55	2.05
	34	7.50	3.80	9.50	4.25	8.35	1.75	5.05	2.20
	67	7.35	3.90	8.50	4.65	18.55	2.20	4.85	2.05
	101	8.90	4.15	9.65	4.75	12.45	2.85	5.15	2.40
	134	7.40	4.65	8.25	4.70	15.85	4.25	5.70	2.70
	168	7.50	4.00	8.50	4.95	21.55	2.55	4.95	2.45
	202	7.90	4.20	9.15	4.75	18.25	2.35	4.85	2.35
Average		**7.74**	**4.10**	**8.79**	**4.66**	**14.36**	**2.54**	**5.16**	**2.31**
ESN	0	7.15	3.90	8.70	4.70	4.95	1.65	4.90	1.85
	34	8.75	3.70	9.05	4.85	7.90	3.90	5.20	2.35
	67	13.25	4.00	8.20	4.25	9.15	2.30	5.30	2.15
	101	9.05	4.20	8.65	4.45	9.25	3.65	5.10	2.45
	134	15.90	5.70	9.15	4.25	10.45	8.95	6.75	3.35
	168	13.25	6.70	9.05	4.45	15.15	10.20	5.75	5.50
	202	14.25	4.45	9.00	5.00	10.50	11.25	6.70	5.15
Average		**11.66**	**4.66**	**8.83**	**4.56**	**9.62**	**5.99**	**5.67**	**3.26**
Statistics		-----------------------------p>F---------------------------				-----------------------------p>F---------------------------			
N rate		NS	0.0017	NS	NS	0.0001	0.0025	NS	0.0007
N material		0.0007	0.0172	NS	NS	0.0008	0.0001	NS	0.0014
*N rate*N material*		NS	0.0194	NS	NS	NS	0.0202	NS	0.0060

Table 7. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Kanawha, 2006.

		NH_4^+				NO_3^-			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Urea	0	7.10	5.85	7.35	3.65	9.45	3.10	6.70	3.10
	34	9.05	5.95	7.65	5.00	14.20	4.00	6.55	6.55
	67	8.15	5.65	6.95	3.80	19.20	4.25	7.75	5.35
	101	9.55	5.95	7.95	2.90	24.70	8.30	9.10	3.90
	134	9.40	6.20	8.15	3.00	31.95	6.90	7.25	5.40
	168	8.65	9.10	7.80	3.80	31.85	10.30	8.70	5.85
	202	10.25	7.75	8.20	3.65	29.85	10.50	13.75	8.15
Average		**8.88**	**6.64**	**7.72**	**3.69**	**23.03**	**6.76**	**8.54**	**5.47**
ESN	0	7.60	6.35	6.75	5.30	8.95	3.05	7.10	5.75
	34	7.25	5.45	7.35	5.95	9.35	3.20	6.95	8.85
	67	11.85	7.35	8.00	2.70	14.35	6.50	8.65	3.25
	101	8.85	8.70	8.15	3.50	15.20	5.40	8.75	5.45
	134	9.35	6.65	7.60	3.65	12.55	9.10	10.55	7.90
	168	8.75	7.40	7.40	3.65	12.95	8.15	11.75	9.55
	202	15.85	8.35	7.30	3.75	22.45	8.35	14.30	10.05
Average		**9.93**	**7.18**	**7.51**	**4.07**	**13.69**	**6.25**	**9.72**	**7.26**
Statistics		----------------------------p>F--------------------------				----------------------------p>F--------------------------			
N rate		NS	NS	NS	NS	<0.0001	0.0052	<0.0001	NS
N material		NS	NS	NS	NS	<0.0001	NS	NS	NS
*N rate*N material*		NS	NS	NS	NS	0.0068	NS	NS	NS

Table 8. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Kanawha, 2007.

		NH_4^+				NO_3^-			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Urea	0	6.25	4.60	7.30	3.99	5.90	2.25	3.64	1.28
	34	7.45	5.60	7.86	3.33	11.00	2.75	3.50	1.32
	67	8.55	5.45	7.96	3.56	17.85	3.35	3.28	1.21
	101	7.00	4.85	7.99	4.25	19.70	3.95	3.57	1.40
	134	8.50	5.25	8.01	4.03	21.65	4.45	3.34	1.76
	168	10.55	6.75	8.09	3.79	24.35	11.85	3.21	1.38
	202	9.95	6.25	8.74	4.27	28.20	6.90	4.84	2.54
Average		**8.32**	**5.54**	**7.99**	**3.89**	**18.38**	**5.07**	**3.63**	**1.56**
ESN	0	6.60	6.35	7.81	3.36	5.95	3.30	3.23	1.24
	34	8.95	5.50	8.61	3.36	7.55	2.90	3.04	1.20
	67	6.85	6.95	8.00	4.39	8.00	4.10	3.56	1.53
	101	10.60	5.80	8.35	3.93	11.25	5.35	3.39	1.41
	134	10.25	6.25	8.96	4.53	17.70	7.35	3.76	1.82
	168	8.00	6.30	8.18	3.78	13.40	5.25	4.54	2.58
	202	10.75	10.90	8.54	3.99	11.65	10.30	4.72	2.65
Average		**8.86**	**6.86**	**8.35**	**3.91**	**10.79**	**5.51**	**3.75**	**1.78**
Statistics		----------------------------p>F--------------------------				----------------------------p>F---------------------------			
N rate		NS	0.0516	NS	0.0636	<0.0001	<0.0001	NS	0.0009
N material		NS	0.0224	NS	NS	<0.0001	NS	NS	NS
*N rate*N material*		NS	NS	NS	NS	0.0475	0.0043	NS	NS

Table 9. Corn biomass response to spring-applied urea fertilizers at Sutherland, 2003, 2005-2007.

N Material	N rate	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]
		2003		2005		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Urea	0	4.72	33	7.43	47	6.48	32	7.94	36
	34	4.35	25	7.83	50	6.90	39	7.86	36
	67	4.74	28	8.68	64	5.85	37	9.04	50
	101	4.68	25	7.55	55	7.93	50	9.02	50
	134	4.69	32	7.85	52	6.70	36	9.18	51
	168	5.29	38	9.03	79	8.20	57	9.35	68
	202	5.84	45	9.20	75	7.90	47	9.70	61
Average		**4.90**	**32**	**8.22**	**60**	**7.14**	**43**	**8.87**	**50**
ESN	0	4.36	24	7.45	48	6.03	25	7.00	32
	34	4.85	28	6.85	44	6.45	39	8.41	48
	67	5.37	32	9.03	67	6.45	33	7.93	49
	101	4.51	25	8.78	62	7.65	54	8.75	48
	134	5.09	29	9.23	74	7.55	51	8.46	49
	168	4.90	38	8.03	66	7.08	42	9.28	57
	202	5.36	35	8.25	64	7.43	50	9.37	63
Average		**4.92**	**30**	**8.23**	**61**	**6.95**	**42**	**8.46**	**49**
Statistics		---p>F---							
N rate		NS	0.0053	NS	0.0001	0.0343	NS	0.0066	<0.0001
Material		NS	NS	NS	NS	NS	NS	NS	NS
*N rate*Material*		NS	NS	NS	NS	NS	NS	NS	NS

[a] dry weight

Table 10. Corn grain response to spring applied urea and ESN fertilizers at Sutherland, 2003, 2005-2007.

N Material	N rate	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]
		2003		2005		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Urea	0	4.60	38	9.76	91	11.03	107	6.37	60
	34	5.55	45	11.48	105	10.59	104	7.37	68
	67	5.99	49	11.35	103	11.86	112	8.93	87
	101	6.11	53	10.65	96	12.43	123	9.99	105
	134	6.87	60	11.48	106	12.43	121	10.85	109
	168	6.80	65	12.12	114	13.12	137	10.54	121
	202	6.84	68	11.99	121	13.69	140	9.76	123
Average		**6.11**	**54**	**11.26**	**105**	**12.16**	**121**	**9.12**	**96**
ESN	0	4.94	38	11.67	108	10.21	93	6.21	56
	34	5.77	46	11.80	109	9.95	90	7.85	81
	67	5.98	50	11.42	109	11.61	116	8.17	84
	101	6.69	58	12.31	119	12.93	131	9.88	99
	134	6.98	63	12.62	124	13.07	135	9.93	101
	168	6.87	64	12.62	135	13.82	144	9.57	99
	202	6.74	65	12.31	123	14.97	160	10.66	116
Average		**6.28**	**55**	**12.10**	**118**	**12.37**	**124**	**8.90**	**91**
Statistics		----------	----------	----------	----------	p>F	----------	----------	----------
N rate		<0.0001	<0.0001	<0.0001	0.0761	<0.0001	0.001	<0.0001	<0.0001
Material		0.0885	NS	<0.0001	0.0215	NS	NS	NS	NS
*N rate*Material*		NS	NS	0.0191	NS	NS	NS	0.0214	0.0619

[a] 155 g kg^{-1}

[b] dry weight

Table 11. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Sutherland, 2005.

		NH_4^+				NO_3^-			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Urea	0	6.20	10.45	10.40	6.05	10.85	3.40	4.95	3.25
	34	7.00	11.25	10.35	6.00	11.25	3.35	4.85	3.20
	67	7.50	11.40	11.10	6.45	15.35	5.35	4.95	3.50
	101	10.85	12.90	10.90	6.10	18.70	4.65	5.40	3.50
	134	10.90	12.45	10.80	5.85	14.20	10.15	5.30	4.20
	168	13.15	13.60	10.70	6.10	23.45	24.90	9.95	8.90
	202	23.80	10.80	11.05	6.75	31.00	22.35	9.45	12.90
Average		**11.34**	**11.84**	**10.76**	**6.19**	**17.83**	**10.59**	**6.41**	**5.64**
ESN	0	6.35	10.45	10.95	5.65	13.35	3.90	4.85	3.05
	34	7.80	10.90	10.05	6.25	11.70	4.55	5.30	3.55
	67	9.50	12.70	10.25	5.90	12.20	7.80	5.80	4.15
	101	9.50	11.85	10.75	5.90	13.85	11.35	7.20	5.10
	134	7.35	14.80	10.55	6.40	11.25	16.50	6.60	5.70
	168	8.90	20.50	10.65	6.30	13.80	20.65	10.90	9.05
	202	16.15	17.40	10.20	6.05	14.90	41.40	15.45	10.35
Average		**9.36**	**14.09**	**10.49**	**6.06**	**13.01**	**15.16**	**8.01**	**5.85**
Statistics		----------------------------p>F--------------------------				----------------------------p>F--------------------------			
N rate		<0.0001	0.0093	NS	NS	<0.0001	<0.0001	<0.0001	<0.0001
N material		NS	0.0192	NS	NS	<0.0001	0.0019	0.0682	NS
*N rate*N material*		NS	NS	NS	NS	<0.0001	0.0042	NS	NS

Table 12. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Sutherland, 2006.

		NH_4^+				**NO_3^-**			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Urea	0	6.80	7.40	9.40	4.60	8.50	4.50	5.85	2.90
	34	8.95	6.35	9.55	5.90	11.15	5.15	9.10	3.75
	67	8.70	6.45	9.25	6.60	11.90	5.90	6.45	4.80
	101	10.10	7.35	9.65	5.55	11.60	9.95	8.35	5.35
	134	21.55	7.20	9.45	6.05	22.50	12.00	10.85	6.50
	168	14.20	7.05	8.55	5.15	15.65	10.90	15.00	6.75
	202	13.70	7.95	9.70	5.90	18.90	12.75	19.55	9.70
Average		**12.00**	**7.11**	**9.36**	**5.68**	**14.31**	**8.74**	**10.74**	**5.68**
ESN	0	6.80	6.20	9.75	5.25	7.35	3.30	5.65	3.35
	34	7.35	6.75	8.50	5.70	7.40	5.45	7.40	4.30
	67	9.20	8.35	8.45	4.95	10.15	5.50	8.80	3.20
	101	11.55	8.70	9.50	5.85	10.85	7.90	12.50	5.15
	134	9.40	9.10	10.60	5.50	9.25	7.60	14.20	4.65
	168	11.90	7.80	9.90	6.40	9.95	9.55	20.75	9.85
	202	10.15	13.50	11.10	7.50	12.95	10.60	19.10	12.35
Average		**9.48**	**8.63**	**9.69**	**5.88**	**9.70**	**7.13**	**12.63**	**6.12**
Statistics		-----------------------------p>F--------------------------				-----------------------------p>F---------------------------			
N rate		0.0036	0.0054	NS	NS	0.0009	0.0040	<0.0001	0.0037
N material		0.0345	0.0085	NS	NS	0.0001	NS	NS	NS
*N rate*N material*		NS	0.0772	NS	NS	0.0434	NS	NS	NS

Table 13. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Sutherland, 2007.

		NH_4^+				NO_3^-			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Urea	0	8.35	9.30	9.40	5.05	7.00	3.40	3.75	1.73
	34	8.65	9.00	9.26	4.53	10.70	4.80	3.47	1.94
	67	8.90	9.65	10.10	4.93	16.05	6.40	3.50	2.13
	101	9.45	10.10	9.13	4.56	22.55	14.10	4.23	2.14
	134	8.95	9.85	10.21	4.90	21.50	16.95	4.04	2.87
	168	9.35	10.10	9.45	4.90	23.80	12.80	5.67	2.90
	202	11.35	11.95	10.90	5.36	38.35	25.60	6.53	5.19
Average		**9.29**	**9.99**	**9.78**	**4.89**	**19.99**	**12.01**	**4.46**	**2.70**
ESN	0	9.90	9.10	9.31	5.12	6.75	3.00	3.42	2.03
	34	11.00	10.20	9.93	4.59	12.05	5.55	4.40	2.37
	67	12.10	11.45	9.78	4.87	13.75	7.45	4.46	2.30
	101	11.70	11.45	9.20	5.24	19.05	11.90	4.33	3.18
	134	13.65	11.20	9.75	4.78	23.75	9.90	7.76	5.53
	168	9.95	12.40	10.95	5.21	15.75	13.95	8.39	6.11
	202	15.75	15.05	10.20	4.72	26.80	18.60	7.61	6.44
Average		**12.01**	**11.55**	**9.87**	**4.93**	**16.84**	**10.05**	**5.77**	**3.99**
Statistics		----------------------------p>F--------------------------				----------------------------p>F--------------------------			
N rate		0.0048	<0.0001	0.0759	NS	<0.0001	<0.0001	<0.0001	<0.0001
N material		<0.0001	<0.0001	NS	NS	0.0025	NS	0.0003	<0.0001
*N rate*N material*		NS	NS	NS	NS	0.0058	NS	0.0316	0.0286

Comparison of ESN and aqua ammonia applied in the fall and spring as sources of nitrogen for corn production in Iowa

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Abstract

Controlled release nitrogen (N) fertilizers are an alternative to using conventional N fertilizers in corn production. A two-year field study was conducted in 2006 and 2007 at two locations in Iowa to evaluate the effect of a controlled release N fertilizer, ESN, and aqua ammonia on corn grain and biomass yields, N uptake, and soil N concentrations. Fertilizer rates from 0 to 202 kg N ha^{-1} in 67 kg N ha^{-1} increments were applied in the fall and spring. The addition of fertilizer N increased biomass yields and biomass N uptake at all four site-years. Biomass yields were statistically higher from the use of spring-applied ESN at one of the four site-years. Corn grain yields increased with the addition of fertilizer N at all four site-years while corn grain N uptake increased at three of four site-years from the addition of fertilizer N. In regards to corn grain yields, one of four site years showed a clear statistical advantage supporting the application of ESN in the spring. Soil nitrate-N and ammonium-N concentrations were usually higher for fall or spring-applied ESN treatments compared to aqua ammonia treatments at all of the sampling times. These soil results are of concern because the residual N that is left behind after crop harvest is easily leached overwinter if field conditions are wet. We did not observe any negative yield responses from the use of ESN at any year or location during the study.

Introduction

The use of fertilizer nitrogen (N) is a common practice in Iowa to improve corn grain yields. Anhydrous ammonia is the most widely used form of nitrogen (N) in the Corn Belt and is usually applied to fields in the fall for corn to be planted the following spring (Kyveryga et al., 2004). Reasons for fall application compared to spring include lower cost of N, more time for fieldwork compared to the spring, and field conditions are usually better suited for application (Randall and Sawyer, 2005). Fall-applied N can be subject to loss over the winter and spring, before planting, primarily from denitrification if soil conditions are less than ideal (Nyborg, et al., 1997). Nitrogen should be applied near the time when it is needed by the crop. Bundy (1986) concluded that fall application of N is acceptable on fine and medium textured soils where winter temperatures will retard nitrification. However, when N is applied under these conditions, yields are generally 10 to 15% less than spring-applied N.

Crop producers are always looking for new ways to increase yields while keeping input costs at a minimum. ESN is a controlled-release N fertilizer (44% N), developed by Agrium, Inc., that has the potential to reduce loss of N from the soil while increasing plant uptake of N. After ESN is applied and comes in contact with soil moisture, water is absorbed through the coating and turns the urea granule into a liquid. The liquid urea then diffuses out through the coating over the growing season. Release of the N is regulated by temperature with higher temperatures leading to increased diffusion rates. Currently, because of higher costs associated with controlled release N fertilizers, their use is mainly restricted to high-value crops such as produce and turf grass (Hauck, 1985). If the cost of these fertilizers can be reduced, or if their use can show greater yields compared to conventional N fertilizers in crops such as corn, the demand for these fertilizers is likely to increase. To date, little research has been published comparing ESN on corn grain yields.

The objectives of this study were to: 1) compare the effects of ESN and aqua ammonia applied in the fall and spring on corn grain and biomass yields and 2) compare soil NH_4^+-N and soil NO_3^--N concentrations at three times during the year, the V-6 growth stage, the V-15 growth stage, and at post-harvest.

Materials and Methods

This experiment was conducted over two growing seasons (2006-2007) at two locations in Iowa: the Northern Research and Demonstration Farm at Kanawha and the Curtiss Farm at Ames. The soil types for the experiments at Kanawha and Ames are listed in Table 1, the cultural practices are listed in Table 2, and baseline soil data are listed in Table 3.

Treatments were arranged as a factorial in a randomized complete block design with four replications. Each experimental plot measured 4.6 m by 12.2 m at Kanawha and Ames and contained six rows of corn spaced 76 cm apart. A set of ESN (44% N) and aqua ammonia (AA) (20% N) treatments were applied each fall and incorporated. Another set of treatments were applied in the spring before planting. These treatments were also incorporated within twenty-four hours. The ESN was applied by hand and the aqua ammonia was injected into the soil using a three row applicator. Aqua ammonia was used in this study because it is more easily handled and more accurately applied than anhydrous ammonia. Nitrogen application rates for all sites in all years were: 0, 67, 134, and 202 kg N ha^{-1}. The corn plots at Kanawha followed soybeans each year, while the plots in Ames were continuous corn.

The plots were scouted several times throughout the growing season to check for overall plant health and damage due to insects, disease, nutrient deficiencies, and weather related events.

Grain Yield and Analysis

The center rows of each plot were harvested (three rows at Kanawha and two rows at Ames) with a combine at Kanawha and by hand at Ames. The weight of the grain in each plot and moisture content were recorded when harvested by the combine at Kanawha. At Ames, after the corn was harvested it was shelled and the weight was recorded. Corn grain yield was adjusted to reflect a moisture content of 155 g kg^{-1}. A sub-sample of the grain was collected, weighed, and dried at 60° C. The sub-sample was used to determine grain moisture of the plot.

Chemical analysis of the grain was conducted as follows: A 0.25g sub-sample of grain was ground, dried for a minimum of twenty-four hours, and was digested using the Hach Digesdahl® Digestion Apparatus, and the Hach Plant Tissue and Tissue Analysis System (Hach Company, 1988), with concentrated sulfuric acid (18 *M* H_2SO_4) and 50% hydrogen peroxide (H_2O_2). The digested product was then used to determine percent N by using a modified Nessler Method test and a Hach DR/3000 Spectrophotometer (DR/3000 Procedure Code N.10) as described in the method for Nitrogen Analysis in Total Plant Tissue (Hach Company, 1988).

Plant Biomass Production and Analysis

Whole plant samples were collected when the plants reached physiological maturity. The entire above-ground portion of six plants, minus the ears of corn were selected from the center two rows (three plants from each row) of each plot. The first plant in the row was skipped because it was generally larger due to more light and nutrient interception. The plant samples were chopped and weighed. A sub-sample was taken, weighed, then dried at 60° C for a minimum of forty-eight hours, weighed again and ground. The dry weight of the sub-sample was used to determine total above ground biomass produced per hectare.

Soil Sampling and Analysis

Soil samples were collected three times a year at each site. The timing of the samples was at the V-6 growth stage, the V-15 growth stage, and after harvest was completed. Three cores were randomly taken to a depth of 30 cm between the center two rows of the plot and combined to form the sample. The post harvest sample contained samples collected from a depth of 31-60 cm.

The soil samples were dried at 60° C for a minimum of twenty-four hours and ground to pass through a 2 mm sieve. A 10 g sub-sample was weighed and extracted with 50 ml of 2 *M* KCl solution. The extract was filtered and analyzed for nitrate-N (NO_3^--N) and ammonium-N (NH_4^+-N) using a QuikChem 8000 Automated Ion Analyzer by the QuikChem Method 12-107-04-1-B (Lachat Instruments, 1992) for the NO_3^--N and QuikChem Method 12-107-06-2-A (Lachat Instruments, 1993) for NH_4^+-N.

Data Analysis

Statistix 8 (Analytical Software, 2003) was used to analyze the data. The analyses for each combination of site and year were done separately. Nitrate-N and NH_4^+-N concentrations for all soil sampling times were also analyzed separately. Differences at the $p>F = 0.05$ level or less were considered significant. Outliers in all of the data, except for corn yield, were identified by using residual graphs and were determined to be non-representative if they were greater than three standard deviations from the experiment mean.

Results and Discussion

Ames Location

Biomass Production

Biomass yields increased significantly with N rate both years of the study (p>F = <0.0001) (Table 4). Biomass yields were not affected by fertilizer treatments in 2006 (Figure 1). In 2007, spring-applied ESN and AA treatments had significantly higher biomass yields than fall-applied AA treatments (Figure 2) (p>F = 0.0405) (Table 4). The interaction between N treatment and N rate was not significant either year of the study. Biomass yields were similar over both site-years.

Nitrogen uptake increased with N rate both years of the study (p>F = <0.0001 and 0.0007) (Table 4). Averaged across N rates, biomass N uptake was significantly higher for spring-applied ESN than fall and spring-applied AA in 2006 (p>F = 0.0045) (Table 4). The interaction between N treatment and N rate was significant in 2006 (p>F = 0.0041) (Table 4). Because N is released at a slower rate compared to the AA, it is likely that more N from the ESN was taken up by the corn than lost due to leaching or denitrification.

Grain Production

Corn grain yields significantly increased with N rate both years of the study (p>F = <0.0001) (Table 5). Averaged across N rates, fall-applied ESN, spring-applied AA, and ESN treatments yielded more than fall applied AA in 2006 (Figure 3), while spring-applied treatments yielded higher than the fall-applied treatments in 2007 (Figure 4) (p>F = <0.0001) (Table 5). The interaction between N treatment and N rate was significant both years of the study (p>F = 0.0131 and 0.0001) (Table 5). Corn grain yields were higher in 2006 compared to 2007. This is probably due to better growing conditions in 2006. In 2007, very little precipitation was received before and during pollination which could be the reason yields were lower.

Grain N uptake increased with N rate both years of the study (p>F = <0.0001) (Table 5). The differences in N uptake among the four fertilizer treatments was higher in 2006 for the fall and spring-applied ESN compared with the other treatments (p>F = <0.0001) (Table 5). In 2007, averaged across N rates, spring-applied AA and ESN had higher N uptake than the other two treatments (p>F = <0.0001) (Table 5). The interaction between N treatment and N rate was significant in 2006 and 2007 (p>F = <0.0001) (Table 5). N uptake was higher in 2006 compared to 2007. Field conditions being more ideal likely played a major role in the higher grain N uptakes.

Soil Analysis

Soil NH_4^+-N concentrations increased with N rate at the V-6 sampling time in 2006 (p>F = 0.0109) (Table 6). The differences among the four treatments was higher for spring-applied ESN treatments than the other treatments at the V-6 sampling time in 2007 (p>F = 0.0692) (Table 7). The interaction between N treatment and N rate was not statistically significant either year of the study.

Soil NH_4^+-N concentrations at V-15 were not affected by N rate or the fertilizer treatments either year of the study. The interaction between N treatment and N rate was significant in 2006 and 2007 (p>F = 0.0059 and 0.0261) (Tables 6, 7). Soil NH_4^+-N concentrations at both post harvest sampling depths were not affected by any factors in either year of the study.

Soil NO_3^--N concentrations were increased with N rate at the V-6 sampling time both years of the study (p>F = <0.0001) (Tables 6, 7). The differences among the four fertilizer treatments was significantly higher for the spring-applied AA treatments in 2006 (p>F= <0.0001) (Table 6) and for the spring-applied ESN treatments in 2007 (p>F = 0.0023) (Table 7). The interaction between N treatment and N rate was statistically significant both years of the study (p>F = <0.0001) (Tables 6, 7).

Soil NO_3^--N concentrations at the V-15 sampling time increased with N rate both years of the study (p>F = <0.0001) (Tables 6, 7). The differences among the four treatments were higher for the fall and spring-applied ESN treatments in 2006 (p>F= <0.0001) (Table 6) and higher for the spring-applied ESN treatments in 2007 (p>F = <0.0001) (Table 7). The interaction between N treatment and N rate was also significant both years of the study (p>F = <0.0001 and 0.0007) (Tables 6, 7).

Post harvest soil NO_3^- -N concentrations increased with N rate in 2006 at the 0-30 cm depth (p>F = <0.0001) (Table 6). In 2006, averaged across N rates, soil NO_3^- -N concentrations from spring-applied ESN treatments were higher at the 31-60 cm sampling depth (p>F = 0.0007) (Table 6). The interaction between N treatment and N rate was also significant at this depth (p>F = <0.0001) (Table 6).

Kanawha Location

Biomass Production

Biomass yields significantly increased with N rate both years of the study (p>F = 0.0086 and <0.0001) (Table 8). The difference among the four fertilizer treatments was significantly higher for spring-applied ESN in 2007 (Figure 5) (p>F = 0.0469) (Table 8). The interaction between N treatment and N rate was not significant in either year of the study. Biomass yields were greater in 2007 than 2006. This could be due to different amounts of rainfall during the growing seasons.

Biomass N uptake was significantly increased by N rate in both years of the study (p>F = <0.0001) (Table 8). The differences among the four fertilizer materials were not significant either year of the study. The interaction between N treatment and N rate was not significant either year of the study. N uptake was greater in 2007. The higher rates of N uptake could be attributed to better growing conditions in 2007.

Grain Production

Corn grain yields increased as N rates both years of the study (p>F = <0.0001) (Table 9). Yields were significantly higher for the fall and spring-applied ESN treatments in 2006 (p>F =<0.0001) (Figure 6) (Table 9). The interaction between N treatment and N rate was statistically significant in 2006 (p>F = 0.0165) (Table 9). Overall, grain yields were about the same in both years of the study.

Grain N uptake increased with the addition of N in 2007 (p>F = 0.0001) (Table 9). In 2007, the spring-applied ESN had a statistically higher N uptake than the other treatments (p>F = 0.0408) (Table 9). The interaction between N treatment and N rate was not significant in either year of the study. Biomass N uptake was higher in 2006. In 2007 there were more events of heavy precipitation which could have led to higher N leaching rates compared with 2006.

Soil Analysis

Soil NH_4^+-N concentrations at the V-6 sampling time were increased with N rate in 2006 (p>F = 0.0152) (Table 10). In 2006 and 2007, soil NH_4^+-N concentrations were higher in the spring-applied ESN treatments which was not expected due to the release characteristics of the coating on the ESN (p>F = <0.0001 and 0.0711) (Tables 10, 11). The interaction between N treatment and N rate was not significant in either 2006 or 2007 for soil NH_4^+-N at the V-6 sampling time.

Soil NH_4^+-N concentrations were higher due to N rate at the V-15 sampling time in 2006 (p>F = 0.0064) (Table 10). The differences among the four fertilizer treatments were greater for the spring-applied ESN treatments in 2006 and 2007 (p>F = <0.0001 and 0.0012) (Tables 10, 11). The interaction between the factors was significant in 2006 (p>F = 0.0033) (Table 10). Soil NH_4^+-N concentrations at the post harvest 31-60 cm depth were higher in 2006 for the fall and spring-applied ESN treatments (p>F = 0.0574) (Table 10). None of the other factors had an effect on NH_4^+-N concentrations at either sampling depth in either year of the study.

Soil NO_3^--N concentrations at the V-6 sampling time were significantly increased by N rate in both years of the study (p>F = 0.0013 and <0.0001) (Tables 10, 11). The difference among the four fertilizer treatments was significantly higher for the spring-applied ESN treatments in 2006 and the fall-applied ESN treatments in 2007 (p>F = <0.0001 and 0.0042) (Tables 10, 11). The interaction between the two factors was also significant both years of the study (p>F = 0.0508 and 0.0022) (Tables 10, 11).

Soil NO_3^--N concentrations at the V-15 sampling time were higher due to N rate both years of the study (p>F = <0.0001 and 0.0005) (Tables 10, 11). The differences among the four fertilizer treatments were highest for fall-applied ESN treatments in 2006 (p>F = <0.0001) (Table 10), while NO_3^--N concentrations were highest for spring-applied ESN in 2007 (p>F = 0.0001) (Table 11). The interaction between N treatment and N rate was statistically significant both years of the study (p>F = <0.0001 and 0.0654) (Tables 10, 11).

Post harvest soil NO_3^--N concentrations were increased with N rate during both years at the 0-30 cm depth (p>F = 0.0005 and 0.0197) (Tables 10, 11). Spring-applied ESN treatments had higher concentrations of soil NO_3^--N during both years of the study (p>F = 0.0004 and 0.0117) (Tables 10, 11). The interaction between the factors was significant in 2006 at the 0-30 cm depth (p>F = 0.0117) (Table 10). At the 31-60 cm sampling depth, soil NO_3^--N concentrations were increased with the addition of N during both years (p>F = 0.0014 and 0.0004) (Tables 10, 11). The differences among the treatments was higher for the spring-applied ESN treatments over the duration of the study (p>F = 0.0044 and <0.0001) (Tables 10, 11). The interaction between the two factors was statistically significant in 2007 (p>F = 0.0513) (Table 11).

Summary and Conclusions

Biomass and corn grain yields increased with the addition of fertilizer N all four site-years of the study. Biomass yields were statistically higher from the use of spring-applied ESN at one of the four site-years. In regards to corn grain yields, one of four site years showed a clear statistical advantage supporting the application of ESN in the spring. Overall, biomass and corn grain yield responses varied over the length of this study which is undoubtedly due to varying environmental conditions at each location.

Soil NH_4^+-N and NO_3^--N concentrations were usually higher for fall or spring-applied ESN treatments compared to aqua ammonia treatments at all of the sampling times. This extra residual N that is left behind after the crop is harvest is of particular worry because it can be easily leached overwinter.

We did not observe any negative yield responses from the use of ESN; however ESN did not consistently result in higher corn grain and biomass yields. We believe that this product has the potential to increase corn grain yields in certain environmental situations such as sandy soils or areas of increased rainfall while preventing N loss. Currently, the cost of this product and the unpredictability of positive yield responses for ESN make it difficult to recommend ESN to producers as an alternative fertilizer to anhydrous ammonia in Iowa.

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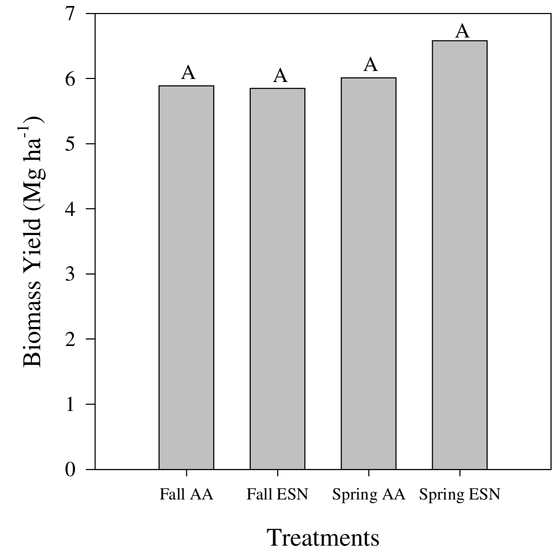

Figure 1. Relationship between N treatments and biomass yield at Ames, 2006.

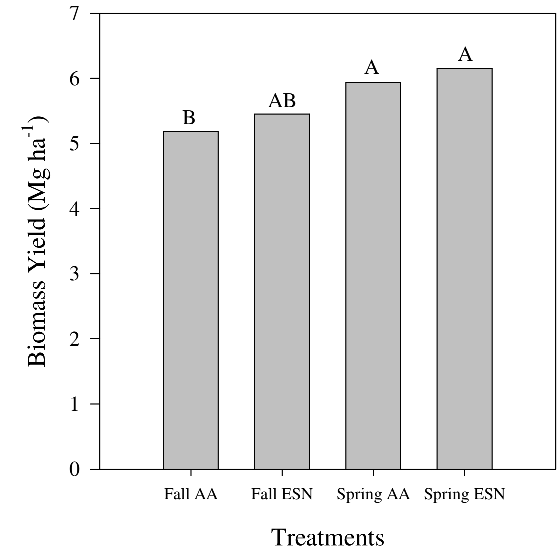

Figure 2. Relationship between N treatments and biomass yield at Ames, 2007.

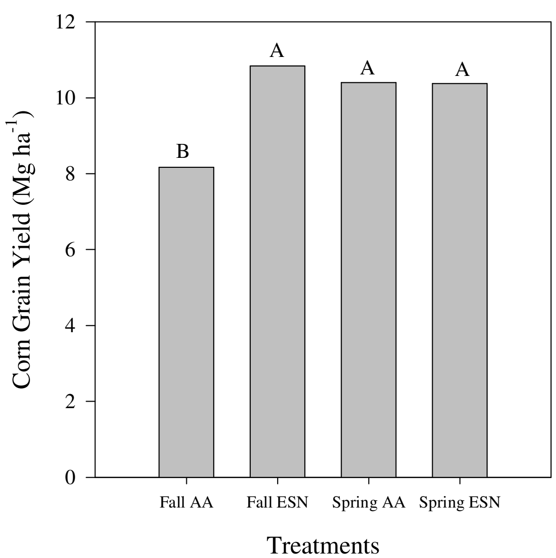

Figure 3. Relationship between N treatments and corn grain yield at Ames, 2006.

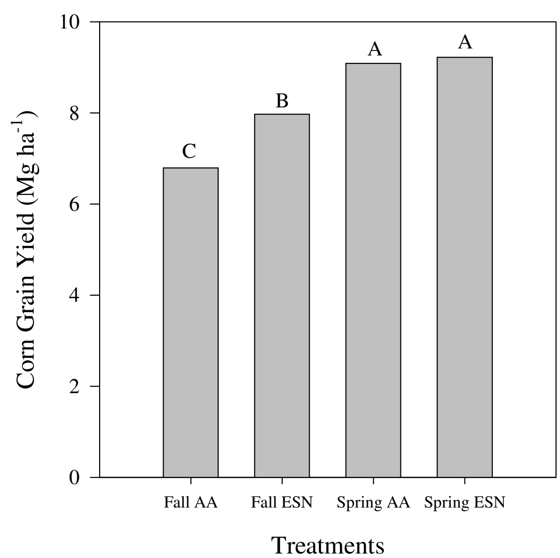

Figure 4. Relationship between N treatments and corn grain yield at Ames, 2007.

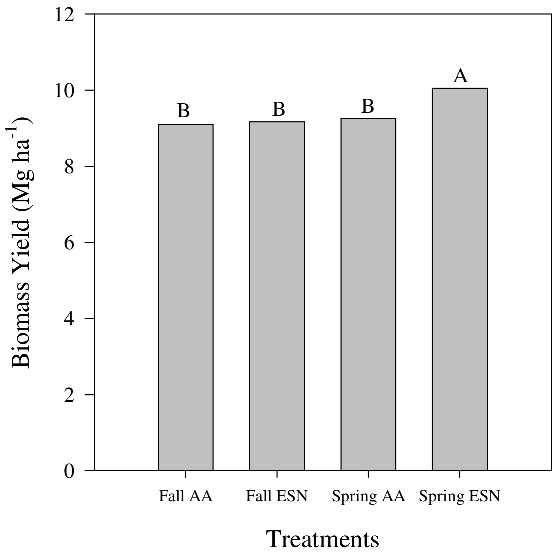

Figure 5. Relationship between N treatments and biomass yield at Kanawha, 2007.

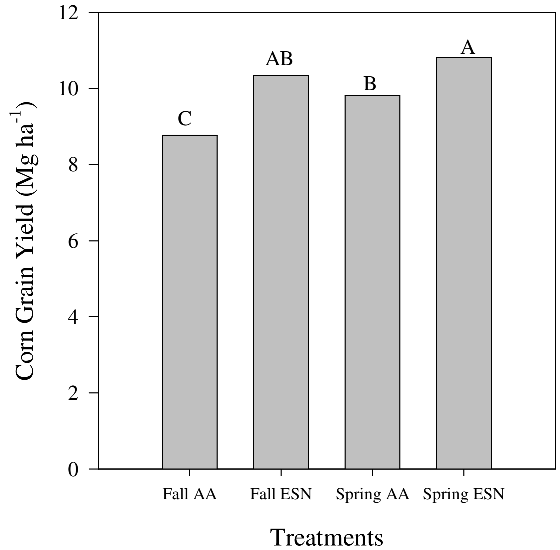

Figure 6. Relationship between N treatments and corn grain yield at Kanawha, 2006.

Table 1. Soil types for all years in the studies at Kanawha and Ames.

Site	Year	Soil type	Soil series description
Kanawha	2006	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludoll
		Canisteo	Fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll
	2007	Webster	Fine-loamy, mixed, superactive, mesic Typic Endoaquall
Ames	2006	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludoll
	2007	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludoll

Table 2. Cultural practices in the fall and spring applied ESN and aqua ammonia studies at Ames and Kanawha, 2006-2007.

Site / Year	**Planting date**	**Hybrid**	**Population seeds/ha**	**Harvest date**
2006				
Ames	May 8	AgriGold 6395 RW	73,853	October 19
Kanawha	May 22	Dekalb 53-32 Bt	81,510	October 24
2007				
Ames	May 11	AgriGold 6395 RW	74,100	October 12
Kanawha	May 10	Pioneer 36W69	81,510	October 6

Table 3. Soil chemical properties at the 0-15 cm depth at Ames and Kanawha, 2006-2007.

Location	**Year**	**OM[a]**	**pH[b]**	**P[c]**	**K[d]**
		$g\ kg^{-1}$		----------------mg kg^{-1}---------------	
Ames	2006	45	6.1	29	127
Ames	2007	39	6.0	39	161
Kanawha	2006	51	5.6	34	227
Kanawha	2007	53	5.9	32	255

[a] organic matter

[b] 1:1 H_2O

[c] Bray P-1

[d] Ammonium Acetate

Table 4. Corn biomass response to fall and spring applied ESN and aqua ammonia at Ames, 2006-2007.

N Treatment	**N rate**	**Yield** [a]	**N uptake** [a]	**Yield** [a]	**N uptake** [a]
		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Fall AA	0	4.93	22	4.09	22
	67	6.43	33	5.22	26
	134	6.23	25	4.96	25
	202	5.98	29	6.44	34
Average		**5.89**	**27**	**5.18**	**27**
Fall ESN	0	4.73	20	4.57	20
	67	5.90	29	5.39	23
	134	4.95	25	5.13	25
	202	7.83	55	6.71	42
Average		**5.85**	**32**	**5.45**	**28**
Spring AA	0	4.88	24	5.38	30
	67	5.88	29	5.61	26
	134	6.85	38	6.16	34
	202	6.43	35	6.57	39
Average		**6.01**	**31**	**5.93**	**32**
Spring ESN	0	4.38	18	4.28	20
	67	6.23	33	5.69	24
	134	7.33	45	7.18	38
	202	8.38	67	7.45	48
Average		**6.58**	**41**	**6.15**	**33**
Statistics		----------------------------------p > F----------------------------------			
N rate		<0.0001	<0.0001	<0.0001	0.0007
Treatment		NS	0.0045	0.0405	NS
*N rate*N Treatment*		NS	0.0041	NS	NS

[a] dry weight

Table 5. Corn grain response to fall and spring applied ESN and aqua ammonia at Ames, 2006-2007.

N Treatment		**N rate**	**Yield [a]**	**N uptake [b]**	**Yield [a]**	**N uptake [b]**
			2006		2007	
		kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Fall AA		0	6.28	40	4.85	37
		67	8.69	62	6.57	51
		134	8.37	58	7.53	58
		202	9.34	66	8.22	65
	Average		**8.17**	**57**	**6.79**	**53**
Fall ESN		0	6.97	48	5.53	43
		67	10.78	77	7.08	56
		134	12.18	103	8.52	66
		202	13.44	131	10.76	97
	Average		**10.84**	**90**	**7.97**	**66**
Spring AA		0	7.17	50	6.30	47
		67	10.21	73	8.02	65
		134	11.42	86	10.27	91
		202	12.80	110	11.78	114
	Average		**10.40**	**80**	**9.09**	**79**
Spring ESN		0	5.96	38	4.59	34
		67	10.65	81	8.06	63
		134	11.61	103	11.33	101
		202	13.25	130	12.91	138
	Average		**10.37**	**88**	**9.22**	**84**
Statistics			-------------------------------------p>F-----------------------------------			
N rate			<0.0001	<0.0001	<0.0001	<0.0001
Treatment			<0.0001	<0.0001	<0.0001	<0.0001
*N rate*N Treatment*			0.0131	<0.0001	0.0001	<0.0001

[a] 155 g kg^{-1}

[b] dry weight

Table 6. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Ames, 2006.

N Treatment	N rate	NH_4^+ V-6	NH_4^+ V-15	NH_4^+ Post Harvest 0-30cm	NH_4^+ Post Harvest 31-60 cm	NO_3^- V-6	NO_3^- V-15	NO_3^- Post Harvest 0-30 cm	NO_3^- Post Harvest 31-60 cm
	kg ha^{-1}	mg kg^{-1}				mg kg^{-1}			
Fall AA	0	8.55	5.75	5.40	2.70	7.25	1.60	5.55	2.30
	67	8.75	6.45	5.20	2.70	8.05	1.60	6.35	2.70
	134	9.25	7.10	6.55	2.80	6.50	1.65	5.80	2.70
	202	7.55	5.75	5.40	2.55	9.85	1.55	5.15	2.30
Average		**8.53**	**6.26**	**5.64**	**2.69**	**7.91**	**1.60**	**5.71**	**2.50**
Fall ESN	0	7.30	6.40	5.05	2.95	6.95	1.50	6.15	2.40
	67	9.30	6.15	5.85	2.85	14.65	2.00	6.70	2.15
	134	8.00	7.00	6.20	3.10	11.00	2.85	6.20	2.55
	202	9.65	6.85	5.85	3.20	24.70	11.20	7.10	3.90
Average		**8.56**	**6.60**	**5.74**	**3.03**	**14.33**	**4.39**	**6.54**	**2.75**
Spring AA	0	8.40	7.20	6.50	2.80	7.50	1.45	5.15	2.30
	67	9.25	6.10	5.30	3.05	15.55	1.60	5.90	2.90
	134	12.55	5.90	5.35	2.75	41.05	1.85	6.05	2.60
	202	8.15	5.85	5.25	3.25	7.40	4.15	5.15	2.75
Average		**9.59**	**6.26**	**5.60**	**2.96**	**17.88**	**2.26**	**5.56**	**2.64**
Spring ESN	0	7.90	5.75	5.30	2.80	6.55	1.40	5.40	2.45
	67	7.70	6.55	5.60	2.85	8.15	1.85	5.70	2.55
	134	10.80	6.75	6.20	3.10	14.20	5.30	7.20	2.90
	202	9.30	8.45	7.45	2.75	9.50	12.70	7.85	5.10
Average		**8.93**	**6.88**	**6.14**	**2.88**	**9.60**	**5.31**	**6.54**	**3.25**
Statistics		p>F				p>F			
N rate		0.0109	NS	NS	NS	<0.0001	<0.0001	NS	<0.0001
Treatment		NS	NS	NS	NS	<0.0001	<0.0001	NS	0.0007
*N rate*N Treatment*		NS	0.0059	NS	NS	<0.0001	<0.0001	NS	<0.0001

Table 7. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Ames, 2007.

N Treatment	N rate	NH_4^+ Sample time V-6	NH_4^+ V-15	NH_4^+ Post Harvest 0-30cm	NH_4^+ Post Harvest 31-60 cm	NO_3^- Sample time V-6	NO_3^- V-15	NO_3^- Post Harvest 0-30 cm	NO_3^- Post Harvest 31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Fall AA	0	6.45	5.90	5.38	2.51	5.45	2.05	4.23	2.35
	67	6.95	6.20	5.68	2.48	6.90	2.20	4.64	2.42
	134	6.95	6.65	4.96	2.48	7.00	2.35	4.93	2.60
	202	7.55	6.60	5.65	2.28	7.25	2.05	4.56	2.27
Average		**6.98**	**6.34**	**5.42**	**2.44**	**6.65**	**2.16**	**4.59**	**2.41**
Fall ESN	0	6.50	5.60	4.88	2.53	5.65	2.25	4.11	2.17
	67	6.90	6.75	4.79	2.17	7.55	2.00	3.66	2.00
	134	7.50	7.25	5.51	2.27	9.60	2.70	4.43	2.10
	202	7.15	6.70	6.39	2.51	19.70	3.50	4.90	2.69
Average		**7.01**	**6.58**	**5.39**	**2.37**	**10.63**	**2.61**	**4.28**	**2.24**
Spring AA	0	7.60	7.25	5.89	2.84	5.25	2.10	4.14	2.38
	67	7.60	6.55	5.11	2.55	12.50	1.90	3.91	2.24
	134	7.20	6.30	4.79	2.33	13.20	3.80	4.02	2.49
	202	7.00	6.40	4.78	2.79	6.30	4.05	4.13	2.60
Average		**7.35**	**6.63**	**5.14**	**2.63**	**9.31**	**2.96**	**4.05**	**2.43**
Spring ESN	0	6.10	5.85	4.88	2.21	4.40	1.85	3.43	1.88
	67	7.65	7.05	5.24	2.40	6.15	2.80	4.43	2.42
	134	11.90	6.40	5.11	2.25	13.95	6.15	4.42	2.27
	202	9.70	8.85	5.19	2.49	28.70	10.20	5.27	2.70
Average		**8.84**	**7.04**	**5.11**	**2.34**	**13.30**	**5.25**	**4.39**	**2.32**
Statistics		----------------------------p>F--------------------------				----------------------------p>F--------------------------			
N rate		NS	NS	NS	NS	<0.0001	<0.0001	NS	NS
Treatment		0.0692	NS	NS	NS	0.0023	<0.0001	NS	NS
*N rate*N Treatment*		NS	0.0261	NS	NS	<0.0001	0.0007	NS	NS

Table 8. Corn biomass response to fall and spring applied ESN and aqua ammonia at Kanawha, 2006-2007.

N Treatment	N rate	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]
		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Fall AA	0	5.53	23	7.42	34
	67	8.58	38	9.17	48
	134	6.60	33	10.19	59
	202	8.50	45	9.56	57
Average		**7.30**	**35**	**9.09**	**49**
Fall ESN	0	6.18	21	7.80	32
	67	7.83	39	9.40	43
	134	9.87	62	9.38	49
	202	6.50	37	10.09	69
Average		**7.60**	**40**	**9.17**	**48**
Spring AA	0	5.50	23	7.71	32
	67	8.58	37	9.33	49
	134	6.73	33	9.95	58
	202	9.65	61	9.99	58
Average		**7.62**	**39**	**9.25**	**49**
Spring ESN	0	7.23	34	9.45	44
	67	7.70	36	10.62	50
	134	8.23	43	10.77	65
	202	8.00	59	9.37	59
Average		**7.79**	**43**	**10.05**	**55**
Statistics		------------------------------------p > F----------------------------------			
N rate		0.0086	<0.0001	<0.0001	<0.0001
Treatment		NS	NS	0.0469	NS
*N rate*N Treatment*		NS	NS	NS	NS

[a] dry weight

Table 9. Corn grain response to fall and spring applied ESN and aqua ammonia fertilizers at Kanawha, 2006-2007.

N Treatment	N rate	Yield [a]	N uptake [b]	Yield [a]	N uptake [b]
		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
Fall AA	0	7.48	75	6.79	63
	67	6.91	78	10.21	101
	134	9.83	102	10.77	99
	202	10.84	110	12.18	121
Average		**8.77**	**91**	**9.99**	**96**
Fall ESN	0	7.48	79	6.06	53
	67	10.65	108	10.38	100
	134	11.61	129	11.66	114
	202	11.61	121	12.26	127
Average		**10.34**	**109**	**10.08**	**98**
Spring AA	0	6.08	63	6.51	59
	67	9.57	102	10.33	96
	134	11.16	119	12.41	125
	202	12.43	146	12.43	123
Average		**9.81**	**108**	**10.41**	**101**
Spring ESN	0	7.74	80	8.49	83
	67	10.91	116	10.07	98
	134	11.99	137	11.93	123
	202	12.62	137	11.88	125
Average		**10.81**	**118**	**10.59**	**107**
Statistics		------------------------------------p>F----------------------------------			
N rate		<0.0001	NS	<0.0001	0.0001
Treatment		<0.0001	NS	NS	0.0408
*N rate*N Treatment*		0.0165	NS	0.0699	NS

[a] 155 g kg^{-1}

[b] dry weight

Table 10. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Kanawha, 2006.

		NH_4^+				NO_3^-			
N Treatment	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	------------------------mg kg^{-1}-----------------------				------------------------mg kg^{-1}-----------------------			
Fall AA	0	7.55	4.60	6.90	3.00	7.40	3.35	7.10	2.20
	67	7.65	5.25	9.40	2.70	9.25	2.95	9.00	2.95
	134	8.60	4.35	6.90	2.90	8.15	3.65	7.95	2.40
	202	7.60	4.10	6.50	3.10	7.45	2.75	7.60	3.20
Average		**7.85**	**4.58**	**7.43**	**2.93**	**8.06**	**3.18**	**7.91**	**2.69**
Fall ESN	0	6.30	4.65	7.95	4.05	8.60	3.20	6.80	2.45
	67	8.70	4.85	7.25	3.05	13.50	5.10	7.55	2.20
	134	8.55	5.85	7.10	3.05	17.15	10.65	10.05	3.00
	202	10.60	5.40	8.00	3.10	23.70	10.25	10.70	3.80
Average		**8.54**	**5.19**	**7.58**	**3.31**	**15.74**	**7.30**	**8.78**	**2.86**
Spring AA	0	7.65	4.05	6.80	2.75	7.20	3.10	6.00	2.00
	67	8.00	4.35	7.40	2.75	7.80	3.15	8.35	2.45
	134	9.15	5.30	8.00	3.05	10.30	4.95	8.65	3.50
	202	7.30	4.75	8.05	2.75	8.05	3.90	8.10	2.85
Average		**8.03**	**4.61**	**7.56**	**2.83**	**8.34**	**3.78**	**7.78**	**2.70**
Spring ESN	0	7.60	4.50	6.95	2.85	7.00	3.45	7.75	2.05
	67	12.30	7.05	7.80	3.25	11.45	5.10	9.15	2.90
	134	16.55	6.00	7.30	3.55	11.75	7.00	11.60	5.40
	202	16.85	8.65	7.60	3.90	16.30	12.20	18.90	7.55
Average		**13.33**	**6.55**	**7.41**	**3.39**	**11.63**	**6.94**	**11.85**	**4.48**
Statistics		----------------------------p>F---------------------------				----------------------------p>F---------------------------			
N rate		0.0152	0.0064	NS	NS	0.0013	<0.0001	0.0005	0.0014
Treatment		<0.0001	<0.0001	NS	0.0574	<0.0001	<0.0001	0.0004	0.0044
*N rate*N Treatment*		NS	0.0033	NS	NS	0.0508	<0.0001	0.0117	NS

Table 11. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Kanawha, 2007.

N Treatment	N rate	NH_4^+ V-6	NH_4^+ V-15	NH_4^+ Post Harvest 0-30cm	NH_4^+ Post Harvest 31-60 cm	NO_3^- V-6	NO_3^- V-15	NO_3^- Post Harvest 0-30 cm	NO_3^- Post Harvest 31-60 cm
	kg ha^{-1}	------------mg kg^{-1}------------				------------mg kg^{-1}------------			
Fall AA	0	9.75	4.30	8.90	3.46	5.65	2.55	3.09	1.25
	67	10.10	4.25	8.70	3.83	7.70	2.50	3.40	1.40
	134	8.85	4.65	8.49	4.04	11.30	2.50	3.80	1.50
	202	8.75	4.30	10.13	4.09	10.20	2.90	4.33	1.60
Average		**9.36**	**4.38**	**9.06**	**3.86**	**8.71**	**2.61**	**3.66**	**1.44**
Fall ESN	0	10.55	4.15	8.11	4.48	5.75	2.70	3.21	1.74
	67	12.15	4.40	9.58	4.39	12.90	3.05	4.39	1.58
	134	9.35	4.05	8.15	3.75	13.95	3.30	3.93	1.47
	202	10.35	5.95	8.35	3.53	28.25	5.05	4.06	1.79
Average		**10.60**	**4.64**	**8.55**	**4.04**	**15.21**	**3.53**	**3.90**	**1.65**
Spring AA	0	8.55	4.15	8.38	4.00	5.55	2.25	3.30	1.41
	67	9.50	4.20	9.16	4.49	14.45	2.95	3.30	1.48
	134	10.70	4.00	8.73	3.68	16.75	4.55	3.48	1.46
	202	10.25	3.90	7.40	3.57	8.70	3.35	3.72	1.63
Average		**9.75**	**4.06**	**8.42**	**3.94**	**11.36**	**3.28**	**3.45**	**1.50**
Spring ESN	0	10.70	4.90	9.29	4.87	7.70	2.85	4.27	1.65
	67	11.10	5.75	9.49	4.58	11.75	4.10	3.48	1.74
	134	13.05	6.15	8.40	4.19	14.45	6.05	4.59	1.91
	202	15.70	6.15	8.83	3.91	20.80	8.15	5.36	2.65
Average		**12.64**	**5.74**	**9.00**	**4.39**	**13.68**	**5.29**	**4.43**	**1.99**
Statistics		------------p>F------------				------------p>F------------			
N rate		NS	NS	NS	NS	<0.0001	0.0005	0.0197	0.0004
Treatment		0.0711	0.0012	NS	NS	0.0042	0.0001	0.0117	<0.0001
*N rate*N Treatment*		NS	NS	NS	NS	0.0022	0.0654	NS	0.0513

Comparison of ESN and aqua ammonia applied in the spring as sources of nitrogen for corn production in Iowa

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Abstract

Controlled-release nitrogen (N) fertilizers currently are not commonly used in corn production. They have been proven to increase yields and reduce N loss compared to conventional fertilizers in certain crops. A two-year field study was conducted in 2006 and 2007 at one location in northwest Iowa to compare the effects of a controlled-release N fertilizer, ESN, and aqua ammonia on corn grain and biomass yields, N uptake and soil N concentrations. Fertilizer rates from 0 to 202 kg N ha^{-1} in 67 kg N ha^{-1} increments were spring-applied. The addition of fertilizer N increased biomass yields one year and biomass N uptake both years. The addition of ESN or aqua ammonia did not significantly increase biomass yields either year. The addition of fertilizer N increased corn grain yields and N uptake during both years of the study. There was no difference in corn grain yields due to fertilizer materials. Soil nitrate-N and ammonium-N concentrations were usually higher for ESN treatments compared to aqua ammonia treatments at all sampling times. These results suggest that the use of ESN could have negative environmental impacts because the residual N that is left behind after the crop harvest is easily leached overwinter if field conditions are saturated. We did not observe any negative yield responses from the use of ESN at any year during the study.

Introduction

The use of nitrogen (N) fertilizer in Iowa is a common practice to increase corn grain yields. Fall application of anhydrous ammonia is widely practiced in the Corn Belt due to factors such as lower cost of N, more time for fieldwork compared to the spring, and field conditions are usually better suited for application (Randall and Sawyer, 2005). However, nitrate can easily be lost in leachate and subsurface drainage, particularly when precipitation exceeds evapotranspiration, which usually occurs every year in Iowa. Nitrate losses from fall application of anhydrous ammonia can be significantly greater compared with spring application because of more time for nitrification before N uptake by plants (Randall and Vetsch, 2005).

Producers are always looking for new ways to increase crop yields while keeping input costs at a minimum. ESN is a controlled-release N fertilizer (44% N), developed by Agrium, Inc., that has the potential to reduce loss of N from the soil while increasing grain yields and plant uptake of N. After ESN is applied and comes in contact with soil moisture, water is absorbed through the coating and turns the urea granule into a liquid. The liquid urea then diffuses out through the coating over the growing season. Release of the N is regulated by temperature with higher temperatures leading to increased diffusion rates.

However, current use of controlled-release fertilizers is not widespread in crops such as corn due to the higher cost when compared to conventional N fertilizers. The higher cost of these fertilizers has restricted their use to high value crops such as ornamentals and turf grass (Hauck, 1985). If the cost can be reduced or increased yields can offset the higher cost of these fertilizers, these types of fertilizers have a higher chance of increased usage. To date, little research has been published comparing ESN with aqua ammonia for application to corn.

The objectives of this study were to: 1) compare the effects of ESN and aqua ammonia applied in the spring on corn grain and biomass yields and 2) compare the effects of spring-applied ESN and aqua ammonia on soil NH_4-N and soil NO_3-N concentrations at three times during the year, the V-6 growth stage, the V-15 growth stage, and at post-harvest.

Materials and Methods

This experiment was conducted at the Northwest Research and Demonstration Farm near Sutherland, Iowa in 2006 and 2007. The soil types for the experiment are listed in Table 1 while the cultural practices are listed in Table 2 and baseline soil data are listed in Table 3.

Treatments were arranged as a factorial in a randomized complete block design with four replications. The experimental plots measured 3.05 m by 12.2 m. These plots contained 4 rows of corn spaced 76 cm apart. A set of ESN (44% N) and aqua ammonia (20% N) treatments were applied in the spring of each year. The ESN treatments were applied by hand and the aqua ammonia was injected into the soil using a two row applicator. Aqua ammonia was used in this study because it is more easily handled and more accurately applied than anhydrous ammonia. Nitrogen application rates for this site in both years were: 0, 67, 134, and 202 kg N ha^{-1}. The corn plots followed soybeans each year. The plots were scouted several times throughout the growing season to check for overall plant health, damage due to insects, disease, and nutrient deficiencies.

Grain Yield and Analysis

The center two rows of each plot were harvested by combine. The weight of the grain in each plot and moisture content were recorded when harvested. A sub-sample of the grain was collected, weighed, and dried at 60° C. The sub-sample was used to determine grain moisture of the plot. Corn grain yield was adjusted to reflect a moisture content of 155 g kg^{-1}.

Chemical analysis of the grain was conducted as follows: A 0.25g sub-sample of grain was ground, dried for a minimum of twenty-four hours, and was digested using the Hach Digesdahl® Digestion Apparatus, and the Hach Plant Tissue and Tissue Analysis System (Hach Company, 1988), with concentrated sulfuric acid (18 *M* H_2SO_4) and 50 % hydrogen peroxide (H_2O_2). The digested product was then used to determine percent N by using a modified Nessler Method test and a Hach DR/3000 Spectrophotometer (DR/3000 Procedure Code N.10) as described in the method for Nitrogen Analysis in Total Plant Tissue (Hach Company, 1988). Nitrogen uptake was calculated by multiplying grain dry weight by the percent of N in the grain.

Plant Biomass Production and Analysis

Whole plant samples were collected when the plants reached physiological maturity. The entire above ground portion of the plant, minus the ears of corn were selected from the center two rows (three plants from each row) of each plot. The first plant in the row was skipped because it was generally larger due to more light interception. The plant samples were chopped and weighed. A sub-sample was taken, weighed, then dried at 60° C for a minimum of forty-eight hours, weighed again, and ground. The dry weight of the sub-sample was used to determine total above ground biomass produced per hectare.

Soil Sampling and Analysis

Soil samples were collected three times during the season each year of the study. The timing of the samples was at the V-6 growth stage, the V-15 growth stage, and post harvest. Three cores were randomly taken to a depth of 30 cm between the center two rows of the plot and combined to form the sample. The post harvest sample included samples collected from a depth of 31-60 cm.

The soil samples were dried at 60° C for a minimum of twenty-four hours and ground to pass through a 2 mm sieve. A 10 g sub-sample was weighed and extracted with 50 ml of 2 *M* KCl solution. The extract was filtered and analyzed for nitrate-N (NO_3-N) and ammonium-N (NH_4-N) using a QuikChem 8000 Automated Ion Analyzer by the QuikChem Method 12-107-04-1-B (Lachat Instruments, 1992) for the NO_3-N and QuikChem Method 12-107-06-2-A (Lachat Instruments, 1993) for NH_4-N.

Data Analysis

Statistix 8 (Analytical Software, 2003) was used to analyze the data. The analyses for each combination of site and year were done separately. Nitrate-N and NH_4^+-N content for all soil sampling times were also analyzed separately. Differences at the $p>F = 0.05$ level or less were considered significant. Outliers in the data, except for corn grain yield, were identified by using residual graphs and were determined to be non-representative if they were greater that three standard deviations from the experiment mean.

Results and Discussion

Biomass Production

Biomass yields increased with N rate in 2007 ($p>F = <0.0001$) (Table 4) but were not affected by N rate in 2006. The difference between the ESN and aqua ammonia and the interaction between material and N rate was not significant either year of the study. Biomass yields varied between the two years of the study but were higher in 2007. This could be due to different environmental conditions experienced each year.

Biomass N uptake increased when N rate increased both years of the study ($p>F$ = 0.0463 and 0.0002) (Table 4). The difference between the two materials and the interaction between material and N rate was not significant during either year of the study. N uptake in the biomass also varied from year to year. It was higher in 2007, which is most likely due to better growing conditions.

Grain Production

Corn grain yield increased as N rate increased both years of the study ($p>F$ = <0.0001) (Table 5). The difference between the materials and the interaction between material and N rate was not significant either year of the study. Grain yields varied over the length of the study. Average yields were higher in 2007 which was more than likely due to better environmental growing conditions.

Grain N uptake increased with N rate both years of the study ($p>F$ = <0.0001) (Table 5). The difference in N uptake between the two fertilizer materials was not significant either year of the study. The interaction between material and N rate was also not significant either year of the study. Grain N uptake was almost identical during both years of the study.

Soil Analysis

Soil NH_4-N concentrations were not affected by N rate at the V-6 sampling time either year of the study. Averaged over N rates, ESN treatments had higher NH_4^+-N concentrations both years of the study ($p>F$ = 0.0285 and 0.0144) (Tables 6 and 7). The interaction between material and N rate was not significant for soil NH_4-N at the V-6 sampling time.

Soil NH_4-N concentrations increased with N rate (p>F = 0.0242 and 0.0002) at the V-15 sampling time in 2006 and 2007 (Tables 6, 7). The difference between the two materials was significantly higher for ESN both years of the study (p>F = 0.0002 and <0.0001) (Tables 6, 7). The interaction between material and N rate was significant in 2007 (p>F = 0.0020) (Table 7).

Post harvest samples at both the 0-30 and 31-60 cm depth were not significantly affected by any of the factors. Soil NH_4^+-N concentrations from the ESN treatments were slightly higher both years and at both depths.

Soil NO_3-N concentrations increased significantly when N rate increased at the V-6 sampling time in 2007 (p>F = <0.0001) (Table 7). The difference between the two fertilizer materials was significantly higher for the ESN treatments both years of the study (p>F = 0.0528 and <0.0001) (Tables 6, 7). The interaction between material and N rate was significant in 2007 for soil NO_3-N at the V-6 sampling time (p>F = <0.0001) (Table 7).

At the V-15 sampling time, soil NO_3-N concentrations were significantly increased with N rate in 2006 and 2007 (p>F = 0.0002 and 0.0001) (Tables 6, 7). The difference between the ESN and AA treatments was significantly higher for the ESN treatments both years of the study (p>F = 0.0020 and <0.0001) (Tables 6, 7). In 2006 and 2007, the interaction between material and N rate was statistically significant (p>F = 0.0752 and 0.0003) (Tables 6, 7).

Post harvest soil NO_3^- -N concentrations at the 0-30 cm depth increased with N rate (p>F = <0.0001 and 0.0515) both years of the study (Tables 6, 7). Averaged over N rates, the ESN treatments had higher NO_3^- -N concentrations in 2006 at the 0-30 cm depth in 2006 (p>F = 0.0013) (Table 6). The interaction between material and N rate was significant in 2006 (p>F = 0.0003) (Table 6). At the 31-60 cm sampling depth, soil NO_3^- -N concentrations were increased when N was applied both years of the study (p>F = 0.0028 and 0.0262) (Tables 6, 7). Higher concentrations of soil NO_3^- -N were found in the ESN treatments in 2006 (p>F = 0.0197) (Table 6). The interaction between material and N rate was significant (p>F = 0.0057) at the 31-60 cm depth in 2006 (Table 6).

Summary and Conclusions

The addition of fertilizer N increased biomass yields one year of the study and corn grain yields in both years. The source of N did not have any effect on biomass or corn grain yields. We did not observe any negative yield responses from the use of ESN; however ESN did not consistently result in higher corn grain and biomass yields. The data suggest slightly higher concentrations of nitrate and ammonium from ESN treatments remained in the soil after the corn was harvested. These residual amounts of N could have negative consequences to crop producers due to the fact that nitrate is easily lost from the soil profile if leaching occurs.

We believe that this product has the potential to increase corn grain yields in certain situations while preventing N loss (sandy soils, high rainfall locations, etc). Currently the cost of this product and the unpredictability of positive yield responses for ESN make it difficult to recommend ESN to producers as an alternative fertilizer to anhydrous ammonia in northwest Iowa.

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Table 1. Soil types in the study at Sutherland, 2006-2007.

Site	Year	Soil type	Soil series description
Sutherland	2006	Marcus	Fine-silty, mixed, superactive, mesic Typic Endoaquoll
	2007	Sac	Fine-silty, mixed, superactive, mesic Oxyaquic Hapludoll
		Primghar	Fine-silty, mixed, superactive, mesic Aquic Hapludoll

Table 2. Cultural practices for the study at Sutherland, 2006-2007.

Site / Year	Planting date	Hybrid	Population seeds/ha	Harvest date
2006				
Sutherland	May 12	Pioneer 35Y61	79,040	October 24
2007				
Sutherland	May 2	Kruger 8602 HX	79,040	October 11

Table 3. Soil chemical properties at the 0-15 cm depth at Sutherland, 2006-2007.

Year	OM[a]	pH[b]	P[c]	K[d]
	g kg^{-1}		----------------mg kg^{-1}---------------	
2006	46	5.1	22	248
2007	46	5.8	21	176

[a] organic matter

[b] 1:1 H_2O

[c] Bray P-1

[d] Ammonium Acetate

Table 4. Corn biomass response to spring applied ESN and aqua ammonia at Sutherland, 2006-2007.

N Material	N rate	Yield [a]	N uptake [a]	Yield [a]	N uptake [a]
		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
AA	0	6.40	34	7.76	34
	67	6.18	29	10.39	48
	134	7.90	44	11.44	66
	202	7.68	46	11.62	70
Average		**7.04**	**38**	**10.30**	**55**
ESN	0	6.13	26	9.55	41
	67	7.18	31	10.88	47
	134	7.73	49	11.10	59
	202	7.25	43	11.74	76
Average		**7.07**	**37**	**10.82**	**56**
Statistics		----------------------------------p > F----------------------------------			
N rate		NS	0.0463	<0.0001	0.0002
Material		NS	NS	NS	NS
*N rate*Material*		NS	NS	NS	NS

[a] dry weight

Table 5. Corn grain response to spring applied ESN and aqua ammonia fertilizers at Sutherland, 2006-2007.

N Material	**N rate**	**Yield [a]**	**N uptake [b]**	**Yield [a]**	**N uptake [b]**
		2006		2007	
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}
AA	0	9.07	93	8.96	81
	67	11.42	129	11.80	116
	134	12.80	153	12.71	139
	202	11.29	136	13.82	154
Average		**11.14**	**127**	**11.82**	**122**
ESN	0	9.07	91	9.49	85
	67	10.53	113	12.06	117
	134	12.80	147	12.76	138
	202	11.99	146	13.14	151
Average		**11.10**	**124**	**11.86**	**123**
Statistics		----------p>F----------			
N rate		<0.0001	<0.0001	<0.0001	<0.0001
Material		NS	NS	NS	NS
*N rate*Material*		NS	NS	NS	NS

[a] 155 g kg^{-1}

[b] dry weight

Table 6. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Sutherland, 2006.

		NH_4^+				NO_3^-			
N Material	**N rate**	**Sample time**				**Sample time**			
		V-6	**V-15**	**Post Harvest**		**V-6**	**V-15**	**Post Harvest**	
				0-30cm	31-60 cm			0-30 cm	31-60 cm
	kg ha^{-1}	-------------------------mg kg^{-1}------------------------				-------------------------mg kg^{-1}------------------------			
AA	0	8.30	6.45	7.80	5.95	10.75	3.55	6.60	3.65
	67	8.00	6.50	8.35	5.70	10.20	4.05	7.65	4.75
	134	8.60	7.10	8.25	5.25	10.60	4.95	7.25	3.80
	202	9.35	6.90	8.55	5.30	9.85	5.25	10.30	4.40
Average		**8.56**	**6.74**	**8.24**	**5.55**	**10.35**	**4.45**	**7.95**	**4.15**
ESN	0	8.15	6.70	8.80	5.95	9.45	3.35	5.65	3.65
	67	10.40	9.65	8.85	6.00	11.10	5.35	8.35	3.80
	134	12.15	13.40	8.50	5.60	13.80	8.35	9.20	5.05
	202	15.45	11.45	9.70	7.50	13.15	7.05	21.55	10.70
Average		**11.54**	**10.30**	**8.96**	**6.26**	**11.88**	**6.03**	**11.19**	**5.80**
Statistics		-----------------------------p>F---------------------------				-----------------------------p>F---------------------------			
N rate		NS	0.0242	NS	NS	NS	0.0002	<0.0001	0.0028
N material		0.0285	0.0002	NS	NS	0.0528	0.0020	0.0013	0.0197
*N rate*N material*		NS	NS	NS	NS	NS	0.0752	0.0003	0.0057

Table 7. Effect of N rate and fertilizer materials on concentrations of soil NH_4^+-N and NO_3^--N at Sutherland, 2007.

N Material	N rate	NH_4^+ Sample time V-6	NH_4^+ V-15	NH_4^+ Post Harvest 0-30cm	NH_4^+ Post Harvest 31-60 cm	NO_3^- Sample time V-6	NO_3^- V-15	NO_3^- Post Harvest 0-30 cm	NO_3^- Post Harvest 31-60 cm
	kg ha^{-1}	mg kg^{-1}				mg kg^{-1}			
AA	0	8.45	8.40	9.66	5.39	6.05	3.15	4.27	2.34
	67	8.85	8.45	9.31	5.68	8.05	4.40	4.58	2.41
	134	9.40	8.70	9.26	5.24	7.45	4.00	4.71	2.52
	202	8.15	9.30	9.31	5.88	8.60	5.45	5.31	3.68
Average		**8.71**	**8.71**	**9.39**	**5.55**	**7.54**	**4.25**	**4.72**	**2.74**
ESN	0	10.00	8.25	9.74	5.36	6.70	3.25	4.04	2.45
	67	12.90	9.70	9.01	5.67	14.95	6.45	4.75	2.22
	134	10.15	14.35	10.44	6.06	15.50	17.25	6.21	5.00
	202	14.40	15.55	9.40	5.65	21.35	13.35	5.14	3.91
Average		**11.86**	**11.96**	**9.65**	**5.69**	**14.63**	**10.08**	**5.04**	**3.40**
Statistics		p>F				p>F			
N rate		NS	0.0002	NS	NS	<0.0001	0.0001	0.0515	0.0262
N material		0.0144	<0.0001	NS	NS	<0.0001	<0.0001	NS	NS
*N rate*N material*		NS	0.0020	NS	NS	<0.0001	0.0003	NS	NS

General Conclusions

Our objectives for these studies were to compare the effects of a controlled release N fertilizer, ESN, urea, and aqua ammonia on corn grain and biomass yields, N uptake, and soil N concentrations. The field studies did not show a consistent advantage for using ESN as a fertilizer N source for corn production in Iowa. There were large differences in biomass and corn grain yields among the sites and years. Soil nitrogen and plant and grain N uptake were also variable over the duration of the studies. One trend that was observed in all studies and locations was the higher content of nitrate and ammonium-N in the ESN treatments that was usually present in the soil. These higher concentrations of residual N could be detrimental to the environment because nitrate-N can be easily lost through leaching.

The inconsistency in the results among years can be interpreted as being due to factors such as climatic conditions over growing seasons or soil conditions. Conditions for leaching and/or denitrification might have been present in some years or locations. Taking more soil samples throughout the season would have been a good idea in order to get a better idea of how quickly ESN releases N over a wide range of climatic and soil conditions.

It should be noted that we did not observe a negative yield response to ESN over the length of these studies. We conclude that ESN may increase yields and prevent N loss in certain situations such as sandy soils and areas of increased rainfall. The cost of ESN will more than likely be the biggest factor that determines how it is used by crop producers. If increased yields can pay for the extra cost of the fertilizer, the use of ESN could become a viable option for corn production in Iowa. If producers should decide to use ESN as an N fertilizer for corn production in Iowa, they should exercise caution since there is risk involved with recovering the added costs of the fertilizer.

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