ABSTRACT

RAJKOVICH, SHELBY RENAE. Corn and Wheat Yields as a Function of Nitrogen Rates and Fertilizer Types or Additives in Three Physiographic Regions of North Carolina. (Under the direction of Deanna Lynn Osmond).

As awareness of the environmental and economic cost of excess nitrogen (N) applications in agriculture increases, the determination of optimum N fertilization rates is critical to preventing over-application and losses of N. Field N rate response trials were designed to: 1) determine optimum N rates for maize (*Zea mays*) and winter wheat (*Triticum aestivum* L.) in three different regions of North Carolina (coastal plain, piedmont, and mountains); and 2) determine the value of alternative fertilizer additives in reducing N losses. The experiments were randomized complete block design with four replications of six N rates for maize and five N rates for wheat. Each rate (except the control) received four different treatments: urea-ammonium-nitrate (UAN) or UAN treated with one of three additives: AgrotainPlus®, Instinct®, or NZone®. Spring N treatments for wheat, applied prior to formation of the first joint, mirrored the maize trial design. For maize, the agronomic optimum N rates (AONR) for all site years as determined by a linear-plateau statistical model closely aligned with current recommendations in the North Carolina Realistic Yield Expectation (RYE) database, with the exception of the mountain location in 2014. There was no significant effect of treatment on grain or stover yield at the coastal plain and mountain locations. A year x treatment interaction was observed for grain yield in the piedmont, but was likely emphasized by a dry year in 2015. The AONR for wheat in the piedmont also matched RYE database recommendations, in contrast to the coastal plain where wheat grain yield continued to increase as N rate increased in both years, exceeding RYE recommended N rates. Treatment was not significant for wheat grain or straw yield at either location. In a parallel trial, Environmentally Smart Nitrogen® (ESN) was evaluated on wheat in the coastal plain and piedmont. All plots received 118 kg N ha^{-1} as one of six treatments in the winter and/or spring as blends of ESN and ammonium sulfate or split/spring applications of UAN and ammonium sulfate (controls). Treatment was not significant for grain or straw yield in three of four site years. In 2013-14, ESN treatments returned significantly higher yields in the coastal plain when applied in spring than winter, but significantly lower yields than the spring applied controls. The dependence of ESN's effectiveness on soil moisture and temperature may have created difficulties in timing applications to crop needs. Results indicate that alternative fertilizer sources and additives do not appear to provide environmental or agronomic benefits compared to UAN alone. Appropriate N application rates may be a more efficient nutrient management strategy, but new decision making tools must be properly vetted. One such tool, Adapt-N, was recently expanded to include North Carolina. The model is designed to recommend N application rates in maize at or after V6, but has not yet been validated against field conditions in the Southeast. Thus, AONR data from the abovementioned N rate trials were compared to Adapt-N and RYE database recommendations. RYE and Adapt-N rates were within 11 kg ha^{-1} of each other for all but one site year; on floodplain soils at the mountain location Adapt-N exceeded the AONR by more than 224 kg ha^{-1}. In grower strip trials in the lower coastal plain, the Adapt-N rate was compared to the grower N rate and +/- 25% of that rate in 18 site years. Treatment significantly affected yield in only 7 site years. Yield was significantly greater when N was applied at the grower N rate compared to the Adapt-N rate in 4 of those site years.

Corn and Wheat Yields as a Function of Nitrogen Rates and Fertilizer Types or Additives in Three Physiographic Regions of North Carolina

by
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DEDICATION

This work is dedicated to my grandfather Nick Rajkovich, who valued family, hard work, and education above all else, and who truly understood the soil.

BIOGRAPHY

Shelby Renae Rajkovich became the “newest little cherry picker in the biz” on May 6, 1988. She was soon joined by siblings Madeline, Samantha, Peter, and Mary Kate. She graduated from Linden High School in 2006 and set off to Cornell University, where she earned her degree in International Agriculture and Rural Development in 2010. Following graduation, she served as a sustainable agriculture volunteer in Niger and Senegal with the Peace Corps, working and living with smallholder farmers. She then dove into the policy world with a position in Washington, D.C. at United Fresh, a fresh fruit and vegetable trade association. But field work was calling, so she packed up for a graduate program at North Carolina State University. Along the way, she met her now husband Adam and adopted a goofy greyhound named Clark.

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CHAPTER 1: LITERATURE REVIEW

Variability in nitrogen (N) recommendations across states, regions, seasons, crops, and even fields complicates the selection of an appropriate N rate, and has led to concerns of the environmental impacts that may result from over-application. Nitrogen from agricultural sources can be lost through volatilization or denitrification, but nitrate (NO_3) leaching constitutes the largest percent of loss and can consequently contaminate ground and surface water (David et al., 1997; Jaynes et al., 2001; Randall and Goss, 2001). This contamination can potentially lead to negative health effects (Spalding and Exner, 1993) for the more than 50% of the United States population who depend on groundwater as a primary drinking water source, especially in infants where excessive NO_3 may cause low blood oxygen levels, a potentially fatal condition (Sogbedji et al., 2001a). Excess NO_3 can also cause eutrophication and hypoxia of lakes and coastal waters (Spalding and Exner, 1993; Randall and Goss, 2001), a consequence that can be devastating to ecosystem biodiversity (Kronvang et al., 2001).

Several studies have highlighted the potential to reduce NO_3 leaching by simply decreasing the amount of fertilizer N applied. In New York, Sogbedji et al. (2000) also observed a decrease in NO_3 leaching with lower N rates. The authors concluded that a pre-sidedress NO_3 test (PSNT) recommended N rate of 101 kg N ha^{-1} (90 lb ac^{-1}) minimized NO_3 leaching losses compared to a higher N rate of 134 kg N ha^{-1} (120 lb ac^{-1}) and did not affect yield. According to Hong et al. (2006), site-specific N management of wheat on a sandy clay loam in North Carolina's coastal plain reduced fertilizer application by 40 kg N ha^{-1} and decreased NO_3-N in the groundwater by 2.3 mg L^{-1} compared to a uniform N rate, all with a 25% increase in harvest N ratio.

Though N rate plays a significant role, temporal water flow fluctuations are also key indicators of NO_3 leaching potential. In the same N rate trials as mentioned above, Hong et al. (2007) report NO_3 groundwater levels were strongly correlated with the depth of the water table, and with wet spring seasons exhibiting levels above the United States Environmental Protection Agency (USEPA) drinking water maximum contaminant level goal (MCLG) of 10 mg NO_3–N L^{-1} (USEPA, 2002). Field-wide mean groundwater NO_3–N concentrations varied from 6 to 15 mg L^{-1} with applied N rates from 0 to 218 kg N ha^{-1} (Hong et al., 2006). In the Midwest, where tile drainage is common, David et al (1997) found NO_3 concentrations in tiles under continuous corn and the nearby Embarras River corresponded directly with tile flow. Total nitrate export varied from 20.2 kg N ha^{-1} in a dry year to 48.3 kg N ha^{-1} in a wetter year. These points demonstrate the connections between N fertilizer applications, which often occur when precipitation amounts and water tables are high, and increased NO_3 in the groundwater.

Lower N rate applications can minimize leaching losses and protect water quality while maintaining crop yields, but identifying that appropriate N rate can be a challenge. Historically, N rate trials have been used to inform nutrient management decisions. The trials generally compare crop yield across intervals of N fertilizer rates by fitting a yield response curve. The question of which curve, or model, is most appropriate to describe the response depends on both the research objective and the preference of the researcher; and has been widely debated as the analysis of field trial N rate data can be highly affected by the model chosen.

Cerrato and Blackmer (1990) demonstrated that corn yield and N rate data sets run with different N models produced equally reliable results (similar R^2 values), yet produced highly varied economic optimum N rates. The quadratic-plateau (QP) model was determined to best describe yield responses, but was also sensitive to grain and fertilizer price assumptions. The linear-plateau (LP) model has historically been used in North Carolina (Anderson and Nelson, 1987; Crozier et al., 2014; Rajkovich et al., 2015) and differs in that it does not incorporate price assumptions, which depending on the scale of the analysis, can vary widely across time and operations and make direct comparisons difficult. The LP also generally represents the most conservative test, reaching the greatest yield for the least amount of N (Cerrato and Blackmer, 1990). Some trials run multiple yield curves, as was the case with Schmidt et al. (2002), and move forward with the model that has the lowest residual sum of squares as an indicator of best fit.

However, Bullock and Bullock (1994) take issue with the QP and LP models that Cerrato and Blackmer (1990) promote. The authors claim that Cerrato and Blackmer "ignore the theoretical complexities presented by producer attitudes towards risk," and that the optimum N rate from the model does not actually maximize profit over a single or multiple years. They instead propose an equation that considers stochastic factors, price of N, output price, and how corn yield responds to N applications.

Regardless of which model is chosen, analysts focus in on the critical point where inputs are optimized. These points are referred to as the agronomic optimum N rate (AONR), which is the N rate at which any additional N does not return an increase in yield, or the economic optimum N rate (EONR), determined as the point where the last increment of N returns a grain yield increase large enough to pay for additional N (Sawyer et al., 2006). The EONR is found by considering the ratio of the price of N to the price of corn along a yield curve generated with a quadratic equation (Kwaw-Mensah and Al-Kaisi, 2006). Though prices can fluctuate, most studies use a value near 0.10, within the general range of 0.05-0.20 (Kwaw-Mensah and Al-Kaisi, 2006; Sawyer et al., 2006). The EONR is generally lower than what might be recommended by a model that does not include an economic component because as the yield reaches a plateau, the cost of applying extra N is not as easily offset, unless the price of corn is high relative to the price of fertilizer. Aside from price fluctuation, Mamo et al. (2003) highlighted the EONR can also vary spatially and temporally as a result of soil characteristics and environmental factors. By identifying areas within the field that were not responsive to N applications, the authors found that variable N rate applications based on the EONR for corn was 46 and 52 percent lower than the recommendation made by the University of Minnesota, and earned \$8 and \$23 ha^{-1} higher profit than the state recommended N rate in 1997 and 1999, respectively. A collection of 72 wheat and barley N response trials in the United Kingdom on sandy soils identified common rotations and growing conditions in which the EONR was approximately 40 kg N ha^{-1} less than what had been previously recommended, yet still produced yields comparable to the AONR (Webb et al., 1998).

However, the maximum return to N (MRTN), the N rate where the economic net return to N application is greatest, has gained traction in the Corn Belt region as an alternative model to making N rate recommendations. Sawyer et al. (2006) propose it as a “bridge between research and practical N rate guidelines” because it provides a range of N rates where profit can be maximized and producers can hedge their risk at the same time. Iowa State maintains an online Corn Nitrogen Rate Calculator based on data collected and analyzed for MRTN from 698 trials from 1983 to 2004 spanning Illinois, Iowa, Minnesota and Wisconsin; and has perhaps become so popular because it attempts to address the concerns voiced by Bullock and Bullock.

Of course, these models are only as relevant as the data collected. Nitrogen rate trials have proven their local importance in making N recommendations by highlighting the spatial and temporal variability in optimum N rates. In Midwest corn response trials by Schmidt et al. (2002), maximum grain yield was reached with rates as low as 52 and as high as 182 kg N ha^{-1} within the same field. The authors note a litany of factors that can contribute to this variability, including soil type, soil water holding capacity and leaching potential, soil chemical and physical properties, landscape position, crop history, and more.

In regards to winter wheat, Farrer et al. (2006) reported that producers in the southeastern United States were known to have applied spring N at rates ranging from 45 to 202 kg N ha^{-1}, depending on economic and environmental factors, and that wide range created an undesired variability in grain protein content. Total N rate recommendations for the region usually fall near 134 kg N ha^{-1}, which is often split between planting and growth stage (GS) 25 or 30 (Scharf and Alley, 1993; Scharf et al., 1993; Weisz et al., 2001). Response trials indicated that limiting N application rates to between 101-134 kg N ha^{-1}, and applying spring N at GS 25, would not only decrease protein variability, but also optimize yield and economic return (Farrer et al., 2006).

In North Carolina, the Realistic Yield Expectations (RYE) database provides N rates for 32 different crops by soil series across the three physiographic regions (North Carolina Nutrient Management Workgroup, 2003). Including all factors that can affect crop yield in a single model can be daunting and complex, which is why North Carolina's recommendations are mostly based on data from N rate trials across the state. The result of an extensive data gathering and review process of N rate trials, the RYE database recommends the AONR as predicted by the LP model, which the North Carolina Nutrient Management Workgroup identified as most advantageous for regional farmers. Part of this decision was driven by the unique challenge to farmers in the southeastern United States; soil N tests fail to reflect the amount of soil N available. The dynamic N cycle is complicated further by the climate, with warm temperatures and rainfall that exceeds evapotranspiration, mineralization, immobilization, denitrification, and leaching all occur at a rapid pace (Williams et al., 2007). Instead of relying on these tests, farmers can consult the database to inform their N rate decisions. The RYE database was most recently updated in 2014 to adjust corn yield goals and their associated N rate recommendations in North Carolina (Rajkovich et al., 2015). The review justified an increase in realistic yield expectations upwards by 20% but found that due to hybrid improvements, the increase could be sustained without increasing current N rates. Certified nutrient management plans in North Carolina must meet USDA-NRCS 590 standard and the standard requires N rates to be determined from the NC RYE database.

Outside of the Southeast, various N tests are more reliable in predicting soil N availability. The pre-sidedress nitrogen test (PSNT, Magdoff et al., 1984), for example, analyzes a soil sample taken just prior to corn growth stage V5 at a 30 cm depth for plant available NO_3-N. The PSNT is commonly used in the Midwest and Northeast to determine NO_3 sufficiency, where an NO_3-N level of 25 mg kg^{-1} or less is considered a strong indicator that the crop will respond to a sidedress application (Miller and Sonon, 2014). Kitchen and Goulding (2001) reported PSNT use on between 60-70 percent of corn acres in Nebraska, though it has been noted results can be delayed, the test can be expensive, and is only able to predict generally what rate of N should be applied. Willams et al. (2007) found the Illinois soil nitrogen test and the gas pressure test to be more well suited to the southeastern region than the PSNT, and able to more specifically predict the amount of N needed to reach an economic optimum N rate for corn.

Other N tests rely on biomass indicators, such as the corn stalk NO_3 test (Binford et al., 1990), which can be administered at the end of the season to indicate the N status of the crop during its growth cycle. The N status can only be classified as deficient, adequate, or excessive but cannot be used to make precise N rate recommendations (Binford et al., 1990; Brouder et al., 2000). The test falls into what Schröder (2000) refers to as the "learning by doing" indicator class, since it is too late to make N adjustments and lessons must be applied to the subsequent crop. Unfortunately, this can mean that any significant loss of N to leaching has already occurred, and by next season, environmental factors may require a very different nutrient management strategy than what the previous corn stalk NO_3 test would have recommended.

Recent attention has been given to instruments that utilize the Normalized Difference Vegetation Index (NDVI) to determine crop yield potential in corn and wheat, such as the GreenSeeker® crop sensing system (Trimble, Sunnyvale, CA). The device measures crop reflectance in both the red (650±10 nm) and near infrared (770±15 nm) bandwidths and calculates the NDVI as = (near infrared – red) / (near infrared + red) (Chung et al., 2010; Rambo et al., 2010). The reflectance is considered to be an indicator of chlorophyll content, with healthy leaves absorbing more red light. When mounted on a boom, the GreenSeeker system can read these measurements and adjust fertilizer rates accordingly as the sprayer equipment travels across the field, resulting in a more efficient use of fertilizer and variable rates as needed. Handheld versions can also be used to survey a field and inform decisions. In winter wheat, Chung et al. (2010) found that the GreenSeeker tool and resulting NDVI was useful in estimating crop N responsiveness at various growth stages and could be used to optimize in-season fertilizer N rate recommendations that could increase apparent nitrogen use efficiency (NUE) and yield, as well as reduce the risk of over application. When tested in corn, Rambo et al (2010) suggested some improvements to increase efficiency, notably by optimizing an algorithm to account for bare soil reflectance and insensitivity of red reflectance at saturation leaf-area indices.

However, the reality is that many farmers refer to more easily accessible sources of information when making N application decisions. A 2011 regional survey of corn farmers in southwest Michigan revealed fertilizer dealers and seed company agronomists as top sources of information, while 77% of respondents said they had never used university recommendations when making N fertilizer decisions (Stuart et al., 2014). This placement of trust in the private sector has also been observed in North Carolina, where farmers in the Neuse River Basin and Jordan Lake watershed voiced concern that university N recommendations were not correct. They were more likely to rely on their own experience and knowledge or consult a local fertilizer dealer (Osmond et al., 2014).

Regardless of where the information comes from, most private and public advisors have promoted the “4Rs” for many years (Natural Resources Conservation Service, 2005; The Fertilizer Institute, 2011; International Plant Nutrition Institute, 2012). The nutrient stewardship platform aims to help farmers think about their N applications in a logical, interconnected way by stressing the 4Rs: right source, right rate, right placement, and right time. This focus creates an effective framework to evaluate N management plans and fertilizer products that are marketed as tools to enhance the producer's ability to meet the 4Rs.

Numerous products have been developed to reduce the amount of N lost to volatilization, leaching, or denitrification; essentially to bolster the "right source" aspect of an N management plan. These are often referred to by the umbrella term "enhanced efficiency fertilizers" (EEFs; Trenkel, 2010). Slow- or controlled-release fertilizers are forms in which the N availability (or other plant nutrient of interest) is delayed by "controlled water solubility of the material by semi-permeable coatings, occlusion, protein materials, or other chemical forms, by slow hydrolysis of water-soluble low molecular weight compounds, or by other unknown means" (Trenkel, 2010). This is in contrast to a stabilized N fertilizer, which results from the addition of a substance that inhibits specific enzyme activity, thus extending the life of the urea- or ammonia-N form in the soil. These substances are most commonly nitrification or urease enzyme inhibitors. Nitrification inhibitors act to prevent the biological oxidation of ammonia to NO_3, while urease inhibitors block hydrolytic action on urea by the enzyme urease. These reactions will be explored in depth in the context of the products used in this research: Environmentally Smart Nitrogen®, Instinct®, AgrotainPlus®, and NZone®. For purposes of the present discussion, Environmentally Smart Nitrogen will be referred to as a controlled-release fertilizer product. Urea ammonium NO_3 (UAN) treated with AgrotainPlus, Instinct, or NZone will be referred to as a stabilized N fertilizer. As a whole, these products aim to decrease N-loss through various modes of action and thus will be referenced as N-loss prevention products rather than EEFs, a descriptor which seems to suggest that all of these products actually achieve what they claim.

ESN (Agrium Inc., Calgary, Alberta, Canada) is a 44% urea granule coated with a proprietary insoluble polymer time release coating. According to the manufacturer, the membrane allows water to diffuse in to create a solution that will slowly release N at a predictable rate, which is controlled by soil temperature and moisture, and may occur over a period of several months (Agrium Advanced Technologies, 2012). The product aims to align N availability with crop N needs. However, when the relatively new product was evaluated in North Carolina, Cahill et al. (2010b) observed no significant improvement in grain yield compared to standard fertilizer treatments in five of six site years. In other trials across the Southeast, surface applied ESN produced similar or worse yields when compared to UAN or urea in corn and grain sorghum (Mitchell and Osmond, 2012). A trial in Pennsylvania confirmed this trend, where ESN did not significantly affect corn grain yield (Dell et al., 2014).

Results from wheat trials have produced similar results to maize. Cahill et al. (2010b) reported lower grain yields in ESN treated plots in one site year, while the other three site years showed no significance difference between ESN and UAN. In conventional and no-till wheat fields in Oklahoma, ESN did not provide a yield advantage compared to urea across four site years (Mitchell and Osmond, 2012). Field trials with wheat, barley, and canola conducted in Western Canada by Khakbazan et al. (2013) did find occasional yield benefit with ESN or ESN blended with urea, but an economic analysis revealed that the yield gain was not enough to offset the cost of the product. An incubation study at a constant moisture level did confirm that ESN released N at a slower rate than UAN, with a range of 7 to 42 days depending on soil type (Cahill et al., 2010a). However, the product's dependence on moisture can make timing an application difficult. Dell et al. (2014) found ESN did not significantly affect corn grain yield, and that rainfed conditions can result in inconsistent patterns of N cycling and plant uptake, and thus reduce the synchronization between N availability and crop demand.

Nitrapyrin ([2-chloro-6-(trichloromethyl) pyridine]) has been approved for agricultural use in the United States by the Environmental Protection Agency (EPA) since 1974 (R.E.D. Facts - Nitrapyrin, 2005). It is registered to Dow AgroSciences LLC and packaged as one of four products: N-Serve® nitrogen stabilizer, N-Serve 24, N-Serve TG, and Instinct. The MSDS for Instinct lists 17.67 percent nitrapyrin as the active ingredient. As the oldest of the products considered here, the literature regarding nitrapyrin is broad. Burzaco et al. (2014) presented a meta-analysis of maize research studies from 1988 to 2011 that included a range of N rates and use of nitrapyrin (n=112 treatment means), with a focus on grain yield, plant N uptake (PNU), and NUE. The analysis found the overall mean grain yield response to nitrapyrin compared to untreated N fertilizer treatments was 116 kg ha^{-1} (2 bu ac^{-1}) (p=0.09), with 56 percent of cases showing a response greater than zero (Burzaco, et al., 2014). However, grain yield and PNU responses were small and no overall increases in NUE could be identified. In contrast, an accompanying field trial in Indiana found nitrapyrin did not significantly affect grain yield across three site years (Burzaco et al., 2014).

High temperature has been noted as a limitation on the effectiveness of nitrapyrin. An incubation of sandy clay loam soil treated with ammonium sulfate ($(NH_4)_2SO_4$) and nitrapyrin at the recommended application rate (1.11 kg ha^{-1}) kept at 35^oC (95^oF) reached a complete nitrification of NH_4^+ in two weeks (Ali et al., 2008). When the nitrapyrin application rate was increased eight-fold, only 50% of the ammonia was nitrified after four weeks. The authors question the feasibility of an increase in nitrapyrin application rates in order to see an inhibitor benefit, but did not explore in depth the reasons why the product may lose efficacy at high temperatures. These soil temperatures are approximately 6^{o}C (10^{o}F) higher than the maximum daily average observed during recent corn growing seasons in North Carolina, but indicate that temperature can greatly influence the product's performance. The manufacturer acknowledges, "Some components of this product can decompose at elevated temperatures," on the MSDS label, but does not specify further (DowAgroSciences LLC, 2013). On the field scale, Rao et al. (1996) agree that higher mean maximum monthly temperatures may contribute to the decreased effectiveness of surface applied nitrapyrin based on winter wheat trials in Oklahoma. However, soil temperature increase is often accompanied by conditions that are not favorable to N loss through leaching and denitrification, which may supersede the effects of nitrapyrin.

Another product considered in the research is AgrotainPlus (Koch Agronomic Services LLC, Wichita, KS, USA) which contains the urease inhibitor N-(n-butyl)-thiophosphoric triamide (NBPT)(3-7% active ingredient) and the nitrification inhibitor dicyandiamide (DCD) (60-100% active ingredient). According to the manufacturer, the product should be used with UAN at the rate of 15 lb per ton of solution, with NBPT cutting down on ammonia volatilization and DCD reducing N loss via denitrification. It should be noted that many recent research studies have considered Agrotain, which is the predecessor of AgrotainPlus and differs only in it does not include the DCD component.

Field trials by Sistani et al. (2014) found no significant effect of AgrotainPlus on corn grain yield, stover yield or whole plant nutrient uptake, but also cautions that management factors could have played a role as the trials were conducted under no-till conditions and N was applied at a single rate in a single application. In winter wheat, Espindula et al. (2013) found urea and NBPT improved NUE and grain yield compared to urea alone.

A greenhouse study by Goos (2013) measured ammonia loss of UAN and UAN treated with Agrotain based on droplet size and amount of straw cover. With no straw cover, the Agrotain treatment reduced ammonia loss compared to UAN alone by 37 and 66 percent applied as large and small droplets, respectively. With straw cover, loss was reduced by 56 and 51 percent, indicating that residues can affect the nitrification process and that the influence of tillage on the performance of N-loss prevention products should not be ignored.

Residue on the soil surface as the result of conservation or no-till management can have important implications for N cycling, and thus the products that aim to disrupt that cycle. When the residue is not incorporated into the soil, Halvorson et al. (2006) points out that the decomposition rate and subsequent release of N from the material is delayed, which may create the need for a higher N rate to reach corn yields comparable to conventionally tilled fields. This delay is influenced by the C:N ratio of the material, with higher ratios leading to N immobilization. Residue cover also decreases soil temperature and increases soil moisture, which Rao et al. (1996) observed was a more ideal condition for fertilizers treated with nitrification inhibitors than surface applied N with less residue.

NZone® is marketed as an N management aid by AgExplore International (Parma, MO). It is a deep-blue colored solution that is added to UAN at the rate of 2 quarts per ton of UAN. The product is not registered with the EPA, but has been classified into the adjuvant chemical family (AgExplore International, 2011) and there are currently no peer-reviewed journal articles available on the product. According to the manufacturer, alkylaryl polyoxyethylene glycols, calcium aminoethylpiperazine and calcium heteropolysaccharides are the active ingredients (33%) that “cause a short term pH increase that causes H^+ to be released from the exchange complex, allowing newly formed ammonium ion to attach.” Marketing materials claim that the higher pH results in higher cation exchange capacity (CEC), which in turn results in increased ammonium absorption. While pH and CEC are often positively correlated, this oversimplified explanation fails to take into account other soil properties which may determine CEC, including clay minerals, organic matter, and amorphous minerals (Sparks, 2002).

CHAPTER 2: NITROGEN RATE AND PRODUCT TRIALS

INTRODUCTION

Variability in nitrogen (N) recommendations across states, regions, seasons, crops, and even fields complicates the selection of an appropriate N rate, and has led to concerns of the environmental impacts that may result from over-application. Nitrogen from agricultural sources can be lost through volatilization or denitrification, but nitrate (NO_3) leaching constitutes the largest percent of loss and can consequently contaminate ground and surface water (David et al., 1997; Jaynes et al., 2001; Randall and Goss, 2001). Aside from the well documented negative health effects of nitrate in the groundwater (Spalding and Exner, 1993; Sogbedji et al., 2001a), excess NO_3 can also cause eutrophication and hypoxia of lakes and coastal waters (Spalding and Exner, 1993; Randall and Goss, 2001), a consequence that can be devastating to ecosystem biodiversity (Kronvang et al., 2001).

Lower N rate applications can minimize leaching losses and protect water quality while maintaining crop yields, but identifying that appropriate N rate can be a challenge. In North Carolina, the Realistic Yield Expectations (RYE) database provides recommended N rates for 32 different crops by soil series across three physiographic regions (North Carolina Nutrient Management Workgroup, 2003). The database is verified through N rate trials across the state, with maize N recommendations updated in 2015 to keep pace with new hybrid developments and management practices (Rajkovich et al., 2015). Nationally, the "4Rs" have been promoted by private and public organizations for many years (Natural Resources Conservation Service, 2005; The Fertilizer Institute, 2011; International Plant Nutrition Institute, 2012) as a platform for farmers to think about their N applications in a logical, interconnected way by stressing: right source, right rate, right placement, and right time (4Rs).

Beyond N rate recommendation tools, farmers also have access to fertilizer products designed to reduce the amount of N lost; essentially to bolster the “right source” aspect of an N management plan. These N-loss prevention products, which can be added to urea ammonium nitrate (UAN) solution, have various modes of action and reported levels of effectiveness in the literature. AgrotainPlus® (Koch Agronomic Services LLC, Wichita, KS, USA) contains the urease inhibitor N-(n-butyl)-thiophosphoric triamide (NBPT)(3-7% active ingredient) and the nitrification inhibitor dicyandiamide (DCD) (60-100% active ingredient). While Sistani et al. (2014) found no effect of the product on maize grain or stover yield or whole plant nutrient uptake in Kentucky, Espindula et al. (2013) did find a grain yield advantage in winter wheat grown in Brazil. Agrotain, the predecessor of AgrotainPlus that included only a urease inhibitor, had been broadly tested in the southeastern United States. A review of those trials found Agrotain did not improve yields in Alabama, New Mexico, Arizona, or Texas for maize, cotton, or wheat (Mitchell and Osmond, 2012). NZone® is marketed as a N management aid by AgExplore International (Parma, MO). The product’s active ingredients are calcium polymers that according to the manufacturer “cause a short term pH increase that causes H^+ to be released from the exchange complex, allowing newly formed ammonium ions to attach” (AgExplore International, 2015). No peer reviewed journal articles on the product were available at time of writing. Finally, Instinct® is a nitrapyrin-based product ([2-chloro-6-(trichloromethyl) pyridine]) that has been registered for use in the United States by the EPA since 1974. A meta-analysis of maize trials from 1988 to 2011 that included nitrapyrin (n=112 treatment means) by Burzaco et al. (2014)

reported overall mean grain yield response to nitrapyrin treatments compared to untreated N fertilizer treatments was 116 kg ha^{-1} (2 bu ac^{-1}) (p=0.09). In contrast, in an accompanying field trial in Indiana, nitrapyrin did not significantly affect yield across three site years (Burzaco et al., 2014).

Given the reported variability in the effectiveness of these N-loss prevention products to improve yields across cropping systems and locations, AgrotainPlus, NZone, and Instinct were applied with UAN in maize and wheat N-rate trials across three different regions of North Carolina to 1) evaluate the value of these alternative fertilizer additives in reducing N losses compared to standard fertilizer applications alone; and 2) analyze yield data at a range of N rates for verification and further refinement of the North Carolina RYE database.

MATERIALS AND METHODS

Maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) N rate and product trials were conducted from 2013-2015 at research stations in three different physiographic locations in North Carolina: coastal plain, piedmont and mountains. Soil series utilized for maize crops included: Lynchburg fine loamy sand (Fine-loamy, siliceous, semiactive, thermic Aeric Paleaquult) or Portsmouth sandy loam (Fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquult) in the coastal plain; Lloyd clay loam (Fine, kaolinitic, thermic Rhodic Kanhapludult) at the piedmont location; and Comus silt loam (Coarse-loamy, mixed, active, mesic Fluventic Dystrudept) or Codorus silt loam (Fine-loamy, mixed, active, mesic Fluvaquentic Dystrudept) in the mountains (Table A1). Wheat was planted into Johns sandy loam (Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludult) or Portsmouth sandy loam in the coastal plain, and Lloyd clay loam in the piedmont (Table A2).

The experiments were randomized complete block design with four replications of four N sources at six N rates for maize and five N rates for wheat. Total nitrogen rates for maize were 0 (control), 45, 90, 134, 179, and 224 kg N ha^{-1} (0, 40, 80, 120, 160, and 200 lb N ac^{-1}), with 45 kg N ha^{-1} (40 lb N ac^{-1}) applied at plant and the remainder applied as a side dress application at growth stage V5-6. Each rate, except 0, received one of four different N sources at each application; urea-ammonium-nitrate [UAN $(NH_2)_2CO$, NH_4NO_3)], or UAN treated with one of three additives: AgrotainPlus®, Instinct®, or NZone®. In North Carolina and much of the southeast, UAN applied alone is the most commonly used N fertilizer, and serves as a reference point as well as the manufacturers' recommended method of applying the additives. The N rates included in the trial do not reflect potential N credit from previous soybean crops, which is accepted as 25 kg ha^{-1} (22 lb N ac^{-1}) in North Carolina (Rajkovich et al., 2015). Soil N measurements were not taken prior to planting, so the conservative assumption that no N remained from the previous crop was made. The N application rate at-plant for wheat was 34 kg N ha^{-1} (30 lb N ac^{-1}) and 0, 45, 90, 134, 179 kg N ha^{-1} (0, 40, 80, 120, and 160 lb N ac^{-1}) as spring applied N prior to formation of the first joint (Feekes stage 4-5 or Zadoks stage 30; Weisz et al., 2001). At-plant N was applied as UAN and spring N was applied as UAN or UAN treated with one of three additives: AgrotainPlus®, Instinct®, or NZone®, mirroring the maize trial design. All UAN and fertilizer products were applied with custom built backpack sprayer and boom (R&D Sprayers, Opelousas, LA), which was calibrated before each application and triple-rinsed with soapy water between each treatment.

Maize

In 2014 and 2015, maize (Pioneer 1690YHR hybrid) was planted April 14 and April 11 in the coastal plain, April 24 and April 13 at piedmont, and May 12 and May 5 in the mountains in plots approximately 3 x 10 m (Table A3). Mean plant population was calculated by extrapolating the population in the inner two rows at harvest to a hectare basis: 74,237 ha^{-1} on 91 cm rows in 2014 and 58,885 ha^{-1} on 76 cm rows in 2015 at the coastal plain location; 81,547 ha^{-1} in 2014 and 61,032 ha^{-1} in 2015 on 76 cm rows at the piedmont location; and 79,305 ha^{-1} in 2014 and 65,324 ha^{-1} in 2015 on 76 cm rows in the mountain fields (Table A3).

Coastal plain and piedmont fields were conservation till following soybeans, while the mountain fields were disked to depth of 30 cm approximately one week prior to planting and followed a winter wheat cover crop. In 2014, the coastal plain field received no lime, whereas in 2015, the field received 1,344 kg ha^{-1} lime and 112 kg ha^{-1} 0-0-60 based on soil test results. In both years, paraquat (1,1'-Dimethyl-4,4'-bipyridinium dichloride) and atrazine (1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) herbicides were applied just prior to planting, and Halex GT herbicides (S-metolachlor, glyphosate, and mesotrione) was applied 40 days post-plant. At the piedmont location, fields received 504 kg ha^{-1} 0-25-25 per soil test recommendations, and herbicides glyphosate (N-phosphonomethyl glycine), and atrazine both years. Lime was applied at the rate of 2,240 kg ha^{-1} in 2015. Due to extremely dry conditions in 2015 at the piedmont location, 25.4 mm of irrigation was applied June 19 (68 DAP) and June 30 (79 DAP) for a total of 50.8 mm. In the mountains, the fields received 347 kg ha^{-1} (310 lb ac^{-1}) 0-26-26 per soil test recommendations and were treated with Trizmet II (atrazine and metolachlor) and paraquat prior to planting both years.

Ears from the same three meter length used to determine population were harvested by hand, weighed, and measured for moisture. Grain yield was normalized to a standard moisture content of 15.5%. A subsample of six ears was dried, shelled, and ground for nutrient analysis. Stover yield was determined from six randomly selected plants harvested from each plot, weighed, chopped and subsampled. The subsample was dried to indicate moisture content and ground to measure nutrient content. Grain and stover N concentration was used to calculate grain N, stover N, and total N content. Apparent nitrogen use efficiency (NUE) was then determined from total N content at each N rate. NUE was defined as total N content in control treatment (0 kg N ha^{-1}) subtracted from total plant N content in fertilized treatment divided by fertilized treatment rate.

Wheat

Prior to planting wheat in the coastal plain (2014), 336 kg ha^{-1} 10-0-20 with 12% S and 5% Mn was broadcast based on soil test recommendations (Table A2). Broadleaf weed and grass control consisted of Osprey Herbicide (mesosulfuron-methyl) and Harmony Extra SG (thifensulfuron methyl and tribenuron methyl). In both years, the piedmont fields were treated with 336 kg ha^{-1} 10-20-20 broadcast per soil test recommendations, followed by Finesse (chlorsulfuron and metsulfuron-methyl) and glyphosate (N-phosphonomethyl glycine) herbicides post-plant.

Wheat trials in the coastal plain were conventionally tilled and seeded at the rate of 3.7 million seeds per hectare with plots measuring 1.2 by 9 m (Table A4). Conservation tillage was used for the wheat trials in the piedmont with the same seeding rate as in the coastal plain, but plot size was 1.5 by 9 m. In 2013, NC Yadkin variety was planted in the coastal plain and Southern States 8350 was planted in the piedmont. In 2014, DynaGro Shirley was planted at both locations (Table A4). The crops followed maize regardless of year or location.

A Wintersteiger Delta plot combine (Wintersteiger Inc., Salt Lake City, UT) was used to harvest wheat. Moisture content and yield data, as well as a subsample of wheat grain, were captured from the combine. Grain yield was normalized to a standard moisture content of 13%. The straw discarded from the combine was collected, weighed, and subsampled to determine straw yield. Subsamples of grain and straw were weighed, dried, re-weighed and ground for nutrient analysis, including N concentration. Grain and straw N concentration was used to calculate grain N, straw N, and total N content. Apparent NUE was determined from total N content at each N rate.

Climate

Precipitation in the coastal plain was well-distributed over the maize growing season in both 2014 and 2015. Total precipitation varied, however, with nearly 280 mm more precipitation than the five-year average in 2014 and 127 mm less in 2015 (Table A5). Average monthly soil and air temperatures were consistent with historical averages. Both years at the piedmont location received less precipitation than the five-year average, but 2015 was extremely dry, with rainfall totals 460 mm below average. In the weeks between planting and side dress, the field received only 66 mm of precipitation. The only month in 2015 to record above average rainfall was September by 2 mm. Lack of rainfall paired with slightly higher than average soil temperatures in June, July, and August was problematic for crop growth. In the mountains, precipitation was slightly less than average, but well-distributed. Cooler average soil and air temperatures relative to other trial locations were conducive to higher observed average soil moisture.

The coastal plain location had two wheat cropping seasons with higher precipitation than the five-year average (Table A6), though the patterns differed. The two months following planting in 21013-14 were wet, followed by two dry months and a wet spring. In contrast, the 2014-15 season was consistently wetter than the five-year average with less total variation. In both years, average soil temperature was fairly consistent with historical trends, though average air temperature in the winter did dip lower. In the piedmont, the 2013-14 season had 92 mm more precipitation than the five-year average, but the 2014-15 season was extremely dry with 301 mm less than the average (Table A6). The lack of precipitation was distributed throughout the cropping year, with November as the only month to record more rainfall than the average with a total of 102 mm.

Sample Analysis

Subsamples of maize and wheat grain were ground with a Retsch Mill Model ZM-100 (Verder Scientific Inc., Newtown, PA). Stover and straw were ground with a Thomas-Wiley Mill Model ED-5 (Arthur H. Thomas Co., Philadelphia, PA). Maize plant tissue samples were analyzed by the NC Department of Agriculture & Consumer Services lab (Raleigh, NC) with an elemental analyzer (NA1500; CE Elantech Instruments; Lakewood, NJ) and an inductively-coupled-plasma (ICP) spectrophotometer (Optima 3300 DV ICP emission spectrophotometer; Perkin Elmer Corporation; Waltham, MA). Wheat grain and straw samples were analyzed by the NC State University Environmental and Agricultural Testing Service (EATS) lab (Raleigh, NC) with an elemental analyzer (2400 CHN/S Elemental Analyzer; Perkin-Elmer Corporation; Waltham, MA).

Laboratory Incubations

The procedure for this aerobic incubation experiment to determine N mineralization rates was adapted from Cahill et al (2010a). A composite soil sample from each trial location was collected at depth of 0-20 cm from unfertilized plots. The soil was dried and passed through a 2 mm sieve. The upper and lower bounds of plant-available water for each soil were estimated by pressure plate (Dane and Hopmans, 2002) utilizing disturbed samples. Soil from each location (100 g dry weight) was mixed in triplicate with one of the four fertilizer treatments in 0.025-mm thick polyethylene bags (16.5 x 15 cm) (Gordon, 1988) until fertilizer N was evenly distributed throughout the soil. Treatments included a control which received no N fertilizer, as well as all fertilizer sources (UAN and UAN treated with AgrotainPlus®, Instinct®, or NZone®) added at a rate equivalent to the highest N application rate for maize (224 kg ha^{-1}). Distilled water was added to each sample to bring the moisture level to 80% of field capacity. Samples were then sealed and placed in an incubator at a relatively constant temperature of 23-26° C. Bags were aerated once weekly and weighed to determine moisture loss. Additional distilled water was added to bags with a weight decrease of 5% or more to maintain ~80% field capacity.

Soil samples were taken at days 0, 2, 7, 14, 28, 42, 56, and 84 from each treatment. At each sampling date, 25 mL of 1M potassium chloride (KCl) was added to a 10 g (dry weight) sample and placed on the shaker for 30 minutes. Extractant was filtered through #2 Whatman filter papers into vials and frozen until analyzed on a Lachat flow injection autoanalyzer (model Quick Chem 8000, Lachat Inc., Loveland, Col.; QuikChem methods 10-107-04-1-A and 10-107-06-2-A) by the NC State University EATS lab (Raleigh, NC) for NO_3-N and ammonium (NH_4-N) concentrations. In the few circumstances when the Lachat returned values that indicated the N concentration was below the detection limit of 0.10 mg L^{-1}, the concentration was assumed to be 0.10 mg L^{-1}. The concentration of NH_4-N and NO_3-N from each sample was corrected for extraction volume and expressed on a soil dry weight basis.

Nitrate-N and NH_4-N concentrations in the control soil were subtracted from the N fertilizer treated samples to account for mineralization of native organic N before determining net mineralization of N applied as fertilizer. If this correction resulted in a negative value, the concentration was set to zero. Total N recovery from the soil was calculated from the sum of 1M KCl extractable NO_3-N and NH_4-N expressed as a percentage of total N applied with each treatment.

Statistical Analysis

Harvest data was analyzed with PROC GLIMMIX in SAS version 9.3 (SAS Institute Inc., Cary, NC). Locations were separated for analysis given known variation in soil properties and climate and to test hypothesis that N-loss prevention products may perform differently in each site's respective conditions. An initial analysis of pooled data confirmed that yields between sites for wheat ($p<0.0001$) and maize ($p<0.0001$) were significantly different. All trials were considered randomized complete block designs with location, year, N rate, and treatment as fixed effects and replications within location-by-year combinations as random effects. Linear-plateau (LP) yield curves were generated with PROC GLM in SAS 9.3 to determine an agronomic optimum N rate (AONR) where an additional application of N fertilizer does not return a significant increase in yield. The LP model was not applied if yield LSMeans did not change over included N rates, or if LSMeans continually increased with no evidence of a plateau (i.e. yields at highest N rate were statistically higher than yields at the previous rate). Additionally, when the LP model was used, the 95% confidence intervals for the estimated parameters were reviewed to check the goodness of the model fit. The significance level applied to all data analysis was $p< 0.05$.

Due to a calculation error, the AgrotainPlus additive was applied at an incorrect rate in the 2013-14 wheat trials and the data from that treatment was deemed to be unusable. The treatment is excluded from that year's analysis, but AgrotainPlus treatment data is included in a separate analysis of the 2014-15 data.

Error bars for data points from the laboratory incubation are based on the standard deviation of replicates of each treatment at each sampling date. An error with the Latchat equipment resulted in indecipherable NH_4-N and % N recovery data from the day 7 sampling of Instinct and AgrotainPlus treated soil in the mountain series and was excluded.

RESULTS AND DISCUSSION

Maize

Treatment was not significant for maize grain yield (p=0.50) or stover yield (p=0.83) in the coastal plain location, stover yield (p=0.08) at the piedmont location, or grain yield (p=0.81) or stover yield (p=0.73) at the mountain location (Table 2.1). The effect of treatment was only significant in the interaction of year x treatment in grain yield (p=0.031) at the piedmont location and stover N content (p=0.006) at the coastal plain location. The interaction effect at the piedmont location was largely influenced by drought-induced low yields in 2015, where there was no significant difference among treatments (Figure 2.1). In 2014, Instinct and NZone had significantly higher yields than UAN, while AgrotainPlus was not significantly different from any of the other treatments. In 2014 at the piedmont, the separation of yield between UAN and the highest yielding treatment (NZone) was 1,216 kg ha^{-1} (Figure 2.2).At the coastal plain, all treatments accumulated significantly higher stover N in 2015 than 2014 (Figure 2.2), which agrees with higher observed stover yields in 2015

(Table A7). Interestingly, in 2014 UAN had the lowest stover N content compared to NZone that had the highest stover N content. This was reversed in 2015, when UAN had the highest stover N content and NZone had the lowest.

Grain yield was significantly affected by the year x N rate interaction at the coastal plain ($p=0.04$), piedmont ($p=0.003$), and mountain locations ($p<0.0001$, Table 2.1). At the coastal plain in 2014, grain yield increased with N rate up to 180 kg N ha^{-1} with a maximum yield of 13,457 kg ha^{-1} (Figure 2.3A). In 2015, grain yield increased with N rate up to the highest application rate of 224 kg N ha^{-1}, and maximum yields from both years were not statistically different. There was a marked decrease in 2015 yields at the piedmont location due to prolonged periods without precipitation (Figure 2.3B). The maximum yield in 2015 (6,104 kg ha^{-1}) was not significantly different from the previous year's yield in plots receiving 0 kg N ha^{-1}. In 2014, grain yield was nearly twice as high, plateauing at the 135 kg N ha^{-1} rate with a maximum yield of 11,004 kg ha^{-1}. Grain yields at the mountain site plateaued at 15,929 kg ha^{-1} at the 90 kg N ha^{-1} rate in 2014(Figure 2.3C). In 2015, the highest yields at 180 and 224 kg N ha^{-1} were not statistically different from each other, however the yield at 224 kg N ha^{-1} was numerically higher than those at the next lowest rate, suggesting that the optimal N rate may have been between these two treatments. In both years, yields were exceptional, likely in response to well-timed rainfall and a cooler climate in the mountains. Though both years reached similar maximum yields on silt loam soils, the trial's location on a low-lying floodplain soil in 2014 may have contributed to higher yields across all N rates than the following year.

Grain N content was significant by the main effects of year and N rate at the coastal plain ($p<0.0001$) and by a year x N rate interaction at the piedmont and mountain locations

($p<0.0001$, Table 2.1). Grain N content increased with N rate at each location, but was lower overall in 2015 at the piedmont and mountain location (Table 2.2). Stover N content was significant by the year x N rate interaction at the piedmont, and by the main effects of year and N rate at the coastal plain and mountain locations. Total N content, of which the grain makes up a larger proportion, predictably followed the same significance trends as grain N at each location (Table 2.2).

Apparent NUE was significant by year only at the coastal plain ($p=0.04$) and piedmont ($p<0.0001$). At both locations, average NUE was higher in 2014 than 2015. Average NUE was 67% and 61% at the coastal plain, and 59% and 28% at the piedmont in 2014 and 2015, respectively. At the mountain location, a year x N rate interaction was observed ($p<0.0001$, Table 2.1). NUE values are not significant between years at N rates of 135 kg ha^{-1} and higher, but vary at lower rates (Figure 2.4). In 2014, NUE values above 100% were likely caused by residual soil nitrate in the floodplain soil.

Grain yield data from each site year was analyzed with a LP model to identify the AONR. Nitrogen rate trials provide valuable data for N rate recommendation tools, such as the RYE database. The RYE recommended N rate aligned with observed AONR at the coastal plain location in 2014 (Figure 2.5), though the observed yields were 3,100 kg ha^{-1} greater than predicted RYE yields. In 2015, yield LSMeans at each N rate were different from the previous N rate, so the LP model was not fit. At the piedmont location, the RYE N rate was in excess compared to LP optimum N rate by 32 kg N ha^{-1} in 2014 (Figure 2.6). The RYE N rate was sufficient in 2015, though yields were extremely low due to drought, with the optimum yield reaching only 5,704 kg ha^{-1}. At the mountain location, the RYE recommended rate of 185 kg N ha^{-1} was well above the LP AONR of 66 kg N ha^{-1} in 2014

(Figure 2.7). This discrepancy reflects a decision made by the North Carolina Nutrient Management Group in setting RYE rates for the historically high-yielding floodplain soil to align with farmer behavior (Rajkovich et al., 2015). In 2015, the trials were conducted on an upland soil and the optimum N rate, as predicted by the LP, was only 13 kg N ha^{-1} greater than the RYE rate. With the exception of the mountain location in 2014, the difference between the AONR and RYE rate averaged 3 kg N ha^{-1}, indicating that current RYE recommendations align with field observations.

Wheat

Treatment was not significant for wheat grain (p=0.41) or straw yield (p=0.40) in the coastal plain or wheat grain (p=0.58) or straw yield (p=0.47) at the piedmont locations (Table 2.3).

A year x N rate interaction effect on grain yield was observed at the coastal plain (p=0.0023, Table 2.3). In both years, yields in the coastal plain continued to increase with N rate (i.e. did not plateau) with highest yields in 2013-14 (6,882 kg ha^{-1}) and in 2014-15 (8,070 kg ha^{-1}) achieved at the 180 kg N ha^{-1} spring application rate (Figure 2.8). The 2014-15 crop yielded higher overall, reaching the previous year's maximum yield at the 90 kg N ha^{-1} rate. The significant difference at each N rate between years was likely influenced by the variation in soil types between years. The Johns sandy loam under the trials in 2013-14 had very low organic matter (1.2%) compared to the Portsmouth sandy loam (12%) utilized the following year. Grain yield did not reach a plateau within the range of included N rates in either year, and although there was evidence of continued yield response at the 180 kg N ha^{-1} application rate, the average total N application rate for wheat falls near 134 kg N ha^{-1} in North Carolina (Scharf and Alley, 1993; Scharf et al., 1993; Weisz et al., 2001), with the risks of lodging increasing greatly at rates beyond that (Scharf and Alley, 1993; Alley et al., 1996; Weisz, 2013).

A year x N rate interaction effect was also observed for grain yield at the piedmont location (p=0.0402, Table 2.3). Yields between the years were only significantly different at the 90 kg N ha^{-1} rate (Figure 2.9). However, the data did meet the criteria for analysis with a LP model, which indicated optimum yield was reached at 6,775 kg ha^{-1} at an N rate of 113 kg N ha^{-1} in 2013-14 and at 6,654 kg ha^{-1} with 130 kg N ha^{-1} in 2014-15. The observed optimum N rates were 2 kg N ha^{-1} and 20 kg N ha^{-1} greater than RYE N rates in 2014 and 2015, respectively (Figure 2.10). The optimum yields at these rates were nearly twice what the RYE database predicted (3,283 kg ha^{-1}), indicating wheat yield values, as well as N factors (kg grain yield per kg N fertilizer), in the RYE database may need to be updated.

Straw yield at the coastal plain was significant by the main effects of year and N rate (p<0.0001, Table 2.3). Yields in both years increased as N rate increased (Table 2.4), though average yields were higher in 2014-15 (Table 2.5). In the piedmont, yield was significantly affected by the interaction of year and N rate (p=0.04, Table 2.3). Straw yield plateaued at 90 kg N ha^{-1} in both years, though the maximum 2014-15 yields were 3,345 kg ha^{-1}, approximately 1,119 kg ha^{-1} less than the previous year (Table 2.6).

Grain N content was significant by the year x N rate interaction at the coastal plain (p=0.003) and piedmont (p=0.04) locations (Table 2.3). Each site exhibited an increase in grain N with increasing N rate (Table 2.7). Straw N content also showed an effect of the interaction at the piedmont (p=0.001), but at the coastal plain only the main effects of year (p<0.0001) and N rate (p<0.0001) were significant. Total wheat N content at the coastal plain and piedmont locations were significant by the year x N rate interaction (p=0.02 and p=0.002, respectively) and generally correlated with grain and straw yields (Table 2.7).

Apparent NUE was significant by the year x N rate interaction at the coastal plain (p=0.008) and piedmont (p=0.002) locations. After an initial peak, a general decrease was observed as spring N rate increased at both locations in both years (Figure 2.11). However, at the piedmont location in 2013-14 year, NUE was much lower and increased from 24% at 45 kg N ha^{-1} to 47% at 90 kg N ha^{-1}, before tapering off to 31% at the highest spring N rate. Both locations display the range of NUE values that are typical to wheat (Thomason et al., 2002; Johnson and Raun, 2003).

A separate analysis of the effectiveness of AgrotainPlus compared to UAN, NZone, and Instinct included only the two environments in which it was applied: the coastal plain and piedmont locations in 2014-15. Treatment, as a main effect or as an interaction, did not have a significant effect on grain yield, straw yield, NUE, straw N, or total N at either location. Grain N was significant by treatment (p=0.0402) and N rate (p<0.0001) at the piedmont location (Table A9). The nitrogen content of AgrotainPlus treated plots was an average of 120 kg N ha^{-1} to the 113 kg N ha^{-1} yielded by UAN alone. It is difficult to determine if the numerically small differences are due to an actual difference in product effectiveness or random noise in the data set given the smaller sample size. Further testing of this product may be warranted.

Laboratory Incubation

At day 0, N recovery in different treatments ranged from 51 to 68% (Figure 2.12C, Figure 2.13C, Figure 2.14C). Ammonium-N concentrations generally increased from day 0 to day 3 as the urea in UAN was converted to NH_4, before steadily declining to day 84. Nitrate-N concentrations generally increased from day 3 as nitrification was occurring.

In the coastal plain and mountain soils, Instinct stabilized NH_4 significantly better than other treatments or UAN alone (Figure 2.12A, Figure 2.13A, Figure 2.14A). At day 84, Instinct coastal plain and mountain treated soils had 58 and 47 ppm NH_4-N remaining, respectively, while all other treatments had lower concentrations by day 28. At the coastal plain, AgrotainPlus showed an advantage over NZone and UAN at day 14, 28, and 42, while the latter were not significantly different. A similar trend was observed in the mountain soil, where AgrotainPlus stabilized NH_4-N significantly better than NZone and UAN on the same sampling dates, while UAN and NZone were only significantly different at day 14.

In a reflection of these trends, coastal plain and mountain soils treated with Instinct had the lowest NO_3-N concentrations over the sampling period (Figure 2.12B, Figure 2.13B, Figure 2.14B). In the coastal plain, UAN was not significantly different from AgrotainPlus or NZone treated soils, while in the mountain soil, AgrotainPlus appeared to delay the conversion of NH_4-N to NO_3-N on days 14 and 28 better than UAN or NZone. Though N gas emissions were not measured in this study, Instinct may have decreased the potential for N_20 production by maintaining a smaller pool of NO_3-N available for denitrification (Dell et al., 2014). Use of this product would also lower the potential for NO_3 leaching from sandy soils.

Overall, N recovery in the coastal plain and mountain soils increased from day 0 to day 3 and remained fairly constant. In both locations, recovery percentages exceeding 100 were recorded, but are most likely due to the additive effects of sampling error. Cahill et al. (2010b) suggest a priming effect as a possible source of additional N in the study bags, but since soil organic matter content was very low and N was not limiting, this is unlikely to have played a significant role (Jenkinson et al., 1985; Chen et al., 2014).

The piedmont location deviated from results obtained for the coastal plain and mountain locations (Figure 2.13). Ensuring thorough mixture of fertilizer treatments and maintaining constant moisture in the Lloyd clay loam soil was difficult and may have affected the results. Since the soil was sieved, structure was almost nonexistent and once water was added, pore space was likely limited. Soil NO_3-N concentrations initially decreased from the 33 to 42 ppm range on day 0 to less than 1 ppm by day 3, then slowly increased. This dramatic drop may have been due to denitrification, which tends to be more dominant in fine-textured soils at higher moisture content (Bollmann and Conrad, 1998; Zhu et al., 2013). Nitrate concentrations for UAN and NZone treated soils leveled off from day 28 to day 84, while Instinct and AgrotainPlus treatments remained lower and reached comparable levels at day 56 before peaking at the observed soil's maximum NO_3-N concentrations at day 84 (Figure 2.13B). At day 3, NH_4-N concentration spiked for NZone and UAN treatments, and then generally decreased with each sampling date. The NZone and AgrotainPlus treatments reached concentrations below 20 ppm by day 28. Soil treated with AgrotainPlus and Instinct maintained constant NH_4-N concentrations from day 3 to day 14, with AgrotainPlus at a significantly higher concentration than Instinct. The decrease beginning at day 28 continued to below 20 ppm by day 84. In contrast to the other two soils, N recovery in the piedmont soil generally reached a maximum between days 3 and 7 and then decreased over the sampling period. By day 84, only 22 to 46% of N was recovered. This likely reflects the initial loss of N as N gas through denitrification. If an average of 40 ppm of N was lost in the first three days, the remainder of the total applied would fall into the observed recovery range (Figure 2.13C).

The effect of treatment varied across the three soils. Instinct appeared to effectively inhibit the nitrification activity of Nitrosomonas bacteria in all three of the soils up to day 42. The effectiveness of Instinct in inhibiting nitrification was similar to that reported for nitrapyrin by Chen et al. (2010). The urease inhibitor component of AgrotainPlus did not significantly prevent the hydrolysis of urea, as indicated by NH_4-N release patterns that are nearly identical to the other treatments. The nitrification inhibitor component of the product showed an effect in two of the three soils. NZone consistently followed the same N release patterns as UAN, indicating very limited effectiveness. The product, which claims to open exchange sites for the binding of NH_4, should theoretically perform well in clay soils with higher CEC where more exchange sites are available. This was not observed in the piedmont soil, with a CEC of 7.9, where favorable conditions were most likely to exist, or in the coastal plain fine loamy sand or the mountain silt loam textured soils with CECs ranging from 6.3 to 7.4 (Table A1).

The potential evidence of delayed nitrification observed with Instinct and AgrotainPlus treatments in the incubation experiment did not correlate well with the results of the field trials of the same products. The benefits of constant temperature and moisture content in lab conditions do not exist in the field, where the products appeared to lose efficacy.

CONCLUSIONS

The application of AgrotainPlus, NZone, or Instinct with UAN compared to UAN alone in maize and wheat did not appear to consistently provide a yield advantage. At the piedmont location, the interaction of year x treatment significantly affected maize grain yield, but there was no clear delineation between the products or evidence of an effect in any other site years. Maize stover N at the coastal plain was also positively affected by a year x treatment factor, but was likely influenced by increased stover yield in 2015 rather than a clear difference in treatment.

Under constant temperature and moisture conditions in a laboratory incubation, there was slightly more evidence of effectiveness, particularly with Instinct, that may validate field observations. Instinct, which has the most extensive history of inclusion in research trials, significantly delayed nitrification up to 84 days and in greater amounts than the other tested products in the coastal plain and mountain soils. However, field conditions overwhelmed potential product effects in nearly all site years for both crops.

The slight advantages observed with these N-loss prevention products may not justify their additional expense, or may not be lending benefit to a grower’s highest priority, which is often yield, as opposed to increased stover N content.

TABLES

Table 2.1 – Results of ANOVA statistical analysis for maize N rate and product trials by location.

Coastal Plain							
Parameter	Year	Treatment	N Rate	Year x Treatment	Year x N Rate	Treatment x N Rate	Year x Treatment x N Rate
Grain Yield	**	NS	**	NS	*	NS	NS
Stover Yield	**	NS	**	NS	NS	NS	NS
NUE	*	NS	NS	NS	NS	NS	NS
Grain N	**	NS	**	NS	NS	NS	NS
Stover N	**	NS	*	*	NS	NS	NS
Total N	*	NS	**	NS	NS	NS	NS
Piedmont							
Parameter	Year	Treatment	N Rate	Year x Treatment	Year x N Rate	Treatment x N Rate	Year x Treatment x N Rate
Grain Yield	**	NS	**	*	*	NS	NS
Stover Yield	**	NS	*	NS	NS	NS	NS
NUE	**	NS	NS	NS	NS	NS	NS
Grain N	**	NS	**	NS	**	NS	NS
Stover N	**	NS	**	NS	*	NS	NS
Total N	**	NS	**	NS	**	NS	NS
Mountains							
Parameter	Year	Treatment	N Rate	Year x Treatment	Year x N Rate	Treatment x N Rate	Year x Treatment x N Rate
Grain Yield	**	NS	**	NS	**	NS	NS
Stover Yield	**	NS	**	NS	*	NS	NS
NUE	**	NS	*	NS	**	NS	NS
Grain N	**	NS	**	NS	**	NS	NS
Stover N	**	NS	**	NS	NS	NS	NS
Total N	**	NS	**	NS	*	NS	NS

***, *, and NS indicate p value of <0.0001, p < 0.05, and not significant (p > 0.05), respectively.*

Table 2.2 – Maize plant N content (kg ha^{-1}) for significant year x N rate interactions by location.

		N Rate (kg ha^{-1})											
Location	**Year**	**0**		**45**		**90**		**135**		**180**		**224**	
		Grain N (kg ha^{-1})											
Piedmont	2014	53	c,d	73	f	104	g	129	h	137	h,i	144	i
	2015	26	a	38	b	46	b,c	59	d	61	d,e	71	e,f
Mountains	2014	71	b	115	c	148	d	156	d,e	170	e	165	e
	2015	36	a	39	a	83	b	115	c	124	c	149	d
		Stover N (kg ha^{-1})											
Piedmont	2014	26	d,e	30	e	35	f	39	f	10	f	53	g
	2015	11	a	12	a	16	a,b	19	b,c	20	b,c	22	c,d
		Total N (kg ha^{-1})											
Piedmont	2014	79	c	103	d	140	e	168	f	178	f	197	g
	2015	37	a	50	b	60	b	78	c	81	c	93	d
Mountains	2014	102	b	156	c	195	d	204	d,e	219	e	217	e
	2015	54	a	60	a	114	b	157	c	162	c	186	d

Table 2.3 - Results of ANOVA statistical analysis for wheat N rate and product trials by location.

Parameter	Year	Treatment	N Rate	Year x Treatment	Year x N Rate	Treatment x N Rate	Year x Treatment x N Rate
Coastal Plain							
Grain Yield	**	NS	**	NS	*	NS	NS
Straw Yield	**	NS	**	NS	*	NS	NS
NUE	NS	NS	NS	NS	*	NS	NS
Grain N	**	NS	**	NS	*	NS	NS
Straw N	**	NS	**	NS	NS	NS	NS
Total N	**	*	**	NS	*	NS	NS
Piedmont							
Parameter	Year	Treatment	N Rate	Year x Treatment	Year x N Rate	Treatment x N Rate	Year x Treatment x N Rate
Grain Yield	NS	NS	**	NS	*	NS	NS
Straw Yield	**	NS	*	NS	*	NS	NS
NUE	**	NS	NS	NS	*	NS	NS
Grain N	*	NS	**	NS	*	NS	NS
Straw N	**	NS	**	NS	*	NS	NS
Total N	**	NS	**	NS	*	NS	NS

***, *, and NS indicate p value of <0.0001, p < 0.05, and not significant (p > 0.05), respectively.*

Table 2.4 - Main effect of spring N rate on straw yield (kg ha^{-1}) at the coastal plain.

Year	**Spring N Rate (kg ha^{-1})**									
	0		**45**		**90**		**135**		**180**	
	Straw Yield (kg ha^{-1})									
2013-14	1220	a	2365	b	3246	c	3781	d	4401	e
2014-15	2,646	a	4,035	b	4,837	c	4,686	c	5,538	d

Table 2.5 - Main effect of year on straw yield (kg ha^{-1}) at the coastal plain.

Year			
2013-14		2014-15	
Straw Yield (kg ha^{-1})			
3002	b	4348	a

Table 2.6 - Wheat straw yield (kg ha-1) for significant year x N rate interaction at the piedmont.

		Spring N Rate (kg ha^{-1})									
		0		45		90		135		180	
Location	Year	Straw Yield (kg ha^{-1})									
Piedmont	2013-14	2,607	a	3,036	a	4,182	b	4,464	b	3,789	b
	2014-15	2,339	a	2,692	b	3,080	c	3,269	c	3,345	c

Table 2.7 - Wheat plant N content (kg ha^{-1}) for significant year x N rate interactions by location.

		Spring N Rate (kg ha^{-1})									
		0		45		90		135		180	
Location	Year	Grain N (kg ha^{-1})									
Coastal Plain	2013-14	40	a	59	b	90	d	112	e,f	134	g
	2014-15	77	c	104	e	120	f	133	g	156	h
Piedmont	2013-14	73	b	81	b,c	109	d	119	e	122	e
	2014-15	63	a	88	c	107	d	121	e	138	f
		Straw N (kg ha^{-1})									
Piedmont	2013-14	7	a	9	a	14	b	17	b	14	b
	2014-15	16	b	24	c	26	c,d	30	d	38	e
		Total N (kg ha^{-1})									
Coastal Plain	2013-14	47	a	70	b	107	d	132	e	160	g
	2014-15	93	c	127	e	147	f	163	g	195	h
Piedmont	2013-14	81	a	89	a	122	b	136	c	136	c
	2014-15	79	a	112	b	133	c	151	d	177	e

Letters denote significance at $p<0.05$ level of year x N rate interaction.

FIGURES

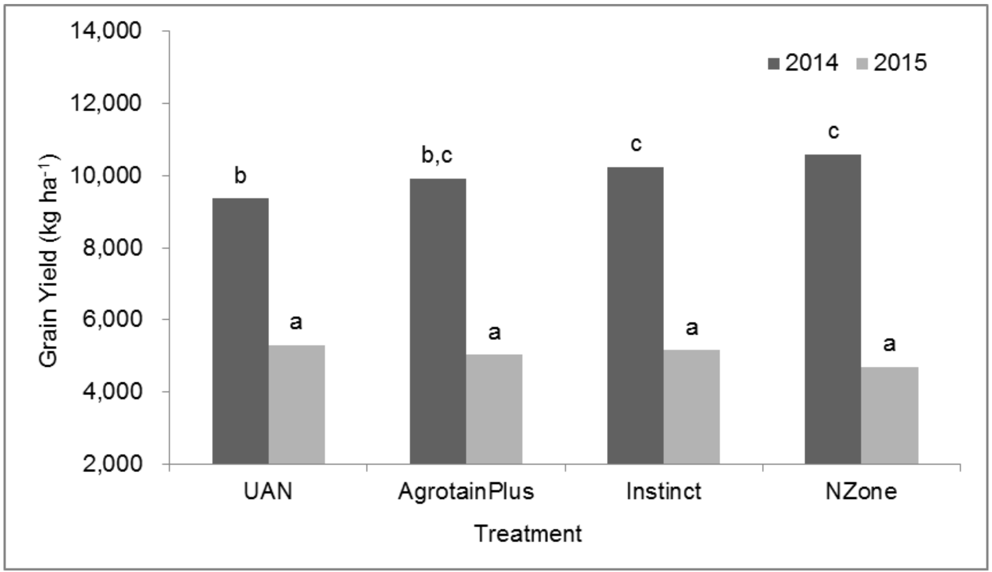


Figure 2.1- Maize grain yield (kg ha^{-1}), significant year x treatment interaction at the piedmont location.

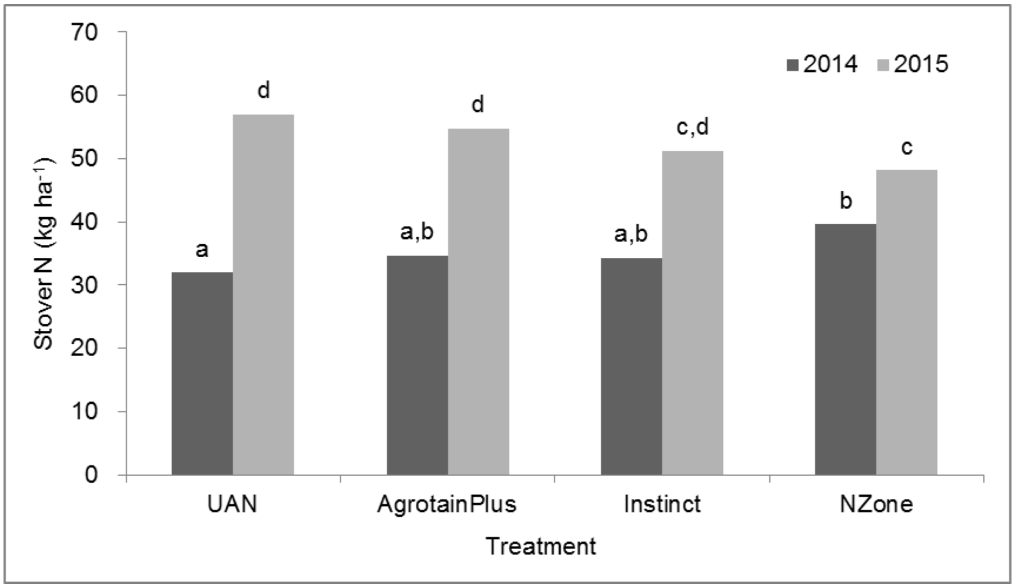


Figure 2.2 – Maize stover N content (kg ha^{-1}), significant year x treatment interaction at the coastal plain location.

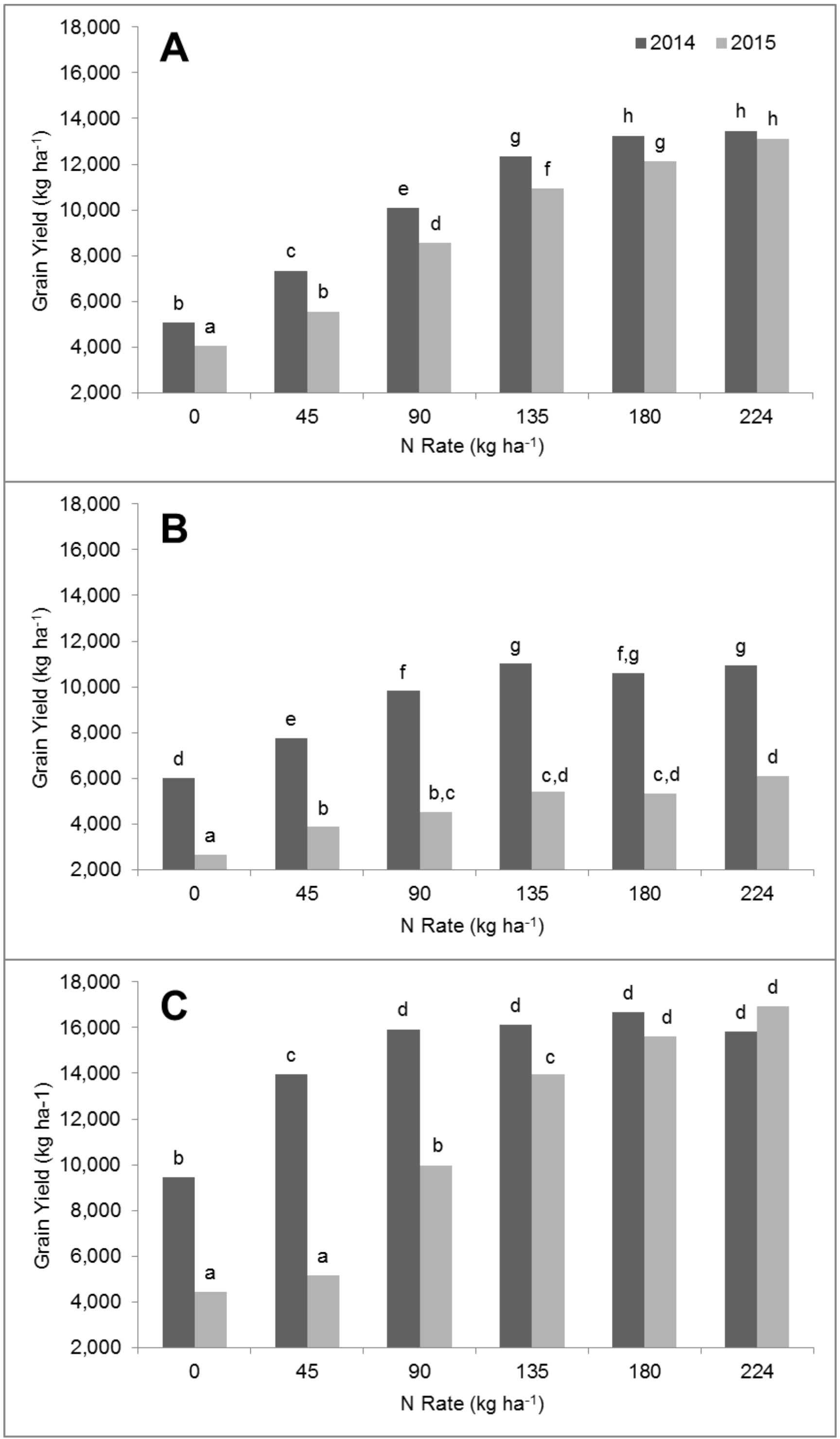


Figure 2.3 - Maize grain yield (kg ha^{-1}) by year x N rate interaction at the A) coastal plain, B) piedmont, and C) mountain locations.

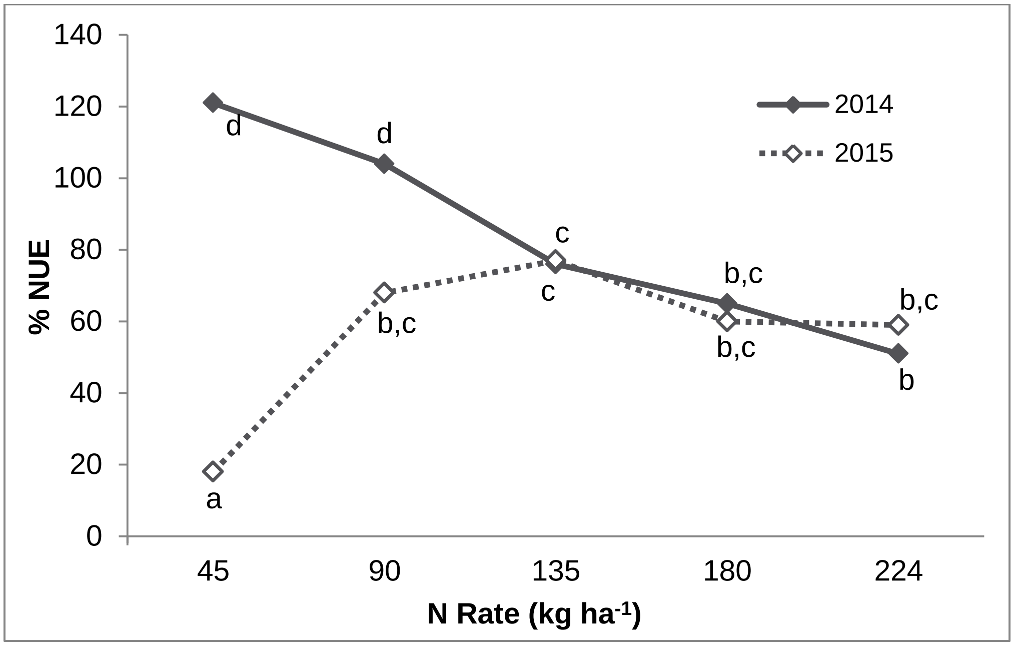
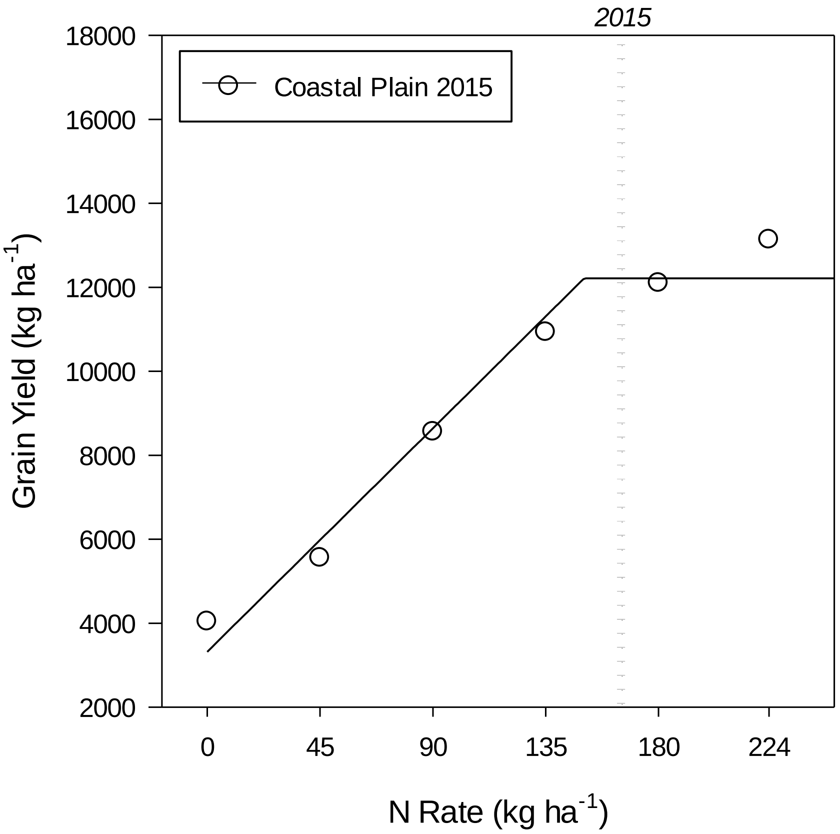
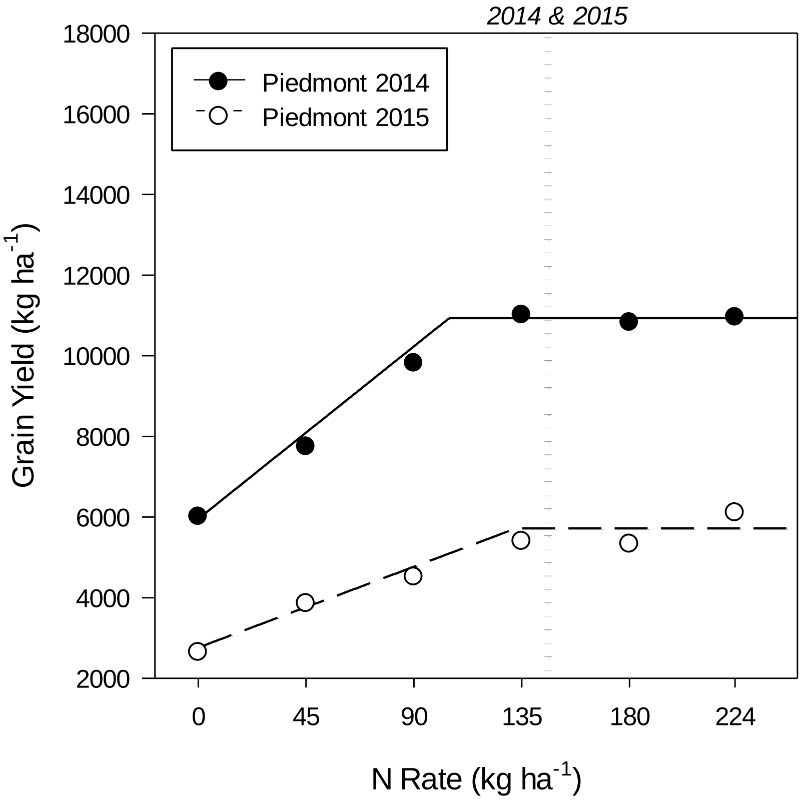


Figure 2.4 - Significant maize apparent NUE (%NUE) year x N rate interaction at mountain location.



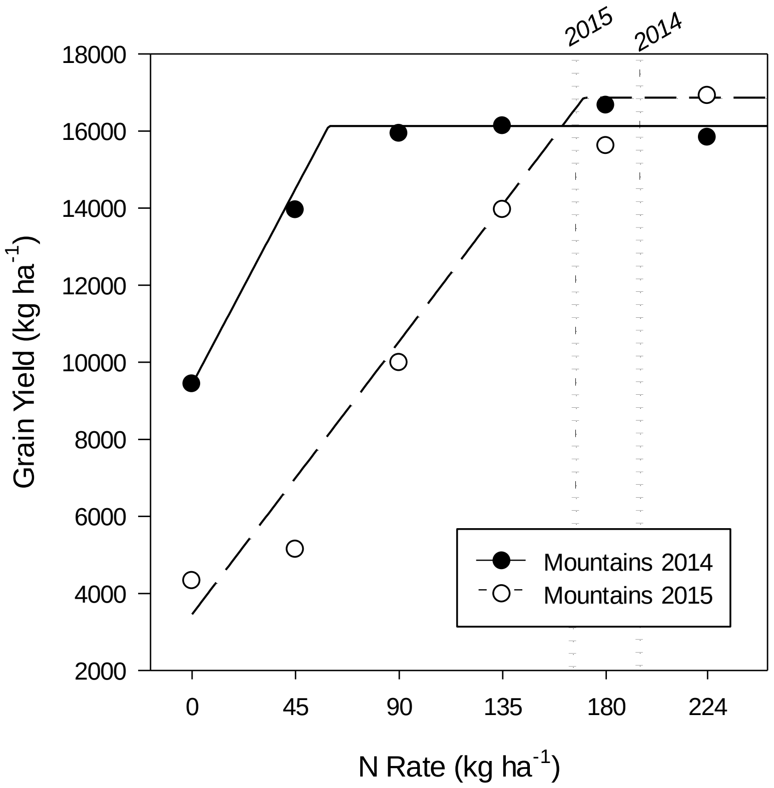
Dotted vertical line indicates RYE recommended N rate for given site.

Figure 2.5 - Maize grain yield linear-plateau at coastal plain location.



Dotted vertical line indicates RYE recommended N rate for given site.

Figure 2.6 - Maize grain yield linear-plateau at piedmont location.



Dotted vertical lines indicates RYE recommended N rate for given site.

Figure 2.7 - Maize grain yield linear-plateau at mountain location.

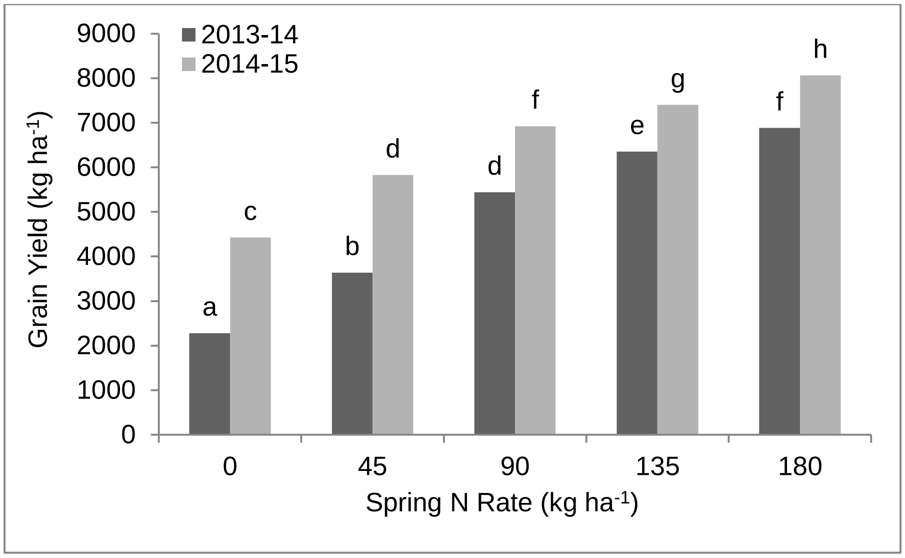


Figure 2.8 - Wheat grain yield (kg ha^{-1}) year x N rate interaction at coastal plain location.

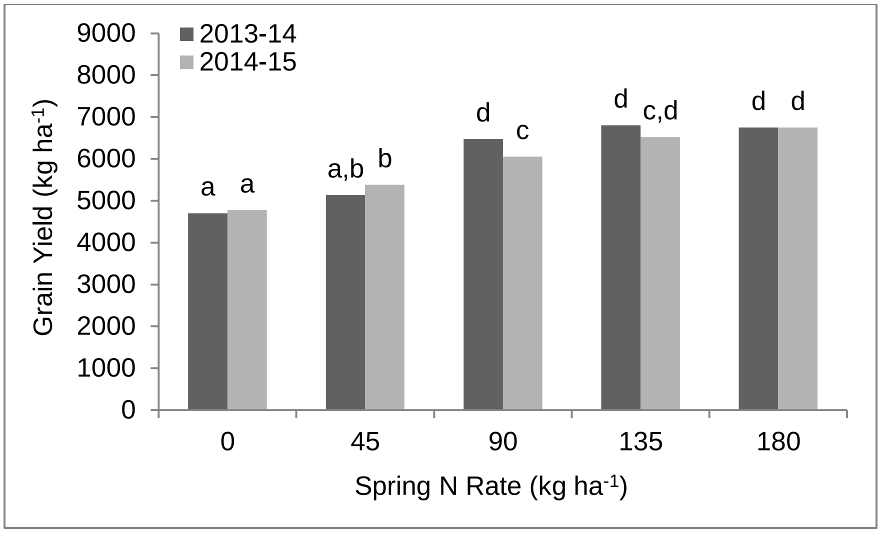
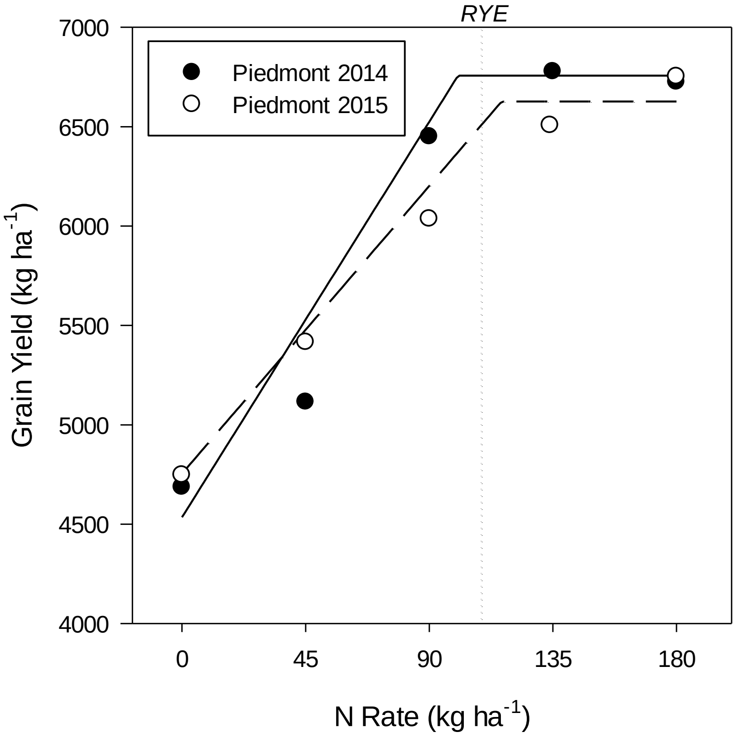


Figure 2.9 - Wheat grain yield (kg ha^{-1}) year x N rate interaction at piedmont location.



RYE recommended N rate indicated by vertical dotted line.

Figure 2.10 - Wheat grain yield linear-plateau curves by year for the piedmont location.

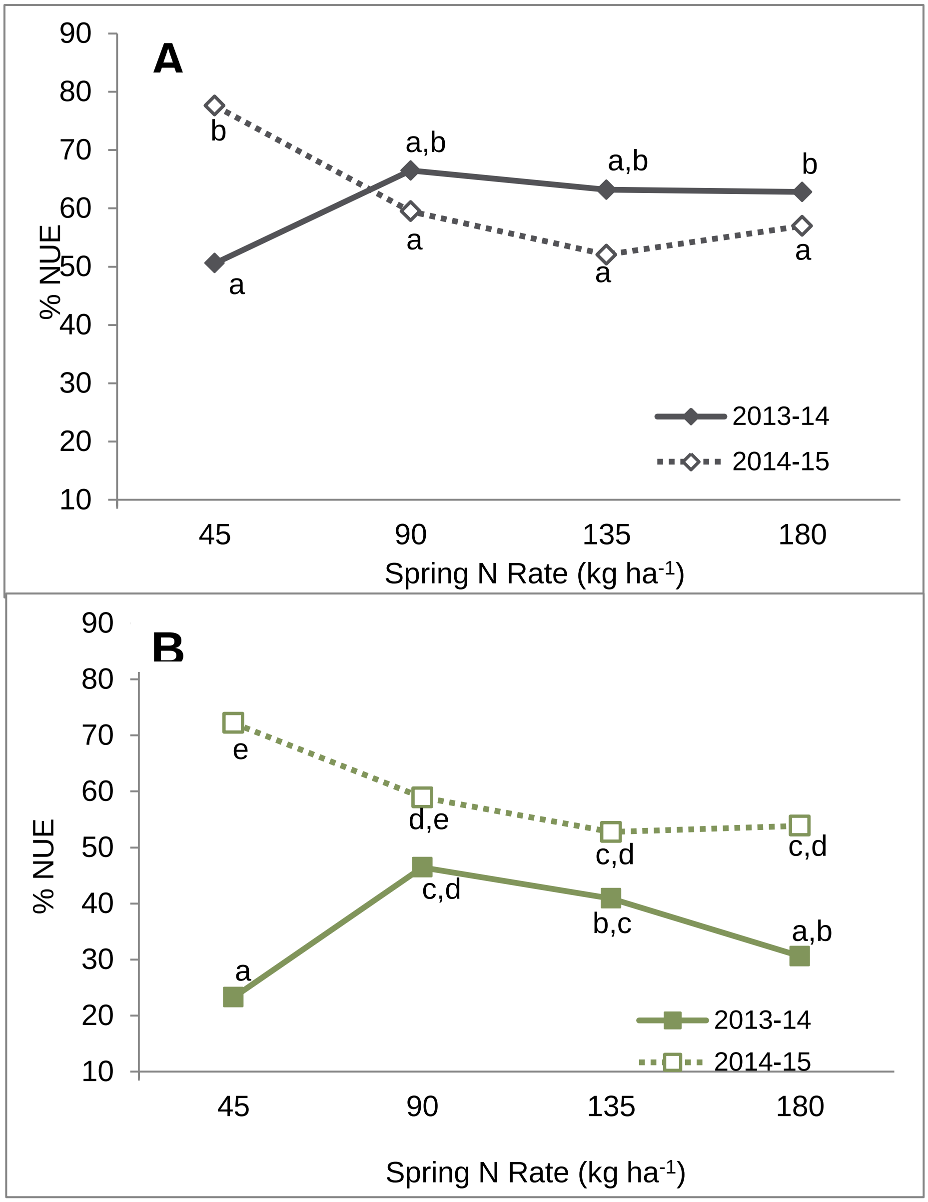


Figure 2.11 - Wheat apparent nitrogen use efficiency (%NUE) year x N rate interaction at A) coastal plain and B) piedmont locations.

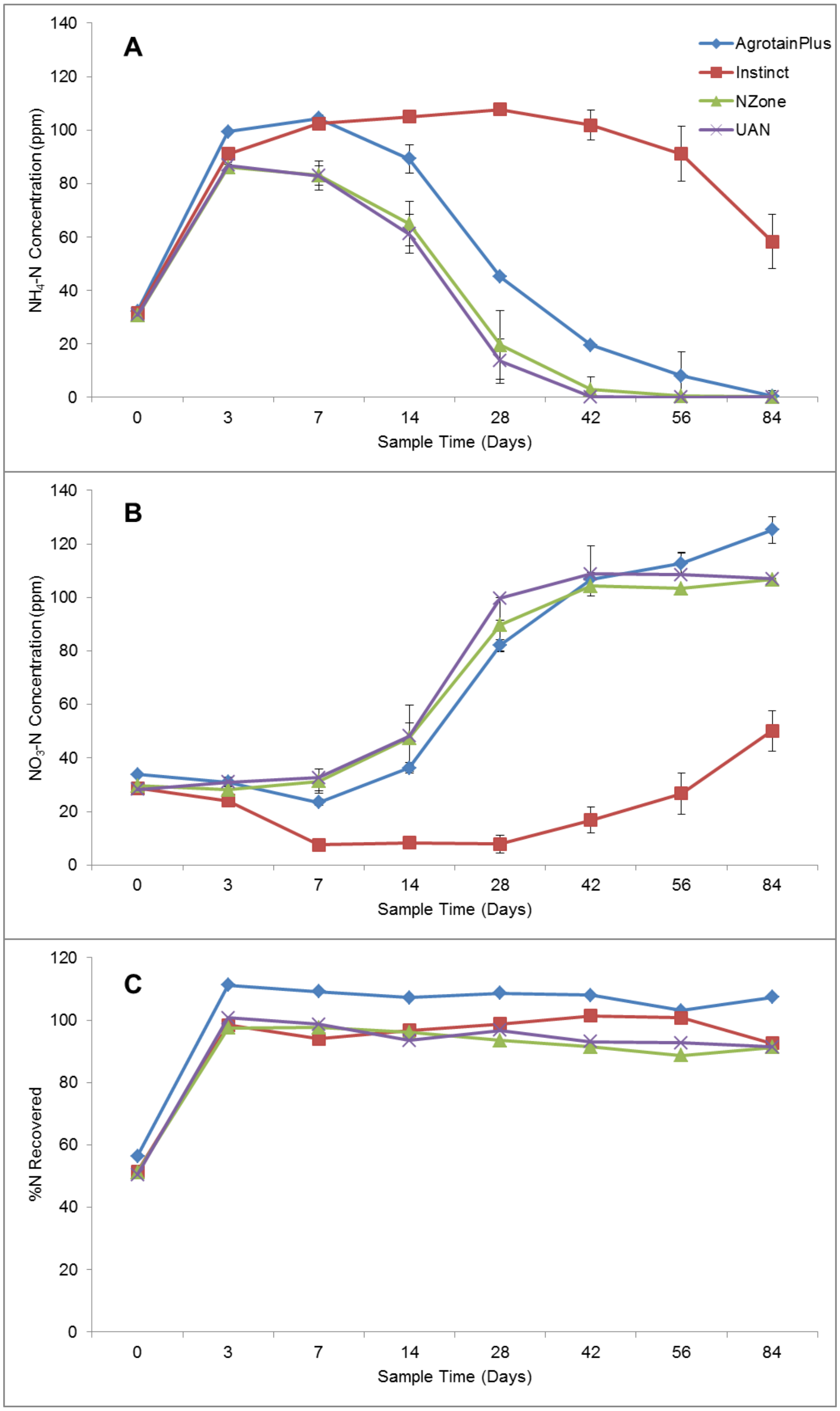


Figure 2.12 - Effect of treatment on A) NH4-N concentration, B) NO3-N concentration, and C) percent N recovered in aerobic incubation of coastal plain soil over sampling period.

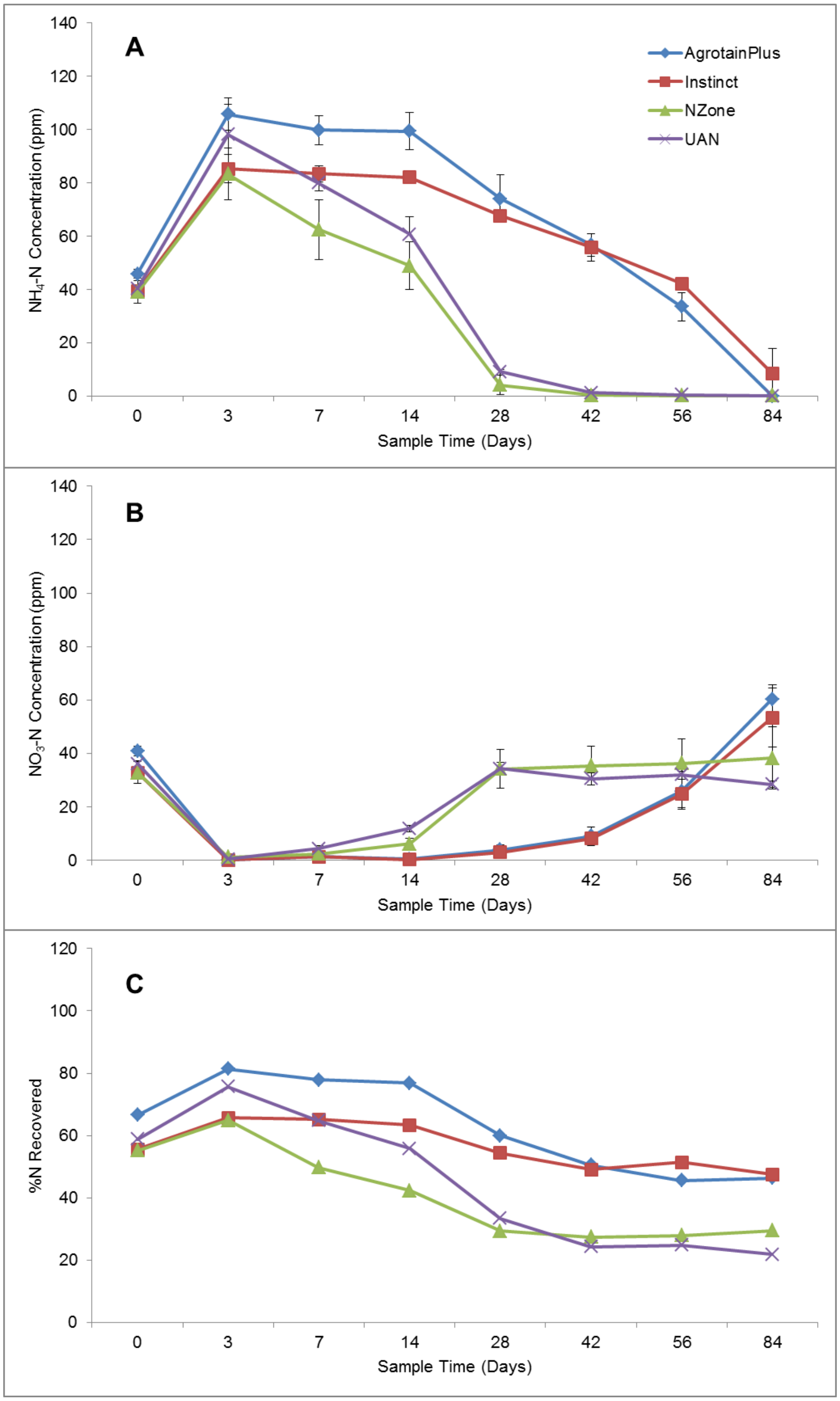


Figure 2.13 - Effect of treatment on A) NH4-N concentration, B) NO3-N concentration, and C) percent N recovered in aerobic incubation of piedmont soil over sampling period.

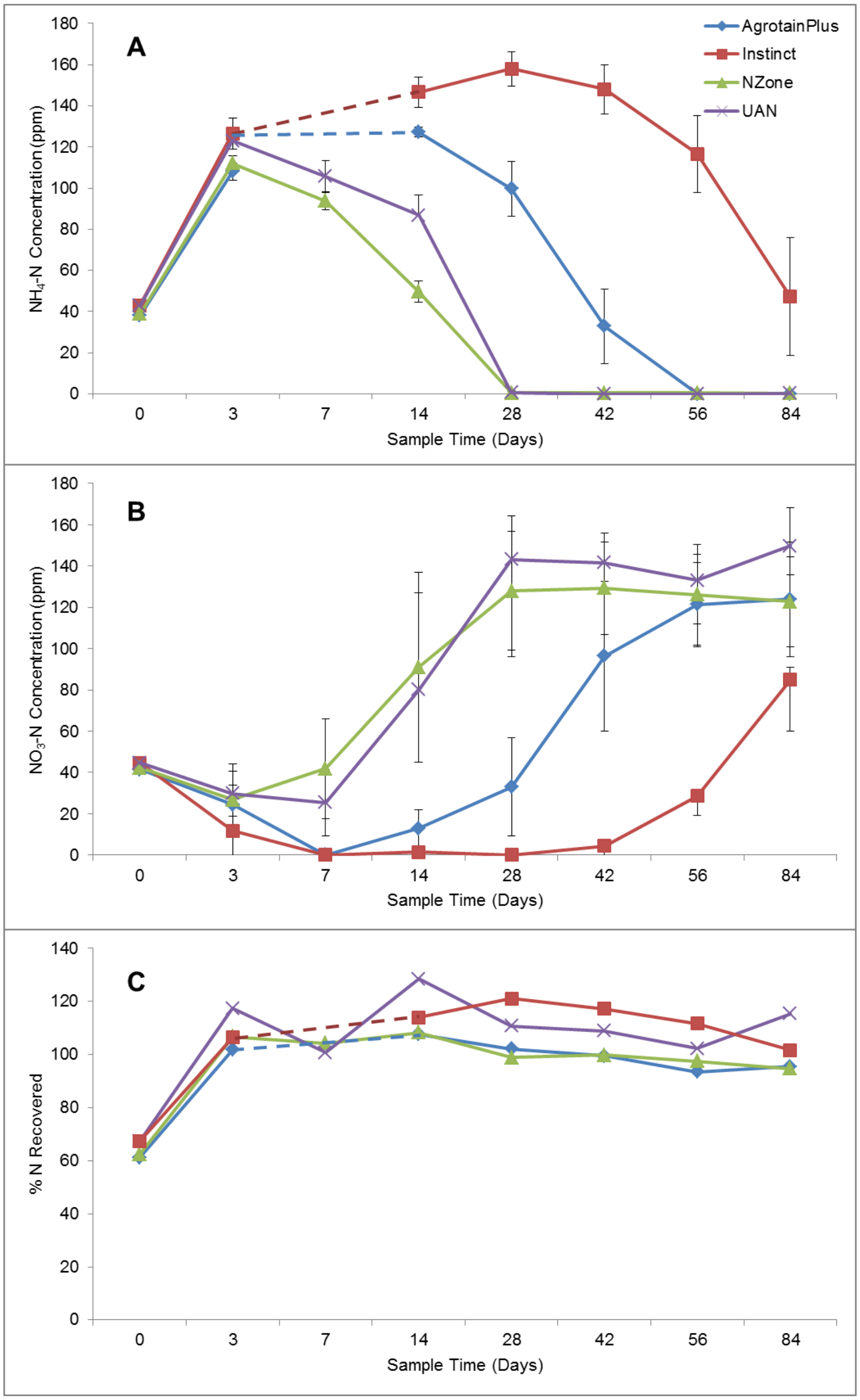


Figure 2.14 - Effect of treatment on A) NH4-N concentration, B) NO3-N concentration, and C) percent N recovered in aerobic incubation of mountain soil over sampling period. Dotted lines indicate missing data.

CHAPTER 3: EVALUATION OF ESN FOR USE IN WINTER WHEAT IN NORTH CAROLINA

INTRODUCTION

Growing awareness of the negative environmental effects of excessive nitrogen (N) fertilizer applications and the rising cost of N has spurred the market to develop products that reduce the amount of N lost to volatilization, leaching, or denitrification. Slow- or controlled-release fertilizers have emerged as a tool for farmers to bolster the “right source” aspect of a 4R nutrient management plan. These fertilizers are formulated to delay the N availability (or other plant nutrient of interest) by “controlled water solubility of the material by semi-permeable coatings, occlusion, protein materials, or other chemical forms, by slow hydrolysis of water-soluble low molecular weight compounds, or by other unknown means” (Trenkel, 2010).

Environmentally Smart Nitrogen® (ESN; Agrium Inc., Calgary, Alberta, Canada) is a 44% urea granule with a proprietary insoluble polymer time-release coating. According to the manufacturer, the membrane allows water to diffuse in to create a solution that will slowly release N at a predictable rate, which is controlled by soil temperature and moisture, and may occur over a period of several months (Agrium Inc., 2014a). The product aims to align N availability with crop N needs.

However, when the relatively new product was evaluated on maize (*Zea mays*) in North Carolina, Cahill et al. (2010b) observed no significant improvement in grain yield compared to standard fertilizer treatments in five of six site years. In other trials across the southeastern United States, surface applied ESN produced similar or worse yields when compared to UAN or urea in corn and grain sorghum (Mitchell and Osmond, 2012). A trial in Pennsylvania confirmed this trend, where ESN did not significantly affect corn grain yield (Dell et al., 2014).

Results from wheat (*Triticum aestivum* L.) trials have produced similar results to maize. Cahill et al. (2010b) reported lower grain yields in ESN treated plots in one site year, while the other three site years showed no significance difference between ESN and UAN. In conventional and no-till wheat fields in Oklahoma, ESN did not provide a yield advantage compared to urea across four site years (Mitchell and Osmond, 2012). Field trials with wheat, barley, and canola conducted in Western Canada by Khakbazan et al. (2013) did find occasional yield benefit with ESN or ESN blended with urea, but an economic analysis revealed that the yield gain was not enough to offset the cost of the product. However, in a bermudagrass production system, Payne et al. (2015) found that 50 and 75% blends of ESN and urea produced similar and occasionally higher yields and were more cost effective than traditional urea or ammonium nitrate treatments.

The literature highlights that the moisture-release mechanism of ESN can make application timing difficult. An incubation study at a constant moisture level confirmed that ESN released N at a slower rate than UAN, with a range of 7 to 42 days depending on soil type (Cahill et al., 2010a). However, on a field scale and particularly in rain fed conditions, inconsistent patterns of N cycling and plant uptake can reduce the synchronization between N availability and crop demand (Dell et al., 2014). The influence of soil temperature is also critical, as confirmed by Golden et al. (2011) who reported N was released more rapidly from ESN as temperature increased incrementally from 15^{o}C to 30^{o}C.

This challenge is particularly relevant to wheat, where N management is the most important aspect to maximizing wheat yield (Irvine et al., 2010) and timing is critical. Winter wheat producers in the southeastern US are known to apply spring N rates ranging from 45 to 202 kg N ha^{-1}, depending on economic and environmental factors (Farrer et al., 2006). Total N rate recommendations for the region usually fall near 134 kg N ha^{-1}, with a small portion applied at planting and the remainder applied at Zadoks growth stage (GS) 25 or 30 (Zadoks et al., 1974; Scharf and Alley, 1993; Scharf et al., 1993; Weisz et al., 2001). Research in North Carolina has demonstrated that if upwards of 555 well-developed tillers per square meter have been established by GS 25, grain yield is maximized by delaying N application until GS 30, when the plants shift from producing tillers to reproductive growth (Scharf et al., 1993; Weisz et al., 2001). At this growth stage, the future grain head begins to form and stem elongation occurs, so N fertilizer applications that meet the crop's increased N requirements are critical (Barber et al., 2015). On the other hand, if GS-25 tiller density is low, a split application is recommended in which half the spring N is applied at GS 25 to stimulate further tillering, and the last half is applied at GS 30 to support reproductive growth.

The sensitivity of wheat to the timing of N applications makes it ideal for research regarding different N management strategies and products that aim to better match changing crop N needs. As such, ESN was evaluated in wheat trials across two different regions of North Carolina to 1) determine the effectiveness of the product alone or in a blend against standard fertilizer applications; and 2) identify optimum timing of ESN applications.

METHODS AND MATERIALS

Winter wheat trials were conducted from 2013 to 2015 to evaluate the effectiveness of ESN in two different physiographic locations in North Carolina: the coastal plain and the piedmont. Wheat was planted into Johns sandy loam (Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludult) or Portsmouth sandy loam (Fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquult) in the coastal plain, and Lloyd clay loam (Fine, kaolinitic, thermic Rhodic Kanhapludult) in the piedmont (Table A2).

Prior to planting wheat in the coastal plain (2014), 336 kg ha^{-1} 10-0-20 with 12% S and 5% Mn was broadcast based on soil test recommendations (Table A2). Broadleaf weed and grass control consisted of Osprey Herbicide (mesosulfuron-methyl) and Harmony Extra SG (thifensulfuron methyl and tribenuron methyl). In both years, the piedmont fields were treated with 336 kg ha^{-1} 10-20-20 broadcast per soil test recommendations, followed by Finesse (chlorsulfuron and metsulfuron-methyl) and glyphosate (N-phosphonomethyl glycine) herbicides pre-emergence.

Seeding rate at all site-years was 3.7 million seeds ha^{-1}. Trials in the coastal plain were conventionally tilled with plots measuring 1.2 by 9 m (Table A4). Conservation tillage was used for the wheat trials in the piedmont, but plot size was 1.5 by 9 m. In 2013, NC Yadkin variety was planted in the coastal plain and Southern States 8350 was planted in the piedmont. In 2014, DynaGro Shirley was planted at both locations (Table A4). The crops followed maize regardless of year or location.

An additional 118 kg N ha^{-1} was applied as one of six treatments in the winter and/or spring. Winter treatments were applied in late January through early February (at approximate GS 25) and spring treatments were applied in early March (at approximately GS 30). Four treatments included ESN to identify optimum product blend and application timing: 1) a winter application with 100% of the N supplied as ESN (Winter-ESN$_{100\%}$); 2) a winter blend with 75% of the N supplied by ESN and the remaining 25% of the N from ammonium sulfate (Winter-$ESN_{75\%}$); 3) a winter blend with 50% of the N supplied by ESN and the remaining 50% as ammonium sulfate (Winter-$ESN_{50\%}$); and 4) a spring applied blend with 50% of the N from ESN plus 50% from ammonium sulfate (Spring-$ESN_{50\%}$). The remaining two treatments followed current recommendations for traditional fertilizers and included: 1) a split application with 50% of the N applied in the winter as ammonium sulfate and the remaining 50% of the N applied in the spring as UAN (Split-Traditional); and 2) all N applied in spring (Spring-Traditional) with 50% of the N supplied from ammonium sulfate and the remainder supplied from UAN. To ensure sulfur (S) was not an additional variable in the experimental design, all six fertilizer treatments received a total of 67 kg ha^{-1} sulfur, equivalent to the maximum amount of S applied as ammonium sulfate. Treatments that did not receive equivalent amounts of S from ammonium sulfate (Winter-$ESN_{100\%}$, Winter-$ESN_{75\%}$) were supplemented with powdered sulfur (90% S, Rattlesnake Brand™, Cape Fear Chemicals, Inc., Elizabethtown, NC). Granular ESN and powdered sulfur were spread by hand, while UAN was applied with a backpack sprayer and boom (R&D Sprayers, Opelousas, LA), which was calibrated before each application.

A Wintersteiger Delta plot combine (Wintersteiger Inc., Salt Lake City, UT) was used to harvest wheat. Moisture content and yield data, as well as a subsample of wheat grain, were captured from the combine. Grain yield was normalized to a standard moisture content of 13%. The straw discarded from the combine was collected, weighed, and subsampled to determine straw yield. Subsamples of grain and straw were weighed, dried, re-weighed and ground for nutrient analysis, including N concentration. N concentration was used to calculate grain N (N_{grain}, kg N ha^{-1}), straw N (N_{straw}, kg N ha^{-1}), and total N uptake (N_{tot}, kg N ha^{-1}).

Sample Analysis

Subsamples of wheat grain were ground with a Retsch Mill Model ZM-100 (Verder Scientific Inc., Newtown, PA). Straw was ground with a Thomas-Wiley Mill Model ED-5 (Arthur H. Thomas Co., Philadelphia, PA). Wheat grain and straw samples were analyzed for N content by the NC State University Environmental and Agricultural Testing Service lab (Raleigh, NC) with an elemental analyzer (2400 CHN/S Elemental Analyzer; Perkin-Elmer Corporation; Waltham, MA).

Statistical Analysis

Harvest data was analyzed with PROC GLIMMIX in SAS version 9.3 (SAS Institute Inc., Cary, NC) as a randomized complete block design with location (coastal plain or piedmont), year, and N treatment considered as fixed effects and replications within location-by-year combinations as random effects. The significance level applied to all data analysis was $p < 0.05$.

Weather

Historical and seasonal climate data for each trial location was collected from the North Carolina Climate Retrieval and Observations Network of the Southeast Database (State Climate Office of North Carolina, 2016).

The coastal plain location experienced two wheat cropping seasons with higher precipitation than the five-year average (Table A6), though the patterns differed. The two months following planting in 2013-14 were wet, followed by two dry months and a wet spring. In contrast, the 2014-15 season was consistently wetter than the five-year average with less total variation. In both years, average soil temperature was fairly consistent with historical trends; though average air temperature in the winter did dip lower.

In the piedmont, the 2013-14 season had 92 mm more precipitation than the five-year average, but the 2014-15 season was extremely dry with 301 mm less than the average (Table A6). The lack of precipitation was distributed throughout the cropping year, with November as the only month to record more rainfall than the average with a total of 102 mm. The average air and soil temperature was slightly colder in both cropping season winters than the five year average, with spring averages more closely aligned with historic values.

RESULTS AND DISCUSSION

The trial was designed to evaluate alternative N sources in typical conditions across the state, so locations were separated for analysis given known variation in soil properties and climate between the coastal plain and piedmont.

Coastal Plain

At the coastal plain, there was a significant year x treatment interaction (Table 3.1) for grain yield (p=0.0002), N_{grain} (p=0.003), and N_{tot} (p=0.004,). Straw yield and N_{straw} differed across years (p<0.0001), but were not affected by N treatment.

Grain yields averaged across treatments at the coastal plain were higher in 2014-15 (7,481 kg ha^{-1}) than in the previous year (4,611 kg ha^{-1}). The significant difference between years was likely influenced by variation in soil types. The Johns sandy loam under the trials in 2013-14 had very low organic matter (1.2%) compared to the Portsmouth sandy loam (12% organic matter) utilized the following year. In 2014-15, treatment yields tended to be very similar (Figure 3.1). However, in 2013-14, spring applied treatments had higher yields than winter treatments and this was the cause of the year x treatment interaction.

In 2013-14, grain yield from treatments that received winter N as ESN (at 100, 75, or 50%) were significantly lower than yields from either the split-traditional or spring-traditional treatments (Figure 3.1). The Spring-ESN$_{50\%}$ treatment, tended to be higher yielding than the winter ESN treatments, but this was not always statistically significant. For example, the Spring-ESN$_{50\%}$ blend was not significantly different from the Winter-ESN$_{50\%}$ application, though the former yielded 378 kg ha^{-1} more. Among the winter ESN treatments, the maximum yield was 4,418 kg ha^{-1} with the Winter-ESN$_{50\%}$ blend and a minimum yield of 3,898 kg ha^{-1} with the Winter-ESN$_{100\%}$ application, which was also the lowest yielding of all treatments. The Winter-ESN$_{75\%}$ blend was not significantly different from the Winter-ESN$_{100\%}$ or ESN$_{50\%}$ blends. The low grain yield observed with the Winter-ESN$_{100\%}$ application supports the manufacturer's advice to apply ESN as a blend (Agrium Inc., 2015), but treatments with the recommended blends of 50% and 75% showed only minor yield advantages that were still lower than the treatments that did not include any ESN.

As indicated above, the highest yields in 2013-14 tended to be associated with spring-applied treatments. Among these, the Spring-Traditional had the highest yield, and the Spring-ESN$_{50\%}$ had the lowest (Figure 3.1). The yield from the Split-Traditional was intermediate and not significantly different from either of the other two spring treatments. The Split-Traditional application of N (at GS 25 and 30) is more appropriate for stands with low tiller counts. Fertilizer applications in March (i.e. Spring-Traditional) are typically prescribed as a best management practice for stands with a high tiller count, where spring N is most effective (Scharf and Alley, 1993; Scharf et al., 1993; Weisz et al., 2001; Barber et al., 2015). The 2013-14 coastal plain stands were in the high tiller range, with a count of 903 tillers m^{-1} on January 26, 2014, so the Spring-Traditional treatment would have been recommended.

The Spring-Traditional application was significantly higher yielding than the Spring-$ESN_{50\%}$ blend with a yield advantage of nearly 519 kg ha^{-1}. This indicates that the spring N applications may have been more effective when applied as UAN and ammonium sulfate rather than ESN plus ammonium sulfate. Since ESN is a delayed-release product, it may not have been available immediately after jointing when the crop N uptake is peaking, while the UAN was available for that period of rapid uptake. In the fourteen days following ESN application, the site received 67 mm of precipitation (Figure 3.2). Given that the release of N from ESN is largely moisture related (Agrium Inc., 2014b), the lack of yield response to ESN highlights the challenges in timing ESN applications.

In the 2014-15 year, grain yields were much less differentiated by treatment. Maximum variation in yield between treatments was only 376 kg ha^{-1} (Figure 3.1). Treatments that included ESN did not statistically differ from either the Split-Traditional, or the Spring-Traditional treatments that supplied all N as UAN plus ammonium sulfate. The Winter- $ESN_{100\%}$, $ESN_{75\%}$, and $ESN_{50\%}$ treatments were not significantly different from each other. The Split-Traditional application was significantly better than the Spring-Traditional application, while the Spring-$ESN_{50\%}$ blend was intermediate between (and not statistically different from) the traditional treatments.

N_{grain} response to N treatments in the coastal plain closely followed the yield trends (Table 3.2). In 2013-14, the Winter- $ESN_{100\%}$, $ESN_{75\%}$, and $ESN_{50\%}$ treatments were not significantly different from each other, but were significantly lower than the higher yielding

Split-Traditional and Spring-Traditional applications. In the 2014-15 crop, N_{grain} was fairly consistent across treatments, with the Spring-$ESN_{50\%}$ application having the highest value (142 kg ha^{-1}), which was significantly different than the Spring-Traditional treatment (130 kg N ha^{-1}). N_{grain} content drove N_{tot}, with nearly identical levels of significance reported between treatments (Table 3.2).

Piedmont

At the piedmont location, N treatment was not significant as a main effect or as an interaction in either year (Table 3.1). Year was the only significant effect for all parameters (Table 3.3). Grain yield was higher in 2014-15 by 804 kg ha^{-1} with a yield of 6,248 kg ha^{-1}, but straw yield was higher in 2013-14 by 791 kg ha^{-1} with a yield of 3,943 kg ha^{-1}. N_{grain}, N_{straw}, and N_{tot} mirrored grain yield trends and were significantly greater in 2014-15.

Discussion

Soil moisture and temperature appears to greatly influence the effectiveness of ESN. In the coastal plain, spring (March, April, May) rainfall was greater than the five year average in 2013-14 and 2014-15 by 36.3 and 38.6 mm, respectively (Table A6). Plentiful spring rainfall increased the likelihood that N applied in the winter was lost to leaching, which was supported by higher yields in the treatments that included spring N in 2013-14. Between the Spring-$ESN_{50\%}$ and spring-traditional treatments, the significant yield disadvantage of the Spring-$ESN_{50\%}$ likely resulted from the delayed release mechanism of ESN. In the fourteen days following these treatments, the site received 67 mm of precipitation in 2013-14 and 36.4 mm of precipitation in 2014-15 (Figure 3.2, Figure 3.3). While greater precipitation in 2013-14 should have triggered the release of the needed N, the soil temperature was low, averaging 9.3^{o} C compared to the 2014-15 average soil temperature of 11.5^{o} C. The higher soil temperature in 2014-15 may have facilitated movement of soil moisture and the diffusion of N out of the polymer coating. These field conditions highlight the challenges in timing ESN applications ahead of unknown climate conditions.

Additionally, N_{tot} values at the coastal plain indicate ESN treatments likely did not provide an environmental advantage over traditional fertilizer applications. From a simplified mass balance perspective, N applied is either taken up by the plant or lost via leaching, volatilization or denitrification. The absence of significant differences between treatments supports the indirect observation that total N losses were not affected by source.

CONCLUSIONS

In the piedmont location, ESN did not have a significant effect on wheat grain yield, straw yield or plant N uptake in either year. At the coastal plain, ESN returned higher yields when applied in March (Spring-$ESN_{50\%}$) than when applied either alone, or in a blend with ammonium sulfate in January (Winter- $ESN_{100\%}$, $ESN_{75\%}$, or $ESN_{50\%}$) in 2013-14 on a sandy loam. However, the Spring-$ESN_{50\%}$ treatment, while yielding more than winter ESN treatments, was not statistically different from the split-traditional application consisting of 50% ammonium sulfate in January and 50% UAN in March. While not statistically significant, the Split-Traditional application resulted in 194 kg ha^{-1} and 191 kg ha^{-1} numerically higher yields compared to the Spring-$ESN_{50\%}$ in 2013-14 and 2014-15, respectively. The Split-Traditional application, which is commonly promoted as a best management practice in North Carolina, distributes N applications temporally to reduce leaching. In conclusion, ESN treatments did not increase grain yield, grain N uptake, or total crop N uptake compared to UAN treatments in the coastal plain or piedmont in any of our tests.

Laboratory studies have confirmed that ESN delays the release of N into the soil (Cahill et al., 2010a; Golden et al., 2011), but it is pairing that potentially advantageous mechanism with the right timing for an application to match a crop’s needs that is the true challenge. In 2013-14, January applications of ESN likely suffered N leaching caused by high spring rainfall. In that same year, plots treated with March applications of ESN may have entered a period of rapid uptake before the N was available. Even with various blends of ESN and attempts to time applications to the crop’s needs, ESN does not appear to provide a strong agronomic benefit to wheat production in North Carolina or necessarily reduce leaching losses on different soil types.

TABLES

Table 3.1 - ANOVA results for grain and straw yield (kg ha^{-1}), and grain N (Ngrain), straw N (Nstraw) and total N uptake (Ntot) (kg N ha^{-1}) for ESN trials in the North Carolina coastal plain and piedmont.

Coastal Plain			
Parameter	Year	Treatment	Year x Treatment
Grain Yield	**	*	*
Straw Yield	**	NS	NS
Grain N	**	*	*
Straw N	**	NS	NS
Total N	**	NS	*
Piedmont			
Parameter	Year	Treatment	Year x Treatment
Grain Yield	**	NS	NS
Straw Yield	*	NS	NS
Grain N	**	NS	NS
Straw N	**	NS	NS
Total N	**	NS	NS

***, *, and NS indicate p value of <0.0001, $p < 0.05$, and not significant ($p > 0.05$), respectively.*

Table 3.2 – Year x treatment interaction for wheat grain and total N content for ESN trials at the coastal plain location.

	Grain N (kg ha^{-1})				Total N (kg ha^{-1})			
Treatment	**2013-14**		**2014-15**		**2013-14**		**2014-15**	
Winter-ESN$_{100\%}$	65	a	138	c,d	77	a	170	d,e
Winter-ESN$_{75\%}$	68	a	132	c	79	a	165	d,e
Winter ESN$_{50\%}$	70	a	134	c,d	83	a,b	165	d,e
Split-Traditional	80	b	140	c,d	95	b,c	165	d,e
Spring-ESN$_{50\%}$	80	b	142	d	94	b,c	173	e
Spring-Traditional	87	b	130	c	103	c	157	d

Significance of least-squares means within columns at the 0.05 level indicated by different letters.

Table 3.3 – Wheat grain and straw yield, plant N content by main effect of year at piedmont location.

Model Parameter	2013-14		2014-15	
Grain Yield	5,444	b	6,248	a
Straw Yield	3,943	a	3,152	b
Grain N	90	b	106	a
Straw N	13	b	30	a
Total N	103	b	125	a

Significance of least-squares means within rows at the 0.05 level indicated by different letters.

FIGURES

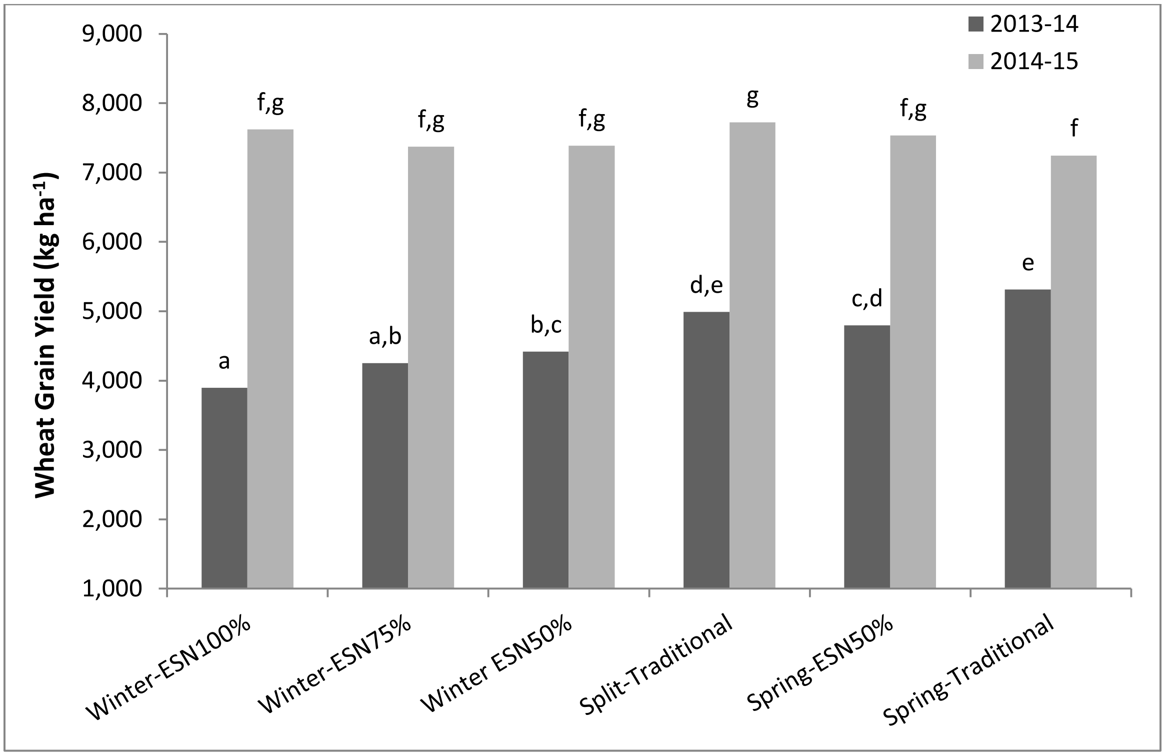


Figure 3.1 - Year x treatment interaction for wheat grain yield for ESN trials at the coastal plain location.

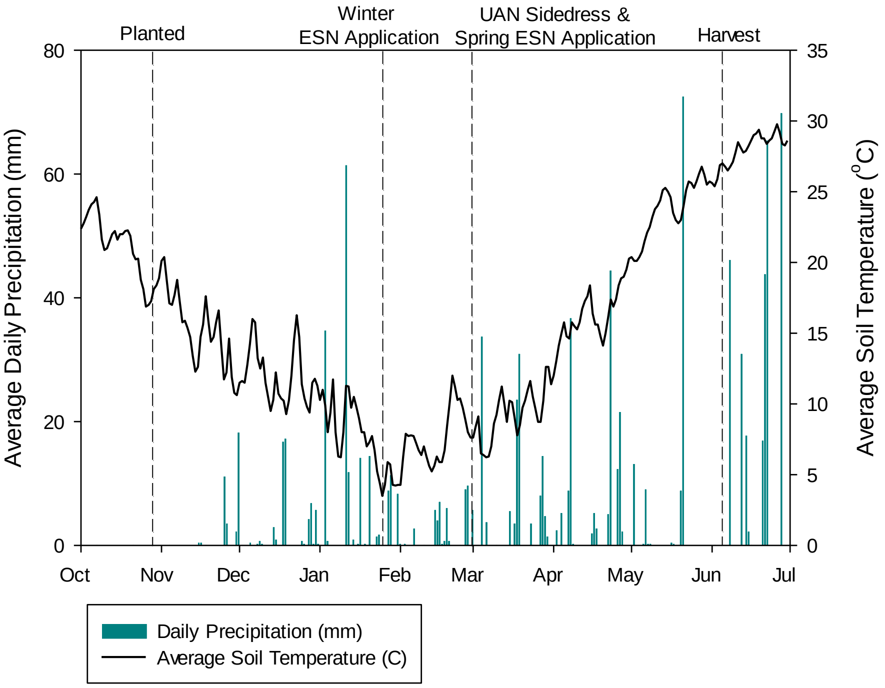


Figure 3.2 – Average daily precipitation and average soil temperature for 2013-14 coastal plain wheat season.

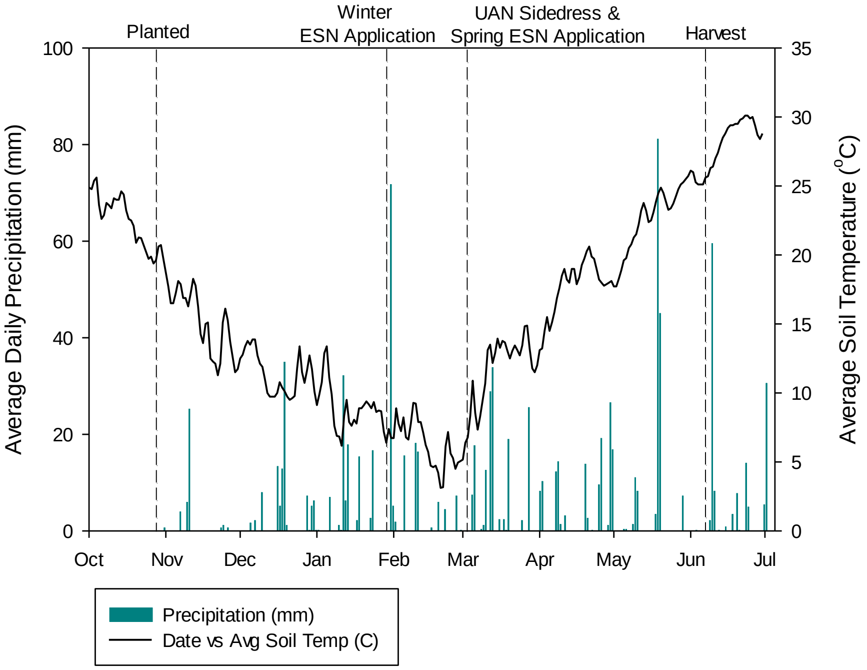


Figure 3.3- Average daily precipitation and average soil temperature for 2014-15 coastal plain wheat season.

CHAPTER 4: EVALUATION OF ADAPT-N IN NORTH CAROLINA

INTRODUCTION

As awareness of the environmental and economic cost of excess nitrogen (N) applications in agriculture increases, the need for producers to be able to confidently make precise N management decisions is critical. Advancing agriculture technology allows broader access to crop conditions and field environments, information which can be used to refine N recommendation models.

Many state universities have produced N rate recommendation databases. North Carolina's Realistic Yield Expectation (RYE) database provides N rates for 32 different crops by soil series across the three physiographic regions (North Carolina Nutrient Management Workgroup, 2003). The database is verified through N rate trials across the state, with maize N recommendations updated in 2015 to keep pace with new hybrid developments and management practices (Rajkovich et al., 2015). Iowa State University spearheaded an effort to develop and maintain a regional Corn Nitrogen Rate Calculator (available online at: http://extension.agron.iastate.edu/soilfertility/nrate.aspx) with collaborators in Iowa, Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin. The model incorporates current crop and fertilizer price data to find the maximum economic return to N (Sawyer et al., 2006).

Industry stakeholders are also taking interest and advantage of new technologies by using existing channels and internal resources to promote their own N management tools. Pioneer® urges users to "manage risk to boost your return," with their Encirca℠ service (Dupont Pioneer Services, 2014), while Trimble® has ConnectedFarm™ to "turn farm data into profit" (Trimble, 2011). These systems aim to help producers make better decisions by leveraging increasingly available information about the well documented spatial and temporal yield and N availability within individual fields (Katsvairo et al., 2003; Kucharik and Ramankutty, 2005; Tremblay et al., 2012).

Adapt-N, a web-based N recommendation tool introduced in 2010, is designed to recommend N application rates in corn at or after V-6 and quantify the environmental fate of N. The calibration and use of Adapt-N has mostly occurred in the Northeast and Midwest. As of this writing, there are no published peer-reviewed articles on the model. Soils and climate data from North Carolina have recently been incorporated into Adapt-N but the model has not been validated against field conditions (e.g. soil, management, crop, yield goals, and weather parameters) in the Southeast. Thus, this research utilized maize field trial data from North Carolina to 1) compare observed optimum agronomic and economic N rates to Adapt-N recommendations; 2) examine simulated N losses from Adapt-N using data from objective 1; and 3) compare Adapt-N recommended rates against grower's standard practices as well as RYE database recommended N rates.

METHODS AND MATERIALS

Adapt-N

The Adapt-N model in its current form is based on the adaptation of several other models into the Precision Nitrogen Management model (PNM, Sogbedji et al., 2006): the soil and water component of LEACHN (Hutson and Wagenet, 1991), and a crop growth and yield model by Sinclair and Muchow (1995).

The Adapt-N model incorporates site-specific field data, such as soils information derived from the NRCS State Soil Survey Geographic Database (SSURGO2), and grower inputs, as well as high-resolution weather data, to make adaptive sidedress N recommendations (Moebius-Clune et al., 2014). The Adapt-N sidedress recommendation is calculated as follows:

Equation 1: Calculation of Adapt-N Sidedress N Rate

$$Sidedress\ N\ rate = Crop\ N_{Harvest} - CropN_{Current} - SoilN_{Current} - SoilN_{Postsidedress} - SoybeanN_{Credit} + Loss_{PostApplication} - Correct_{Profit}$$

The weather component of Adapt-N heavily influences N cycling and is a driver for four of these seven factors: 1) the amount of N currently in the crop; 2) the amount of N currently in the soil; 3) the amount of N in the soil post sidedress; and 4) potential N losses post sidedress (Moebius-Clune et al., 2014).

Users are required to input crop and management information, such as grain maturity class and tillage (Table 4.1). Recommendations and the predicted status of N in the crop and field are provided as PDF or graphical outputs.

Nitrogen Rate Trials

Nitrogen rate response trials were conducted in the coastal plain, piedmont, and mountain regions of North Carolina (Rajkovich, 2016; Chapter 2). The trials were randomized complete block designs with four replications of six N rates: 0 (control), 45, 90, 134, 180, and 224 kg N ha^{-1} with 45 kg N ha^{-1} applied at plant and the remainder applied as a side dress application at growth stage V5-6. Adapt-N recommended N rates for these trials were generated based on actual field conditions and the expected yield given by the North Carolina RYE database.

Coastal plain and piedmont fields were in conservation tillage following soybeans, while the mountain fields were disked to depth of 30 cm approximately one week prior to planting and followed a wheat cover crop. Fertilizer (with the exception of N) was applied based on soil test recommendations and sites were managed for weeds and pests by research station managers. Soil organic matter content for each site year was determined via loss on ignition (LOI) method (Zhang and Wang, 2014). Additional information on trial sites can be found in Rajkovich (2016).

Grower Strip Trials

Nitrogen rate strip trials were conducted in the lower coastal plain of North Carolina with four replications of four treatments: grower N rate (Grower_{N}), +/- 25 percent of grower N rate ($\text{Grower}_{+25\%}$, $\text{Grower}_{-25\%}$), and an Adapt-N recommended rate. The Adapt-N recommended rate was generated for each site by using actual field conditions and grower inputs (Table 4.1), including the grower's expected yield data. The strips were managed by the grower and/or landowner. Yield data were collected from ten locations in 2014 and eight in 2015. Soil organic matter content for each site year was determined via loss on ignition (LOI) method (Zhang and Wang, 2014). Location information, soil type, previous crop, hybrid, and seeding rate are summarized in Table 4.2 and Table A10.

Statistical Analysis

Harvest data from the six site years of N rate trials were analyzed with PROC GLIMMIX in SAS version 9.3 (SAS Institute Inc., Cary, NC) as a randomized complete block design. Linear-plateau (LP) yield curves were generated with PROC GLM in SAS 9.3 to determine an agronomic optimum N rate (AONR) where an additional application of N fertilizer does not return a significant increase in yield. The LP model was not applied if yield LSMeans did not significantly change over applied N rates, or if LSMeans continually increased with no evidence of a plateau (i.e. yields at highest N rate were statistically higher than yields at the previous rate). Additionally, when the LP model was used, the 95% confidence intervals for the estimated parameters were reviewed to check for goodness of fit.

The LP model has historically been used in North Carolina (Anderson and Nelson, 1987; Crozier et al., 2014; Rajkovich et al., 2015) and generally represents the most conservative test, reaching the greatest yield for the least amount of N (Cerrato and Blackmer, 1990). Additionally, the N rate trial data was evaluated with a quadratic plateau (QP) model in R version 3.1.1 (R Core Team, 2014) to determine economic optimum N rates (EONR). The price ratio was set at 0.18 based on corn prices of \$0.06 kg^{-1} and UAN prices of \$1.54 kg^{-1} as of November 2015. The QP was selected for EONR based on similar uses in the literature and goodness of fit (Sawyer et al., 2006; Spargo et al., 2009). The resulting AONRs from the LP model, as well as the QP generated EONRs, were then compared to the Adapt-N and North Carolina Realistic Yield Expectation (RYE) database N rate recommendations. The significance level applied to all data analysis was $p < 0.05$.

Yield data collected from the 18 site years of grower N rate strip trials was also analyzed with PROC GLIMMIX in SAS as a randomized complete block design. Least-squares means among treatments, excluding strips that received at-plant fertilizer only, were determined at the significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Nitrogen Rate Trials

The observed optimum N rate, or AONR, as determined by the LP model was used as a baseline for which to evaluate the RYE recommended N rate and Adapt-N generated N rate. At the coastal plain location in 2015, the RYE recommended N rate aligned very closely with the AONR (Figure 4.1; Table 4.3), with a difference of only 1.12 kg ha^{-1}, while observed yields exceeded RYE database expectations by 2,480 kg ha^{-1}. Coastal plain data from 2014 was not analyzed with the LP model due to lack of fit. At the piedmont site, the RYE N rate exceeded the AONR by 32 kg N ha^{-1} in 2014 (Figure 4.2; Table 4.3). In 2015, though the AONR and RYE N rate only differed by 1.12 kg ha^{-1}, the observed yield was a mere 5,704 kg ha^{-1}, compared to the RYE average of 8,742 kg ha^{-1}, due to extended dry periods. The RYE recommended N rate of 185 kg N ha^{-1} in the mountains was well above the AONR of 66 kg N ha^{-1} in 2014 (Figure 4.3; Table 4.3). This discrepancy reflects a decision made by the North Carolina Nutrient Management Group in setting RYE N rates for the historically high-yielding floodplain soil to align with farmer behavior (Rajkovich et al., 2015). In the following year, trials were conducted on an upland soil, which resulted in a more reasonable AONR prediction that was only 13 kg N ha^{-1} greater than the RYE rate. With the mountain 2014 situation excluded, the RYE N rate was greater than the AONR by an average of 3 kg N ha^{-1}, an amount within the margin of error for typical agriculture spray equipment.

In contrast, Adapt-N generally underestimated the appropriate N rate compared to the AONR (Table 4.3). The exception, again, was the mountain 2014 site year, where Adapt N recommended an N rate 180 kg N ha^{-1} greater than the observed AONR to reach the RYE yield of 15,500 kg ha^{-1} (Table 4.3). The high yield observed is typical of the region and soil (Rajkovich et al., 2015), and can be achieved with minimal N rates. The floodplain soil in this unique environment is not reflected accurately in the Adapt-N program or any recommendation system. Excluding that site year, the Adapt-N model recommended N rates were an average of 83 kg N ha^{-1} less than the AONR for the remaining sites. In three of five site years where the AONR could be determined (coastal plain, 2015; piedmont 2014 and 2015), Adapt-N made a sidedress N recommendation of 0 kg N ha^{-1}.

The Adapt-N model includes a profit correction that considers the price ratio and risk factors. It accounts for the cost of fertilizer relative to returns from additional yield at higher N rates with the assumption that there is a greater profit penalty for under-prediction than over-prediction of the optimum N rate (Moebius-Clune et al., 2014). Essentially, the model seeks out an EONR. However, Adapt-N recommended lower N rates than the QP generated EONR in five of six site years (Table 4.4). Estimated dollar losses that would occur if the crop was fertilized at the lower Adapt-N recommended rate ranged from \$119 ha^{-1} to \$848 ha^{-1}. At the aforementioned problematic mountain site in 2014, Adapt-N returned its lowest dollar loss margin at \$74 ha^{-1}, even though the recommended N rate was 48 kg N ha^{-1} greater than the EONR. The RYE recommended N rate was generally closer to the EONR with less severe dollar losses, ranging from \$5 ha^{-1} to \$198 ha^{-1} (Table 4.4)

Total mineralization for the N rate trials was calculated from the grain and stover N accumulation in control plots that received 0 kg N ha^{-1}. The Adapt-N predicted mineralized N rate was derived from the program's graphical outputs for a simulation of a field receiving 0 kg N ha^{-1} covering the period between planting and harvest. In four out of 6 sites, Adapt-N overestimated the amount of N mineralized in the soil, estimating 5 to 116 kg N ha^{-1} greater than observed mineralization rates (Table 4.5). High mineralization rates derived from Adapt-N modeling corresponded with underestimation of recommended N rates. If the modeled N mineralization rates had been lower, it is likely that the suggested N rates would more closely match the AONR.

A preliminary investigation of Adapt-N input factors highlighted the importance of the soil organic matter (SOM) input. When all other variables were held constant, a 1% increase in SOM increased nitrogen by 34 kg N ha^{-1}. Given that the model is sensitive to field levels of SOM (which are entered by the program user), determination of SOM values are critical.

Walkley-Black (1934) is considered the most accurate, direct measurement method of SOM but is no longer widely used due to concerns over hazardous waste from the acidic dichromate ($Cr_2O_7^{2-}$) used to oxidize carbon. Loss on ignition (LOI) is a commonly used indirect method of measuring SOM, where organic matter is oxidized to CO_2 at high temperatures and the resulting weight change of the soil sample is used to calculate percent SOM. However, the LOI method is not without issues. Hoskins (2002) reported variability in the range of +/- 21% on a single reference sample. By accounting for variability in heat distribution in a muffle furnace the variability was reduced by nearly 50%, which lead the author to the conclusion that corrections for soil texture could be important. Other reports of precision range from 4.8 to 21.5% with a median of 8.2% (Zhang and Wang, 2014). In some situations, the LOI results can be correlated with other SOM methods for specific regions. Combs and Nathan (1998) regressed LOI estimates to the Walkley-Black method in Missouri with a slope that ranged from 0.66 to 1.04. The LOI method is also utilized as part of the

Cornell Soil Health Assessment, where soil organic matter is reported after weight loss from combustion is adjusted with an equation (Moebius-Clune et al., 2016).

In 2012, the North Carolina Department of Agriculture (NCDA) tested about 388,000 soil samples from nearly 46,000 farms across the state. While they do not directly test for SOM, an NaOH extractant method by Mehlich (1984) is used to determine humic matter (HM). The extractant dissolves humic and fulvic acid, major components of soil humus, which are then quantified with spectrophotometric analysis. The original intention of the method was to aide in making effective herbicide recommendations, but there was emerging research in North Carolina that suggested a simple doubling of the soil test humic matter percentage is an appropriate rough estimate for SOM percentage, though there is not enough evidence to prove this holds true for all soil textures (Hardy, 2016).

To ensure that SOM and 2 times HM (NCDA-HM) were equivalent, we compared the methods for each site. The NCDA-HM and LOI analyses were in general agreement for the coastal plain with differences of less than 1%. However, in the piedmont and mountain locations, the LOI results were greater by up to 4.1% and 3.7% (Table 4.6). The explanation for the large difference in results is unclear, but could potentially be derived from the NCDA method of HM extraction. Fulvic and humic acid in the soil are soluble in an alkali NaOH extractant, but the procedure may not account for the humin fraction (Swift, 1996). Humin can make up varying percentages of total soil organic matter, from approximately 33% in Mollisols and Alfisols, to up to 65% in Vertisols (Stevenson, 1994). As previously discussed, differing OM values have important implications for the Adapt-N model's estimation of total mineralized N (Table 4.5).

In silty soils under maize production, John et al. (2005) found 86-91% of the soil organic carbon in the heavy mineral fraction, but that occluded organic matter was also noticeably present and aged anywhere from 49-83 years. The longevity of occluded organic matter in a system is due to it being relatively inaccessible, so even if it is measured it is likely unavailable to a crop. Thus, the presence, and inability of the NCDA-HM methodology to detect, occluded organic matter may also contribute to the variation in SOM results. Because SOM is an important user input in Adapt-N, it is critical that SOM methodologies are well vetted for different soil types.

Adapt-N predicted N losses are based on soil and weather conditions and these losses are reported by the model in a numeric summary and graphical output from January 1 of the given year to the date when the simulation is run. Nitrogen losses from each N rate were calculated for the period from planting to harvest based on the abovementioned graphical output. Across all site years, total N losses increased as N rate increased (Figure 4.4, 4.5, and 4.6). The greatest total estimated N losses across sites were reported at the coastal plain location. The maximum N lost was 116 kg N ha^{-1} and 142 kg N ha^{-1} from plots receiving 224 kg N ha^{-1} in 2014 and 2015, respectively. High N loss is not unusual at the coastal plain location, where sandy loam soil textures and precipitation events promote leaching (Smith and Cassel, 1991). Minimum total N losses occurred at the piedmont location with an average of 6 kg N ha^{-1} for both years.

The Adapt-N model, however, partitioned the majority of the total N losses from five of six site years to gaseous losses (Figure 4.4, 4.5, and 4.6). The model does not distinguish between volatilization losses and potential gaseous losses from denitrification, but an inspection of rate constants used in the LEACHN model would imply that volatilization losses, at least in that model, are given more weight (Johnson and Cabrera, 1999; Hutson, 2010). The large gaseous losses predicted by the Adapt-N model also appear to be largely influenced by the user selection of surface application of UAN as opposed to an injection, supporting the assumption that the majority of gaseous losses in this case are via ammonia (NH_3) volatilization. When injection to a depth of 5-10 cm is selected as an input in Adapt-N, gaseous losses decrease considerably. Surface applications of UAN were necessary to facilitate applications of various rates across the trial and to reflect grower practices in North Carolina; UAN moved quickly into the soil at all locations. The LEACHN model acknowledges that NH_3 volatilization is a complex pH-dependent process and as such, describes it with first order kinetics as a function of a rate constant (which is not temperature or moisture related) and the concentration of ammonium (NH_4) in the upper soil segment (Hutson, 2010). This is in contrast to denitrification rate constants, which are always adjusted for soil water content, regardless of temperature, and will continue as long as sufficient organic carbon is present (Hutson, 2010).

The soils included in this trial also had fairly low pH, in the range of 5.2-6.5, which is not ideal for high volatilization losses (Meisinger and Randall, 1991), but is appropriate for soils in North Carolina (Hardy et al., 2014). Meisinger and Randall (1991) approximate that UAN surface applied to soil with pH below 7 should lose 0 to 15 percent of fertilizer N to volatilization, dependent on weather. Predictions from the Adapt-N model were at the higher end, or exceeded this range in most site years. In four of six site years, precipitation in the five days following sidedress should have been adequate to significantly slow or stop volatilization losses. The highest gaseous losses modelled by the Adapt-N program were reported at the coastal plain location, with 40 and 86 kg N ha^{-1} in 2014 and 2015, respectively. These values are much higher than the average 0-4 kg N ha^{-1} volatilized from a similar loamy sand treated with 134 kg N ha^{-1} reported by Sogbedji et al (2001) in their calibration of LEACHN in New York.

Gaseous losses generally increased as a percentage of total N losses as N rate increased, while N leaching losses tended to decrease as a proportion of total N losses as N rate increased. In five of six site years, N leaching losses remained fairly constant over all N rates (Figure 4.4, 4.5, and 4.6). Typically, leaching losses increase with excess nitrate in the soil, but the model assumes a small soil N pool due to large gaseous losses at application. At the coastal plain, leaching losses modelled by Adapt-N ranged from 27 to 76 kg N ha^{-1} as N rates increased in 2014 and from only 52 to 57 kg N ha^{-1} in 2015. In evaluations of riparian buffers in similar soils in the area, observed mean nitrate concentrations in groundwater at the field edge were reported in the range of 3 to 12 mg L^{-1} (Messer et al., 2012; Wiseman et al., 2014), which translates to a loss of between 7 and 34 kg N ha^{-1} yr^{-1} (Gilliam, 2015). At the piedmont, leaching losses modelled by Adapt-N remained constant at 2.9 kg N ha^{-1} and 1.7 kg N ha^{-1} as N rates increased in 2014 and 2015, respectively. In a validation of LEACHN in the Georgia piedmont, Johnson and Cabrera (1999) observed 25 ($^{+}$/-12) kg NO_3-N ha^{-1} leached from corn following a winter rye cover crop in a normal rainfall year (833 mm), and 1 kg NO_3-N ha^{-1} lost from a low rainfall year (198 mm). Both crops received fertilizer treatments of 168 kg N ha^{-1}. The piedmont N rate trials received about half the precipitation of the Johnson and Cabrera normal rainfall year (409 mm), but nearly an equivalent amount in 2015, the dry year (221 mm). While the dry year N leaching values are similar, the reported losses in the wet year do not correlate with the Adapt-N model.

It is entirely possible that rate constants set in Adapt-N differ from those used in its predecessor, LEACHN, and comparisons between the two are meant to highlight the functionality of the models and relative weight of certain N transformations. It should also be noted that these simulated losses cannot be verified for these trials because collection of N loss data was beyond the scope of this research.

Grower Strip Trials

Treatment was statistically significant in 7 of 18 site years (Table 4.7). Strips treated with the Grower_{N} rate returned higher yields than Adapt-N rates in 4 site years by an average of 1.240 kg ha^{-1} (Farm 2, 3, 6 in 2014 and Farm 11 in 2015). In the remaining 3 significant site years, there was no significant difference in yield between the Grower_{N} and Adapt-N rates (Farm 3 and 6 in 2015 and Farm 10 in 2014).

Treatment was not significant in 11 of 18 site years (Table 4.7). In these cases, the assumption can be made that the lowest N rate included in the trial is sufficient to produce optimum yields. The $\text{Grower}_{-25\%}$ N rate was the lowest in 10 out of the 11 non-significant site years, with the exception of Farm 2 in 2015, where the Adapt-N rate was lower than the $\text{Grower}_{-25\%}$ N rate by 26 kg ha^{-1}. Though not statistically different, overall the $\text{Grower}_{-25\%}$ N rate produced an average yield of 186 kg ha^{-1} less than the Adapt-N rate. It should also be noted that grain yield in plots treated with $\text{Grower}_{-25\%}$ met or exceeded the grower’s yield goal in 8 of the 18 site years.

The Adapt-N program aims to make more efficient N recommendations than the current grower practices. Thus, the Grower_{N} rate yields in the 11 non-significant site years were compared to the Adapt-N rate yields for numerical differences. The Grower_{N} rate resulted in a greater yield than the Adapt-N rate in 9 of those site years by an average of 248 kg ha^{-1} (4 bu ac^{-1}).

Another important consideration of the suitability of the Adapt-N model is how it performed relative to the currently accepted RYE N rate recommendation database. Observed Grower$_N$ and Adapt-N rates and yields were normalized for site-specific yield and RYE N rate goals. Adapt-N generally recommended greater N rates by an average of 17 kg N ha^{-1}, which in turn produced a yield advantage that was nearly 744 kg ha^{-1} greater than what the RYE database predicted. The margin of difference between Adapt-N and the RYE values was smaller than the margin between Grower$_N$ and RYE values. In the latter case, the Grower$_N$ rate was nearly 43 kg N ha^{-1} greater, but returned higher yields by an average of 1,240 kg ha^{-1}. When plotted, a majority of the Grower$_N$ and Adapt-N treatment normalized values fell into quadrant I, indicating that for both treatments, N rates and resulting yields were greater than RYE database recommendations (Figure 4.7). Five Adapt-N site years and 7 Grower$_N$ site year treatments fell into quadrant I and returned higher yields for less N input. In quadrant II, Adapt-N recommended lower N rates but returned higher yields than the RYE database in five site years. However, an equal number of Adapt-N site years were recommended greater N rates and recorded lower yields than the RYE database (quadrant IV). There does not appear to be a clear advantage to Grower$_N$ or Adapt-N rates relative to the RYE database. Adapt-N does recommend lower N rates than Grower$_N$, which is likely a function of the economic component of the model. However, the RYE database made recommendations with generally lower N factors (amount of N applied per unit of yield) in the range of 0.88 to 0.95 compared to the 0.73 to 1.24 achieved with the Grower$_N$ rate (Data not shown).

CONCLUSIONS

The Adapt-N model has potential as an N rate recommendation tool, but several issues must be addressed. First, the SOM algorithm used causes Adapt-N to overestimate the amount of N mineralized and thus underestimate the appropriate N rate. It is important to note, as Schröder (2000) does in a review of soil N status assessment tools, the literature is unclear on the portion of soil organic matter that is readily mineralizable in any given year, and there are significant difficulties in predicting the amount of soil mineral N available at any given depth or time of the year.

The partitioning of N losses should also be adjusted to regional climates. Nitrogen cycling in the humid Southeast leads to different loss pathways than the Midwest. The description of losses can be a helpful tool to growers with nutrient sensitive watersheds, but may mask the issue or cause unintended over-application if estimated leaching losses are low. It is unlikely that the amount of N lost through leaching is constant or independent of the amount of N applied, as the model suggested in several scenarios.

In grower strip trials, the Grower_{N} rate showed a slight advantage over the Adapt-N rate when treatment was significant. In all other circumstances, the lack of differences among treatments indicated the $\text{Grower}_{\text{-25\%}}$ rate, which was generally less than the Grower_{N} and Adapt-N rates, would be appropriate to meet growers’ expected yields.

TABLES

Table 4.1 - Summary of Adapt-N user inputs and program outputs.

Adapt-N User Inputs	Adapt-N Model Outputs
Field location	N sidedress recommendation
% Slope	Expected N in crop at harvest
Drainage class	N mineralization so far
Soil type/texture	N loss so far
Rooting depth	Soybean credit
Tillage method	N in crop now
Tillage date	Expected future N loss
Tillage depth	Future net N credits
Tillage % residue	N in soil now
Soil test	Rainfall since planting
Soil test sample depth	Rainfall since Jan 1
Soil organic matter %	Current nitrate N in top 12"
Crop maturity class	Virtual PSNT
Expected harvest population	Water in root zone
Expected yield	Water at field capacity
Planting date	Root zone inorganic N
Previous crop	Total N loss
Sod termination date	Precipitation
Sod legume percent	
Sod termination method	
Fertilizer application method	
Application date	
Fertilizer type	
Amount of fertilizer	
Placement depth	
Enhanced efficiency product	

Table 4.2 - Grower strip trial field information.

Site	Year	Soil Series	Previous Crop	Tillage	Hybrid	Seeding Rate (seed ha^{-1})
Farm 1	2014	State	Soybean	Conventional	Augusta 5566	61,750
Farm 1	2015	Stallings	Cotton	Conventional	DKC64-69	76,570
Farm 2	2014	Augusta	Cotton	Conventional	DKC 66-97	67,925
Farm 2	2015	Deloss	Cotton	Conventional	Dyna-Gro 57VP51	67,925
Farm 3	2014	Rains	Cotton	Strip	DKC 68-05	74,100
Farm 3	2015	Craven	Cotton	Strip	DKC 64-69	67,925
Farm 4	2014	Goldsboro	Peanut	No-Till	Dyna-Gro 57VP51	74,100
Farm 5	2014	Lynchburg	Cotton	Conventional	DKC 64-69	67,925
Farm 5	2015	Goldsboro	Sweet Potatoes	Conventional	DKC64-69	67,925
Farm 6	2014	Rains	Soybean	Strip	Phoenix 6542	80,275
Farm 6	2015	Tomotley	Cotton	Strip	*	74,100
Farm 7	2014	Rains	Corn	Conventional	DKC 68-05	80,275
Farm 8	2014	Goldsboro	Soybean	Conventional	Dyna-Gro 57VP51	80,275
Farm 8	2015	Goldsboro	Soybean	Conventional	*	80,275
Farm 9	2014	Rains	Soybean	Strip	DKC 68-03	74,100
Farm 10	2014	Aycock	Soybean	Conventional	DKC 64-69	61,750
Farm 11	2015	Stockade	Soybean	No-Till	Pioneer 0604AM	80,275
Farm 12	2015	Goldsboro	Soybean	Conservation	Pioneer 0604AM	80,275

** indicates data not reported by participating grower.*

Table 4.3 – Comparison of total recommended N rates (kg N ha^{-1}) for each site year as determined by the linear plateau model (AONR), the RYE database, and Adapt-N model.

Location	Year	AONR (kg N ha^{-1})	RYE N Rate (kg N ha^{-1})	Adapt-N Rate (kg N ha^{-1})
Coastal Plain	2014	150	151	112
	2015	168	169	45
Piedmont	2014	117	147	45
	2015	148	147	45
Mountains	2014	67	185	246
	2015	191	177	112

Table 4.4 – Comparison of Adapt-N and RYE recommended N rates to economic optimum N rate (EONR) for each site year as determined by quadratic-plateau model.

Site Year	EONR (kg N ha^{-1})	Adapt-N Rate (kg N ha^{-1})	Dollar loss from EONR (\$ ha^{-1})	RYE N Rate (kg N ha^{-1})	Dollar loss from EONR (\$ ha^{-1})
Coastal Plain 2014	152	112	269	151	5
Coastal Plain 2015	158	45	848	169	17
Piedmont 2014	110	45	366	147	57
Piedmont 2015	161	45	119	147	5
Mountains 2014	198	246	74	185	121
Mountains 2015	198	112	815	177	198

Table 4.5 - Comparison of measured and Adapt-N simulated N mineralization under maize crop by location.

Location	Year	Total N Mineralization (kg ha^{-1})		
		Measured	Adapt-N (NCDA-HM)	Adapt-N (LOI)
Coastal Plain	2014	67.7	90.4	71.7
	2015	79.4	185.6	196.0
Piedmont	2014	79.2	7.4	67.2
	2015	36.6	11.1	80.6
Mountains	2014	101.9	9.3	38.1
	2015	53.3	22.8	70.6

Table 4.6 - Comparison of soil organic matter content for soils used in each site year as determined by doubling the humic matter reported by NCDA (NCDA-HM) and via loss on ignition (LOI) method.

Location	Year	Percent Organic Matter	
		NCDA-HM	LOI
Coastal Plain	2014	4.16	3.302
Coastal Plain	2015	10.18	10.737
Piedmont	2014	0.44	4.104
Piedmont	2015	0.64	4.714
Mountains	2014	1.12	4.803
Mountains	2015	1.72	5.123

Table 4.7 – Maize yield (kg ha^{-1}) by treatment (-25% Grower N Rate, Grower N Rate, +25% Grower N Rate, and Adapt-N Rate) for each site year.

Grower N > Adapt N

			-25% Grower N Rate		Grower N Rate		+25% Grower N Rate		Adapt N Rate	
Farm ID	**Year**		**Maize Yield (kg ha-1)**							
Farm 2	2014	**	12,834	b	13,826	a	14,136	a	12,834	b
Farm 3	2014	***	9,362	d	11,532	b	12,772	a	10,354	c
Farm 6	2014	*	12,028	a	12,276	a	12,276	a	10,912	b
Farm 11	2015	*	7,998	b,c	9,176	a,b	9,300	a	7,688	c

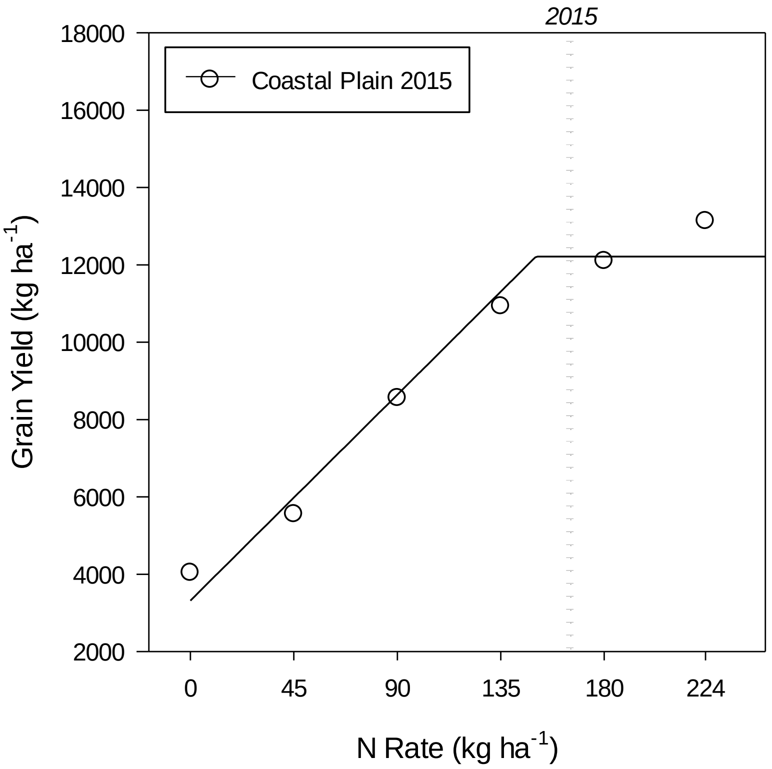
Grower N = Adapt N

			-25% Grower N Rate		Grower N Rate		+25% Grower N Rate		Adapt N Rate	
Farm ID	**Year**		**Maize Yield (kg ha-1)**							
Farm 3	2015	*	4,898	b,c	5,146	a,b	4,712	c	5,208	a
Farm 6	2015	**	9,796	b	11,408	a	11,966	a	11,346	a
Farm 10	2014	*	10,354	b	11,904	a	11,594	a	11,222	a

Treatment Was Not Significant

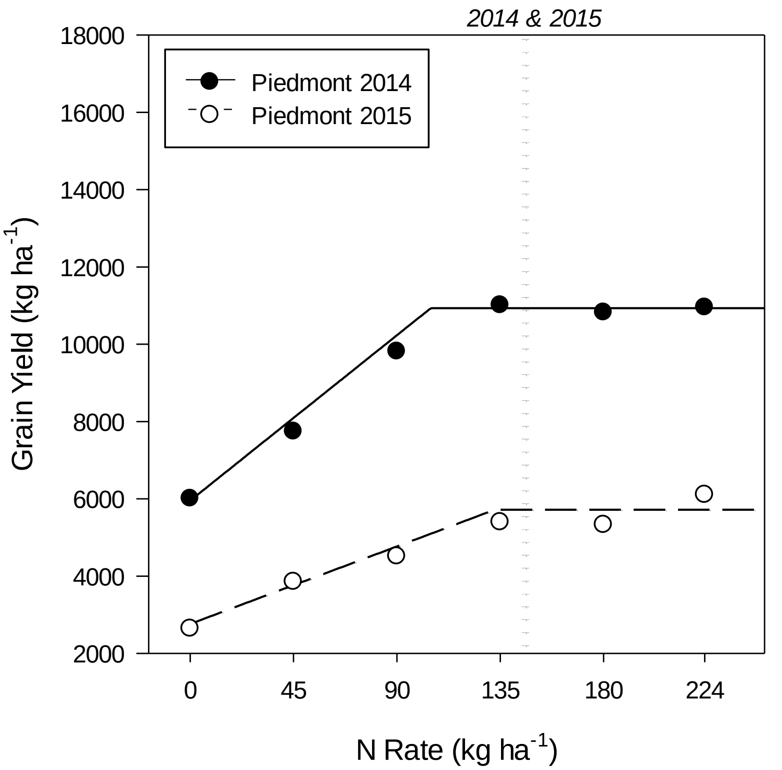
			-25% Grower N Rate		Grower N Rate		+25% Grower N Rate		Adapt N Rate	
Farm ID	**Year**		**Maize Yield (bu ac-1)**							
Farm 1	2014	NS	12,152	a	12,834	a	12,834	a	12,958	a
Farm 1	2015	NS	7,688	a	8,060	a	7,750	a	7,936	a
Farm 2	2015	NS	9,610	a	10,168	a	11,284	a	10,230	a
Farm 4	2014	NS	11,284	a	11,780	a	12,152	a	11,284	a
Farm 5	2014	NS	10,416	a	10,850	a	11,036	a	10,726	a
Farm 5	2015	NS	11,408	a	11,904	a	12,586	a	11,718	a
Farm 7	2014	NS	9,300	a	9,672	a	9,548	a	9,548	a
Farm 8	2014	NS	10,974	a	11,532	a	11,842	a	11,222	a
Farm 8	2015	NS	6,324	a	6,944	a	7,130	a	6,572	a
Farm 9	2014	NS	9,424	a	9,672	a	9,734	a	9,362	a
Farm 12	2015	NS	9,300	a	9,362	a	8,804	a	8,618	a

FIGURES



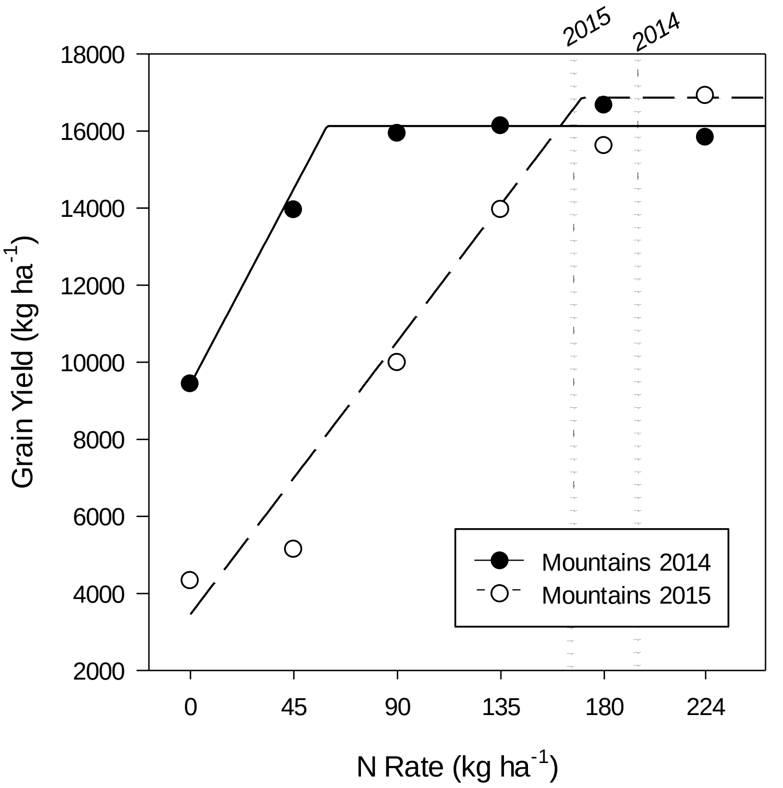
Dotted vertical line indicates RYE recommended N rate for given site.

Figure 4.1 - Linear-plateau yield curve for maize grain yield at coastal plain location.



Dotted vertical line indicates RYE recommended N rate for given site.

Figure 4.2 - Linear-plateau yield curve for maize grain yield at piedmont location.



Dotted vertical lines indicates RYE recommended N rate for given site.

Figure 4.3 - Linear-plateau yield curve for maize grain yield at mountain location.

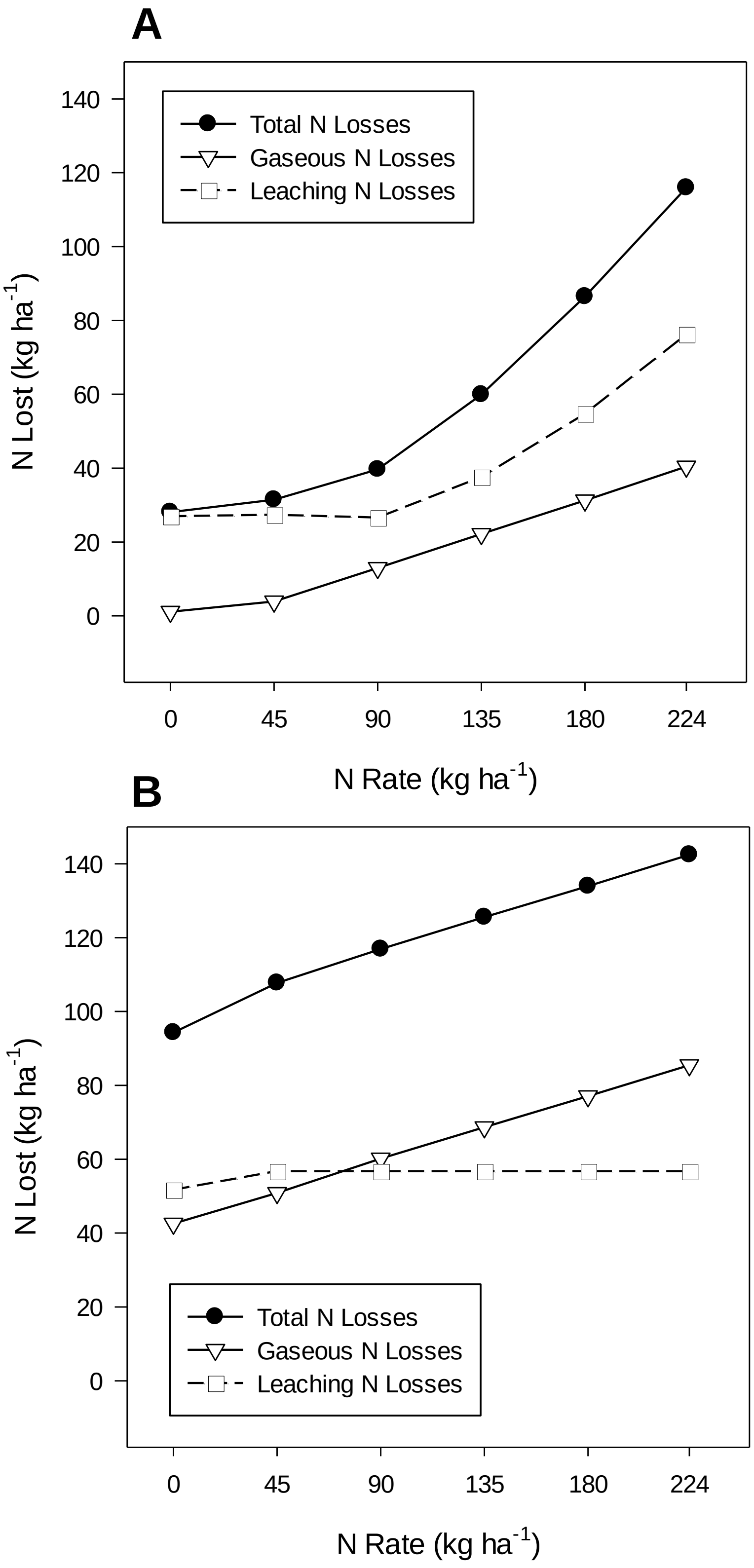


Figure 4.4 – Adapt-N simulated nitrogen loss patterns under maize crop at the coastal plain in A) 2014 and B) 2015.

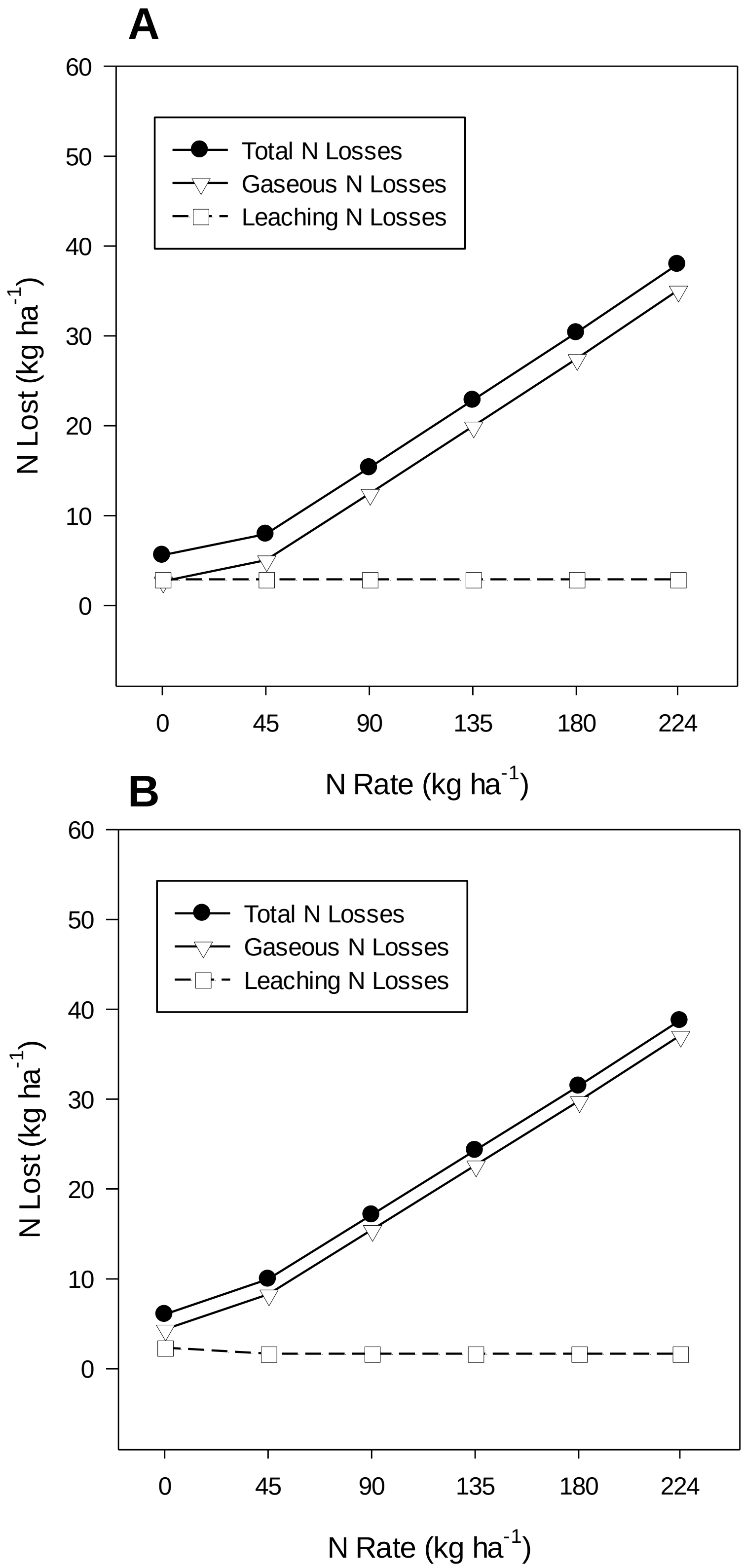


Figure 4.5 - Adapt-N simulated nitrogen loss patterns under maize crop at the piedmont in A) 2014 and B) 2015.

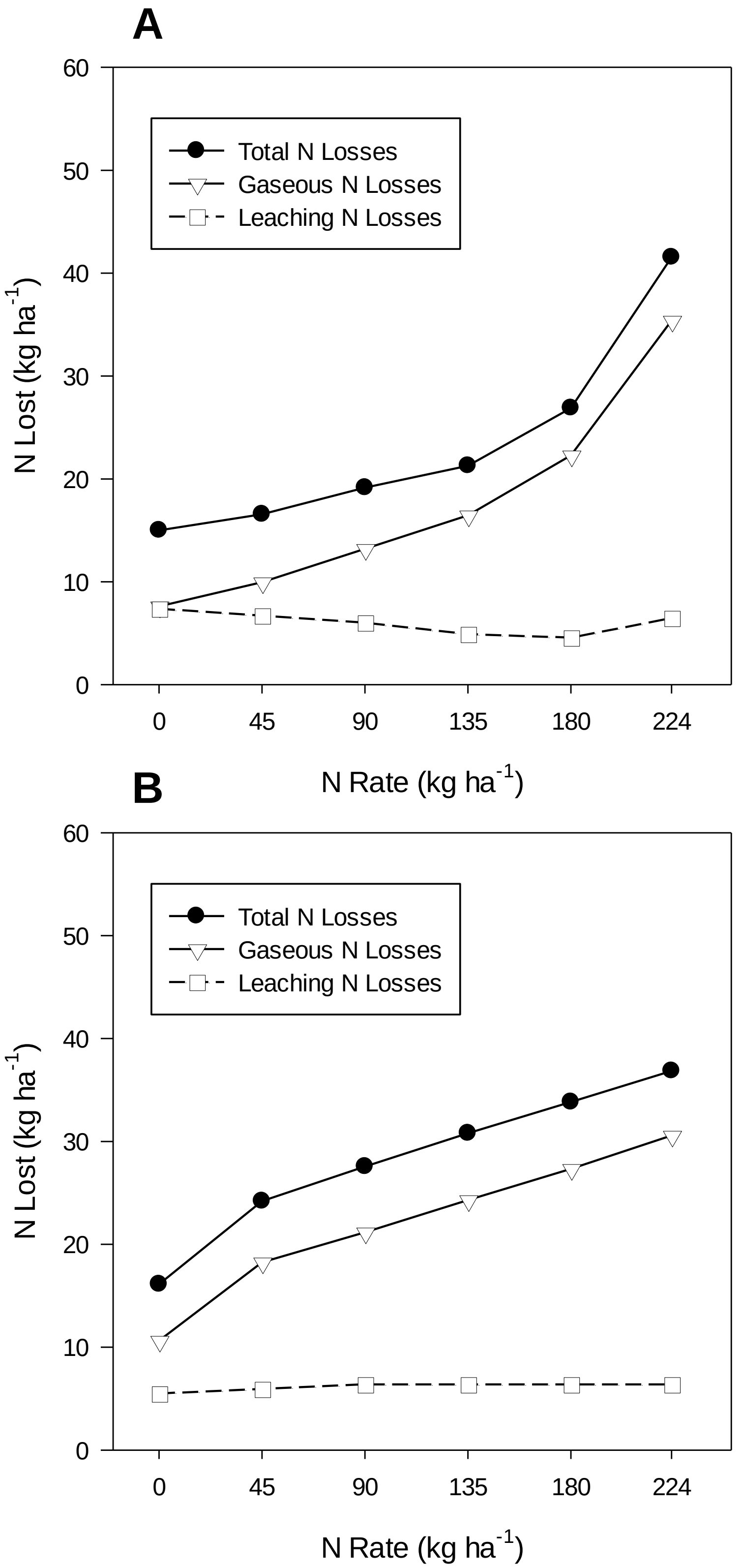


Figure 4.6 - Adapt-N simulated nitrogen loss patterns under maize crop in the mountains in A) 2014 and B) 2015.

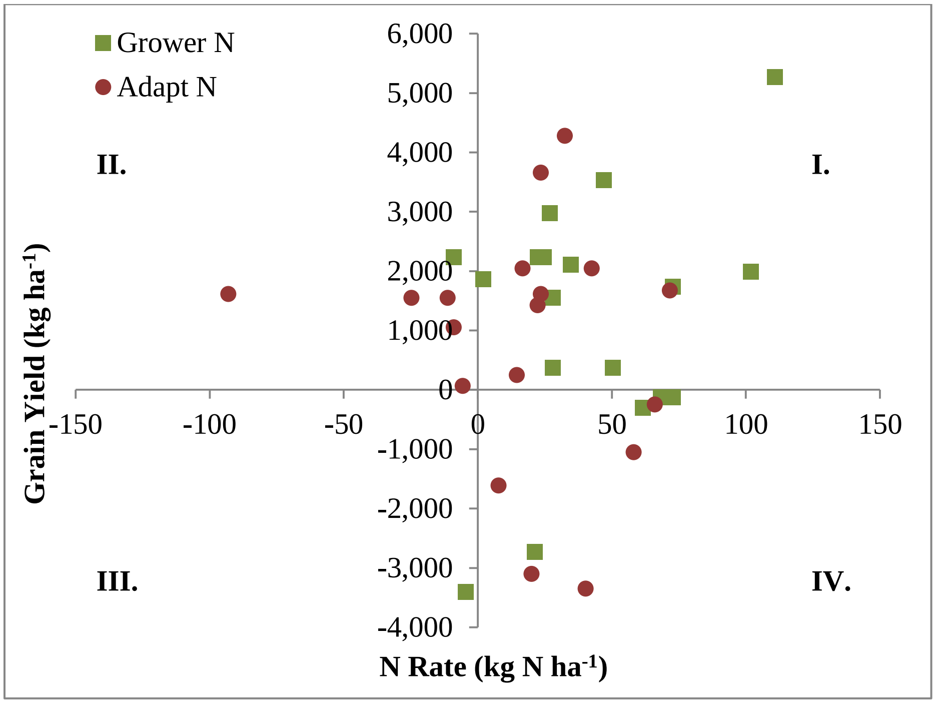


Figure 4.7 - Grower$_N$ and Adapt-N grain yield (kg ha^{-1}) normalized to RYE database recommendations.

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APPENDICES

APPENDIX A

Table A1 - Soil chemical properties of maize field sites by location.

Crop/Year	**Maize 2014**			**Maize 2015**		
Station	Coastal Plain	Piedmont	Mountains	Coastal Plain	Piedmont	Mountains
Soil Series	Lynchburg	Lloyd	Comus	Portsmouth	Lloyd	Codurus
Phase	fine loamy sand	clay loam	silt loam	loam	clay loam	loam
Soil Class	mineral	mineral	mineral	mineral	mineral	mineral
HM%	2.08	0.22	0.56	5.09	0.32	0.86
W/V	1.22	1.08	0.93	1.06	0.98	0.9
CEC	7.4	7.5	6.3	7.3	7.9	7.2
BS%	82	89	75	64	71	80
Ac	1.4	0.8	1.6	2.6	2.3	14.0
pH	6.1	6.5	5.7	5.2	5.4	6
P-I	218	14	35	144	56	32
K-I	70	19	52	101	49	28
Ca%	58	62	51	46	46	58
Mg%	19	26	20	10	55	20
S-I	36	39	47	46	51	151
Mn-I	81	966	106	73	768	101
Mn-Al(1)	64	590	74	61	478	108
Mn-Al(2)	n/a	n/a	74	n/a	471	78
Zn-I	125	83	66	165	148	78
Zn-Al	125	83	66	206	148	248
Cu-I	82	167	98	105	200	31
Na	0.1	0.1	0.1	0.1	0.0	25.0

Table A2 - Soil chemical properties of wheat field sites by location.

Crop/Year	**Wheat 2013-14**		**Wheat 2014-15**	
Station	Coastal Plain	Piedmont	Coastal Plain	Piedmont
Soil Series	Johns	Lloyd	Portsmouth	Lloyd
Phase	sandy loam	clay loam	loam	clay loam
Soil Class	mineral	mineral	mineral	mineral
HM%	0.6	0.32	6.58	0.27
W/V	1.29	1.05	0.94	1.03
CEC	5	8.4	10	8
BS%	76	89	68	82
Ac	1.2	1.0	3.2	1.4
pH	5.7	6.4	5.2	6.1
P-I	142	35	249	57
K-I	86	65	166	62
Ca%	49	60	50	54
Mg%	19	25	9	24
S-I	30	31	45	54
Mn-I	70	1435	61	1159
Mn-Al(1)	52	871	59	711
Mn-Al(2)	52	n/a	n/a	704
Zn-I	91	130	355	99
Zn-Al	91	130	589	99
Cu-I	30	169	198	201
Na	0.1	0.0	0.1	0.1

Table A3 – Nitrogen rate and product trial maize field management summary by location.

Coastal Plain		
Year	**2013-14**	**2014-15**
Variety	Pioneer 1690YHR	Pioneer 1690YHR
Plant Date	4/14/2014	4/11/2015
Planting Density	69,355 ha^{-1}	75,809 ha^{-1}
Row Spacing	97 cm	76 cm
Tillage	Conservation	Conservation
Prior Crop	Soybean	Soybean
Fertilizer N at Plant	45 kg ha^{-1}	45 kg ha^{-1}
Sidedress Date	5/22/2014	5/26/2015
Harvest	9/16/2014	8/30/2015
Piedmont		
Year	**2013-14**	**2014-15**
Variety	Pioneer 1690YHR	Pioneer 1690YHR
Plant Date	4/24/2014	4/13/2015
Planting Density	78,527 ha^{-1}	75,809 ha^{-1}
Row Spacing	76 cm	76 cm
Tillage	Conservation	Conservation
Prior Crop	Soybean	Soybean
Fertilizer N at Plant	45 kg ha^{-1}	45 kg ha^{-1}
Sidedress Date	6/3/2014	5/29/2015
Harvest	10/1/2014	9/9/2015
Mountains		
Year	**2013-14**	**2014-15**
Variety	Pioneer 1690YHR	Pioneer 1690YHR
Plant Date	5/12/2014	5/5/2015
Planting Density	78,527 ha^{-1}	78,527 ha^{-1}
Row Spacing	76 cm	76 cm
Tillage	Conventional	Conventional
Prior Crop	Maize	Maize
Fertilizer N at Plant	45 kg ha^{-1}	45 kg ha^{-1}
Sidedress Date	6/12/2014	6/16/2015
Harvest	10/16/2014	9/14/2015

Table A4 - Nitrogen rate and product trial wheat field management summary by location.

	Coastal Plain		**Piedmont**	
Year	**2013-14**	**2014-15**	**2013-14**	**2014-15**
Variety	Yadkin	Shirley	Southern States 8350	Shirley
Plant Date	10/29/2013	10/29/2014	11/11/2013	10/21/2014
Planting Density	3.7 million ha^{-1}	3.7 million ha^{-1}	3.7 million ha^{-1}	3.7 million ha^{-1}
Row Spacing	15 cm	15 cm	19 cm	19cm
Tillage	Conventional	Conventional	Conservation	Conservation
Prior Crop	Maize	Maize	Maize	Maize
Fertilizer N at Plant	34 kg ha^{-1}	34 kg ha^{-1}	34 kg ha^{-1}	34 kg ha^{-1}
Sidedress Date	3/1/2014	3/4/2015	3/5/2014	3/6/2015
Harvest	6/9/2014	6/8/2015	6/17/2014	6/19/2015

Table A5 – Summary of key climate indicators for maize cropping seasons by site year.

Month	Precipitation (mm)	5-year average precipitation (mm)	Difference of observed year from average	Average soil temperature (C)	5-year average soil temperature (C)	Average air temperature (C)	5-year average air temperature (C)	Average soil moisture (m^3/m^3)
Coastal Plain 2014								
April	118.6	87.7	30.9	16.2	16.6	16.9	16.5	0.4
May	82.9	127.5	-44.6	23.8	22.6	22.2	21.4	0.1
June	293.6	175.8	117.9	28.0	27.1	24.9	24.7	0.2
July	286.6	186.7	99.9	29.1	29.3	25.3	26.3	0.3
August	151.9	156.5	-4.6	28.2	28.5	24.2	24.6	0.3
September	166.5	88.4	78.1	27.2	26.3	22.5	22.1	0.1
Total	**1100.1**	**822.5**	**277.6**					
Coastal Plain 2015								
April	58.7	87.7	-29.0	8.8	16.6	16.9	16.5	0.1
May	146.2	127.5	18.7	22.6	22.6	21.2	21.4	0.2
June	139.1	175.8	-36.7	27.9	27.1	26.1	24.7	0.1
July	163.7	186.7	-23.0	29.3	29.3	26.6	26.3	0.1
August	98.1	156.5	-58.4	28.4	28.5	24.8	24.6	0.1
September	90.0	88.4	1.6	26.4	26.3	22.9	22.1	0.2
Total	**695.8**	**822.5**	**-126.7**					
Piedmont 2014								
April	175.1	127.4	47.7	15.4	16.0	15.1	15.3	0.2
May	101.2	91.7	9.5	22.9	21.8	20.3	20.1	0.4
June	69.7	148.5	-78.8	27.0	26.0	23.8	23.7	0.4
July	74.0	156.7	-82.7	27.5	26.2	23.9	25.1	0.4
August	106.6	136.3	-29.7	23.9	20.5	23.2	23.7	0.4
September	42.3	75.1	-32.8	22.6	23.6	21.1	20.7	0.4
Total	**568.9**	**735.7**	**-166.8**					
Piedmont 2015								
April	61.8	127.4	-65.6	7.7	16.0	15.7	15.3	0.2
May	6.9	91.7	-84.8	22.3	21.8	20.9	20.1	0.3
June	69.6	148.5	-78.9	28.1	26.0	25.3	23.7	0.3
July	14.0	156.7	-142.7	29.6	26.2	26.1	25.1	0.3
August	46.6	136.3	-89.7	28.8	20.5	24.7	23.7	0.3
September	77.3	75.1	2.2	24.7	23.6	21.4	20.7	0.4
Total	**276.2**	**735.7**	**-459.5**					
Mountains 2014								
May	116.7	115.7	1.0	19.4	20.1	17.5	17.7	0.4
June	134.8	167.8	-33.0	23.8	24.2	21.4	21.3	0.4
July	135.1	196.5	-61.4	24.7	25.7	21.3	22.5	0.4
August	88.3	116.3	-28.0	24.5	25.2	21.5	21.3	0.4
September	135.7	119.5	16.3	23.6	22.9	19.7	18.8	0.4
October	111.1	92.2	18.9	17.1	16.8	13.3	12.9	0.4
Total	**721.7**	**808.0**	**-86.3**					
Mountains 2015								
May	49.1	115.7	-66.6	21.8	20.1	18.5	17.7	0.1
June	199.2	167.8	31.4	25.0	24.2	21.9	21.3	0.4
July	98.3	196.5	-98.2	25.6	25.7	23.2	22.5	0.3
August	82.1	116.3	-34.2	26.3	25.2	21.6	21.3	0.4
September	117.0	119.5	-2.5	23.0	22.9	18.5	18.8	0.3
October	137.0	92.2	44.8	8.1	16.8	12.6	12.9	0.2
Total	**682.7**	**808.0**	**-125.3**					

Table A6 - Summary of key climate indicators for wheat cropping seasons by site year.

Month	**Precipitation (mm)**	**5-year average precipitation (mm)**	**Difference of observed year from average**	**Average soil temperature (C)**	**5-year average soil temperature (C)**	**Average air temperature (C)**	**5-year average air temperature (C)**	**Average soil moisture (m^3/m^3)**
Coastal Plain 2013-14								
October	1.0	64.7	-63.7	21.1	21.3	17.2	16.9	0.4
November	75.4	52.4	23.0	15.3	14.5	10.6	10.4	0.4
December	143.5	92.2	51.3	11.9	11.6	9.1	9.3	0.4
January	59.8	77.9	-18.1	7.6	8.8	4.2	6.6	0.4
February	81.4	94.9	-13.5	8.3	8.1	6.7	6.4	0.4
March	150.1	100.1	50.0	9.3	11.3	8.8	11.1	0.4
April	118.6	87.7	30.9	16.2	16.6	16.9	16.5	0.4
May	82.9	127.5	-44.6	23.8	22.6	22.2	21.4	0.1
June	293.6	175.8	117.9	28.0	27.1	24.9	24.7	0.2
Total	**1006.3**	**873.1**	**133.2**					
Coastal Plain 2014-15								
October	38.5	64.7	-26.2	22.5	21.3	17.6	16.9	0.2
November	81.2	52.4	28.8	15.2	14.5	9.2	10.4	0.2
December	103.2	92.2	11.0	11.4	11.6	7.9	9.3	0.3
January	150.1	77.9	72.3	8.7	8.8	5.5	6.6	0.3
February	123.8	94.9	28.9	7.0	8.1	2.7	6.4	0.3
March	102.9	100.1	2.8	11.5	11.3	11.2	11.1	0.3
April	104.8	87.7	17.1	17.7	16.6	16.9	16.5	0.3
May	146.2	127.5	18.7	22.6	22.6	21.2	21.4	0.2
June	139.1	175.8	-36.7	28.0	27.1	26.1	24.7	0.1
Total	**989.8**	**873.1**	**116.7**					
Piedmont 2013-14								
October	36.5	68.1	-31.6	18.2	17.6	15.6	14.9	0.2
November	108.6	99.2	9.4	10.2	10.7	7.6	8.1	0.2
December	154.9	95.6	59.4	7.6	8.6	6.8	7.2	0.1
January	105.7	87.8	17.9	3.2	5.9	0.9	4.0	0.4
February	62.6	67.6	-5.0	6.8	6.4	5.8	4.8	0.5
March	164.6	101.2	63.5	8.0	10.4	7.4	9.8	0.5
April	175.1	127.4	47.7	15.4	16.0	15.1	15.3	0.2
May	101.2	91.7	9.5	22.9	21.8	20.3	20.1	0.4
June	69.7	148.5	-78.8	27.0	26.0	23.8	23.7	0.4
Total	**978.9**	**887.1**	**91.9**					
Piedmont 2014-15								
October	52.9	68.1	-15.2	17.8	17.6	15.6	14.9	0.4
November	102.3	99.2	3.1	9.2	10.7	7.2	8.1	0.4
December	62.3	95.6	-33.3	7.3	8.6	6.2	7.2	0.4
January	60.2	87.8	-27.6	4.9	5.9	3.4	4.0	0.4
February	59.6	67.6	-8.0	4.2	6.4	1.6	4.8	0.5
March	70.8	101.2	-30.4	10.7	10.4	10.4	9.8	0.4
April	101.2	127.4	-26.2	16.4	16.0	15.7	15.3	0.4
May	6.9	91.7	-84.8	22.3	21.8	20.9	20.1	0.3
June	69.6	148.5	-78.9	28.1	26.0	25.3	23.7	0.3
Total	**585.8**	**887.1**	**-301.3**					

Table A7 – Year x N rate interaction of nitrogen rate and product trial wheat grain and straw yield by location.

Wheat Grain Yield (kg ha^{-1})											
		Spring N Rate (kg ha^{-1})									
Location		**0**		**45**		**90**		**135**		**180**	
Coastal Plain	2013-14	2,280	a	3,640	b	5,441	d	6,353	e	6,882	f
	2014-15	4,426	c	5,827	d	6,922	f	7,401	g	8,062	h
Piedmont	2013-14	4,705	a	5,134	a,b	6,474	d	6,803	d	6,749	d
	2014-15	4,775	a	5,380	b	6,053	c	6,523	c,d	6,749	d

Wheat Straw Yield (kg ha^{-1})											
		Spring N Rate (kg ha^{-1})									
Location		**0**		**45**		**90**		**135**		**180**	
Coastal Plain	2013-14	1,220	a	2,365	b	3,246	c	3,781	d	4,401	e,f
	2014-15	2,646	b	4,035	d,e	4,837	g	4,686	f,g	5,538	h
Piedmont	2013-14	2,607	a,b	3,036	b,c	4,182	d,e	4,464	e	3,789	d
	2014-15	2,342	a	2,888	a,b,c	3,034	b,c	3,143	b,c	3,220	c

Table A8 - Total wheat N content in N rate and product trials at coastal plain by main effect of treatment.

Treatment					
UAN		**NZone**		**Instinct**	
Total N (kg ha^{-1})					
134	a	136	a,b	143	b

Table A9 - Results of ANOVA statistical analysis of 2014-15 wheat N rate and product trials (including AgrotainPlus).

Coastal Plain			
Parameter	Treatment	N Rate	Treatment x N Rate
Grain Yield	NS	**	NS
Straw Yield	NS	**	NS
NUE	NS	*	NS
N Grain	NS	**	NS
N Straw	NS	**	NS
N Total	NS	**	NS
Piedmont			
Parameter	Treatment	N Rate	Treatment x N Rate
Grain Yield	NS	**	NS
Straw Yield	NS	*	NS
NUE	NS	*	NS
N Grain	*	**	NS
N Straw	NS	**	NS
N Total	NS	**	NS

***, *, and NS indicate p value of <0.0001, p < 0.05, and not significant (p > 0.05), respectively.*

Table A10 - Taxonomic soil descriptions for N rate trials and grower strip trials by location.

Site	Year	Soil Series	Surface Phase	Taxonomic Description
N Rate Response Trials				
Coastal Plain	2014	Lynchburg	Loamy fine sand	Fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults
Coastal Plain	2015	Portsmouth	Fine sandy loam	Fine-loamy over sandy, mixed, semiactive, thermic Typic Umbraquults
Piedmont	2014	Lloyd	Clay loam	Fine, kaolinitic, thermic Rhodic Kanhapludults
Piedmont	2015	Lloyd	Clay loam	Fine, kaolinitic, thermic Rhodic Kanhapludults
Mountains	2014	Comus	Silt loam	Coarse-loamy, mixed, active, mesic Fluventic Dystrudepts
Mountains	2015	Codurus	Silt loam	Fine-loamy, mixed, active, mesic Fluvaquentic Dystrudepts
N Rate Strip Trials				
Farm 1	2014	State	Silt loam	Fine-loamy, mixed, semiactive, thermic Typic Hapludults
Farm 1	2015	Stallings	Loamy sand	Coarse-loamy, siliceous, semiactive, thermic Aeric Paleaquults
Farm 2	2014	Augusta	Loam	Fine-loamy, mixed, semiactive, thermic Aeric Endoaquults
Farm 2	2015	Deloss	Fine sandy loam	Fine-loamy, mixed, semiactive, thermic Typic Umbraquults
Farm 3	2014	Rains	Loamy sand	Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults
Farm 3	2015	Craven	Silt loam	Fine, mixed, subactive, thermic Aquic Hapludults
Farm 4	2014	Goldsboro	Loamy sand	Fine-loamy, siliceous, subactive, thermic Aquic Paleudults
Farm 5	2014	Lynchburg	Loamy fine sand	Fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults
Farm 5	2015	Goldsboro	Loamy sand	Fine-loamy, siliceous, subactive, thermic Aquic Paleudults
Farm 6	2014	Rains	Loamy sand	Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults
Farm 6	2015	Tomotley	Fine sandy loam	Fine-loamy, mixed, semiactive, thermic Typic Endoaquults
Farm 7	2014	Rains	Loamy sand	Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults
Farm 8	2014	Goldsboro	Loamy sand	Fine-loamy, siliceous, subactive, thermic Aquic Paleudults
Farm 8	2015	Goldsboro	Loamy sand	Fine-loamy, siliceous, subactive, thermic Aquic Paleudults
Farm 9	2014	Rains	Loamy sand	Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults
Farm 10	2014	Aycock	Very fine sandy loam	Fine-silty, siliceous, subactive, thermic Typic Paleudults
Farm 11	2015	Stockade	Fine sandy loam	Fine-loamy, mixed, superactive, thermic Umbric Endoaqualfs
Farm 12	2015	Goldsboro	Loamy sand	Fine-loamy, siliceous, subactive, thermic Aquic Paleudults

APPENDIX B

Table B1 – Maize N rate & product field trials raw data by site year.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2014	101	1	UAN	90	10000	7843	89.0	39.2	128.2	67.54
Coastal_Plain	2014	102	1	Instinct	225	13971	7326	160.7	41.8	202.4	60.14
Coastal_Plain	2014	103	1	AgrotainPlus	135	13126	7573	131.3	35.6	166.9	73.77
Coastal_Plain	2014	104	1	AgrotainPlus	0	5520	4366	45.3	23.1	68.4	.
Coastal_Plain	2014	105	1	NZone	45	7387	7836	62.8	53.3	116.1	107.97
Coastal_Plain	2014	106	1	NZone	180	13591	8364	133.2	49.3	182.5	64.08
Coastal_Plain	2014	107	1	UAN	180	12304	6660	130.4	26.0	156.4	49.49
Coastal_Plain	2014	108	1	Instinct	0	6422	6972	55.9	29.3	85.1	.
Coastal_Plain	2014	109	1	NZone	225	13221	6839	145.4	37.6	183.0	51.49
Coastal_Plain	2014	110	1	UAN	225	13358	5456	146.9	26.2	173.1	47.06
Coastal_Plain	2014	111	1	AgrotainPlus	45	7871	7123	70.8	35.6	106.5	86.50
Coastal_Plain	2014	112	1	Instinct	135	11239	5714	112.4	25.7	138.1	52.38
Coastal_Plain	2014	113	1	Instinct	90	10366	6118	91.2	33.6	124.9	63.80
Coastal_Plain	2014	114	1	AgrotainPlus	90	9710	8160	88.4	36.7	125.1	64.04
Coastal_Plain	2014	115	1	Instinct	180	13058	5847	137.1	43.3	180.4	62.88
Coastal_Plain	2014	116	1	UAN	135	11179	6904	112.9	33.8	146.7	58.81
Coastal_Plain	2014	117	1	NZone	90	10327	7435	94.0	39.4	133.4	73.30
Coastal_Plain	2014	118	1	UAN	45	7040	6042	64.1	25.4	89.4	48.52
Coastal_Plain	2014	119	1	Instinct	45	6647	5681	60.5	23.9	84.4	37.17
Coastal_Plain	2014	120	1	UAN	0	5463	5043	48.1	16.1	64.2	.
Coastal_Plain	2014	121	1	AgrotainPlus	180	.	5268	111.0	30.0	141.1	40.94
Coastal_Plain	2014	122	1	AgrotainPlus	225	12726	4794	133.6	16.3	149.9	36.70
Coastal_Plain	2014	123	1	NZone	135	9808	6360	102.0	38.8	140.8	54.39
Coastal_Plain	2014	124	1	NZone	0	4171	4078	38.0	16.7	54.7	.
Coastal_Plain	2014	201	2	NZone	180	13209	7552	134.7	30.2	164.9	54.26
Coastal_Plain	2014	202	2	AgrotainPlus	0	4197	3536	38.2	13.1	51.3	.
Coastal_Plain	2014	203	2	Instinct	90	9297	5811	80.9	24.4	105.3	41.95
Coastal_Plain	2014	204	2	AgrotainPlus	180	13035	9760	131.7	49.8	181.4	63.46
Coastal_Plain	2014	205	2	NZone	0	4636	3422	42.6	15.4	58.0	.
Coastal_Plain	2014	206	2	NZone	225	13933	8424	150.5	42.1	192.6	55.76
Coastal_Plain	2014	207	2	UAN	225	12133	5255	139.5	26.3	165.8	43.80
Coastal_Plain	2014	208	2	AgrotainPlus	225	13741	5747	162.1	37.4	199.5	58.84
Coastal_Plain	2014	209	2	AgrotainPlus	135	12121	6858	127.3	33.6	160.9	69.32
Coastal_Plain	2014	210	2	UAN	135	11534	6392	110.7	24.3	135.0	50.08
Coastal_Plain	2014	211	2	UAN	0	5685	4948	48.9	21.3	70.2	.
Coastal_Plain	2014	212	2	UAN	45	7358	5092	66.2	28.0	94.2	59.21
Coastal_Plain	2014	213	2	UAN	90	9082	7024	82.7	33.0	115.7	53.53
Coastal_Plain	2014	214	2	AgrotainPlus	45	6475	4252	58.9	19.1	78.1	23.12
Coastal_Plain	2014	215	2	AgrotainPlus	90	9941	6907	90.5	43.5	134.0	73.97
Coastal_Plain	2014	216	2	NZone	90	10816	4787	110.3	27.3	137.6	78.02
Coastal_Plain	2014	217	2	NZone	135	13538	5916	139.4	30.2	169.6	75.82
Coastal_Plain	2014	218	2	UAN	180	13199	6010	139.9	34.3	174.2	59.41
Coastal_Plain	2014	219	2	Instinct	180	13826	5611	165.9	27.5	193.4	70.15
Coastal_Plain	2014	220	2	Instinct	135	10270	6778	111.9	28.5	140.4	54.10
Coastal_Plain	2014	221	2	Instinct	0	5439	5994	46.8	25.2	72.0	.
Coastal_Plain	2014	222	2	Instinct	45	7928	6952	72.9	31.3	104.2	81.51
Coastal_Plain	2014	223	2	Instinct	225	14239	6666	172.3	32.7	205.0	61.27
Coastal_Plain	2014	224	2	NZone	45	7440	.	67.7	.	.	.
Coastal_Plain	2014	301	3	Instinct	225	14123	6044	165.2	33.2	198.5	58.38
Coastal_Plain	2014	302	3	NZone	135	13840	6198	139.8	34.1	173.9	79.00
Coastal_Plain	2014	303	3	UAN	0	4986	5348	48.9	25.1	74.0	.
Coastal_Plain	2014	304	3	Instinct	0	5909	4911	55.5	24.1	79.6	.
Coastal_Plain	2014	305	3	UAN	180	13646	7864	148.7	40.1	188.8	67.60
Coastal_Plain	2014	306	3	Instinct	180	13588	7954	157.6	35.8	193.4	70.15
Coastal_Plain	2014	307	3	AgrotainPlus	180	12350	8340	150.7	50.9	201.5	74.69
Coastal_Plain	2014	308	3	AgrotainPlus	45	6401	6819	65.3	33.4	98.7	69.19
Coastal_Plain	2014	309	3	NZone	0	4870	4878	44.8	22.0	66.8	.
Coastal_Plain	2014	310	3	UAN	90	10426	5904	110.5	24.2	134.7	74.80

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2014	311	3	AgrotainPlus	90	8933	6504	92.0	28.6	120.6	59.07
Coastal_Plain	2014	312	3	AgrotainPlus	225	14243	6819	189.4	34.1	223.5	69.56
Coastal_Plain	2014	313	3	Instinct	45	7516	7751	75.2	34.9	110.0	94.50
Coastal_Plain	2014	314	3	Instinct	90	10680	6790	114.3	36.0	150.3	92.15
Coastal_Plain	2014	315	3	UAN	225	13711	6424	167.3	35.3	202.6	60.22
Coastal_Plain	2014	316	3	NZone	225	13929	6596	206.2	35.6	241.8	77.71
Coastal_Plain	2014	317	3	Instinct	135	12089	7953	140.2	35.8	176.0	80.60
Coastal_Plain	2014	318	3	UAN	135	13998	8077	166.6	38.8	205.3	102.41
Coastal_Plain	2014	319	3	UAN	45	9430	7379	111.3	33.2	144.5	171.39
Coastal_Plain	2014	320	3	AgrotainPlus	135	13257	7411	127.3	33.3	160.6	69.13
Coastal_Plain	2014	321	3	AgrotainPlus	0	5331	7486	46.9	37.4	84.3	.
Coastal_Plain	2014	322	3	NZone	45	7485	8071	61.4	30.7	92.0	54.34
Coastal_Plain	2014	323	3	NZone	90	9903	6578	91.1	30.9	122.0	60.63
Coastal_Plain	2014	324	3	NZone	180	13987	7595	144.1	40.3	184.3	65.07
Coastal_Plain	2014	401	4	NZone	0	4804	4457	44.2	24.5	68.7	.
Coastal_Plain	2014	402	4	UAN	90	11168	7145	109.4	36.4	145.9	87.26
Coastal_Plain	2014	403	4	Instinct	45	6129	6861	53.3	28.8	82.1	32.22
Coastal_Plain	2014	404	4	Instinct	135	13647	7304	143.3	30.7	174.0	79.07
Coastal_Plain	2014	405	4	UAN	0	4656	3539	41.4	16.6	58.1	.
Coastal_Plain	2014	406	4	UAN	135	13536	6664	139.4	41.3	180.7	84.10
Coastal_Plain	2014	407	4	NZone	45	9127	6457	84.9	30.3	115.2	106.09
Coastal_Plain	2014	408	4	UAN	225	13619	6922	155.3	29.8	185.0	52.38
Coastal_Plain	2014	409	4	NZone	135	12210	9087	127.0	55.4	182.4	85.35
Coastal_Plain	2014	410	4	NZone	180	11909	9759	135.8	44.9	180.7	63.03
Coastal_Plain	2014	411	4	UAN	180	12503	4725	127.5	23.6	151.2	46.57
Coastal_Plain	2014	412	4	AgrotainPlus	135	12200	4294	119.6	16.7	136.3	51.04
Coastal_Plain	2014	413	4	AgrotainPlus	90	11034	6976	110.3	32.8	143.1	84.18
Coastal_Plain	2014	414	4	Instinct	0	3974	4180	38.9	21.3	60.3	.
Coastal_Plain	2014	415	4	UAN	45	6501	8636	59.8	43.2	103.0	78.76
Coastal_Plain	2014	416	4	Instinct	225	12898	8948	144.5	59.1	203.5	60.63
Coastal_Plain	2014	417	4	Instinct	90	9225	9132	81.2	51.1	132.3	72.12
Coastal_Plain	2014	418	4	AgrotainPlus	180	14717	7332	172.2	46.9	219.1	84.50
Coastal_Plain	2014	419	4	NZone	225	14050	8016	167.2	53.7	220.9	68.40
Coastal_Plain	2014	420	4	AgrotainPlus	225	11412	8218	146.1	55.1	201.1	59.57
Coastal_Plain	2014	421	4	NZone	90	10489	8099	102.8	51.0	153.8	96.11
Coastal_Plain	2014	422	4	Instinct	180	13742	6440	153.9	29.0	182.9	64.28
Coastal_Plain	2014	423	4	AgrotainPlus	45	6708	6387	57.7	26.2	83.9	36.09
Coastal_Plain	2014	424	4	AgrotainPlus	0	4931	5233	40.9	26.7	67.6	.
Coastal_Plain	2015	101	1	Instinct	90	9451	7813	101.1	40.6	141.7	69.62
Coastal_Plain	2015	102	1	UAN	225	11280	10008	143.3	84.1	227.3	66.05
Coastal_Plain	2015	103	1	AgrotainPlus	225	12167	8320	146.0	61.6	207.6	57.23
Coastal_Plain	2015	104	1	Instinct	45	5506	8552	49.6	45.3	94.9	34.63
Coastal_Plain	2015	105	1	NZone	90	9511	9703	90.4	64.0	154.4	83.74
Coastal_Plain	2015	106	1	NZone	45	6567	8716	58.4	56.7	115.1	79.77
Coastal_Plain	2015	107	1	UAN	180	10809	7701	129.7	60.1	189.8	61.61
Coastal_Plain	2015	108	1	AgrotainPlus	45	5745	7033	57.4	38.0	95.4	35.85
Coastal_Plain	2015	109	1	AgrotainPlus	180	12401	8549	146.3	52.1	198.5	66.47
Coastal_Plain	2015	110	1	Instinct	180	10563	9552	126.8	64.0	190.8	62.16
Coastal_Plain	2015	111	1	Instinct	135	11315	9453	117.7	61.4	179.1	74.22
Coastal_Plain	2015	112	1	UAN	45	6515	9842	59.3	52.2	111.5	71.61
Coastal_Plain	2015	113	1	NZone	135	11293	6481	127.6	30.5	158.1	58.56
Coastal_Plain	2015	114	1	AgrotainPlus	135	12519	7272	137.7	61.1	198.8	88.86
Coastal_Plain	2015	115	1	AgrotainPlus	90	10252	8791	94.3	51.0	145.3	73.60
Coastal_Plain	2015	116	1	UAN	0	4772	7215	41.5	41.8	83.4	.
Coastal_Plain	2015	117	1	AgrotainPlus	0	5357	6264	47.7	37.0	84.6	.
Coastal_Plain	2015	118	1	NZone	225	13843	8923	170.3	54.4	224.7	64.88
Coastal_Plain	2015	119	1	Instinct	0	5259	6436	47.3	39.9	87.2	.
Coastal_Plain	2015	120	1	NZone	180	13029	8777	131.6	67.6	199.2	66.85

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2015	121	1	NZone	0	3139	5454	31.7	27.3	59.0	.
Coastal_Plain	2015	122	1	UAN	90	7583	8048	70.5	39.4	110.0	34.13
Coastal_Plain	2015	123	1	Instinct	225	12694	9652	157.4	64.7	222.1	63.71
Coastal_Plain	2015	124	1	UAN	135	11146	9694	103.7	73.7	177.3	72.89
Coastal_Plain	2015	201	2	AgrotainPlus	180	12727	8060	142.5	54.0	196.5	65.39
Coastal_Plain	2015	202	2	AgrotainPlus	0	4739	6194	44.5	40.3	84.8	.
Coastal_Plain	2015	203	2	UAN	225	13920	8222	161.5	61.7	223.1	64.18
Coastal_Plain	2015	204	2	AgrotainPlus	45	5595	6737	61.5	34.4	95.9	36.92
Coastal_Plain	2015	205	2	Instinct	90	8347	8693	77.6	56.5	134.1	61.12
Coastal_Plain	2015	206	2	NZone	135	10819	7183	107.1	42.4	149.5	52.17
Coastal_Plain	2015	207	2	AgrotainPlus	90	9536	7505	98.2	50.3	148.5	77.16
Coastal_Plain	2015	208	2	NZone	225	13690	7715	156.1	54.8	210.8	58.69
Coastal_Plain	2015	209	2	Instinct	180	10986	7210	134.0	46.9	180.9	56.66
Coastal_Plain	2015	210	2	Instinct	45	4816	7389	42.9	34.0	76.9	.
Coastal_Plain	2015	211	2	UAN	0	3312	6346	33.4	42.5	76.0	.
Coastal_Plain	2015	212	2	Instinct	0	3594	6584	33.1	30.3	63.4	.
Coastal_Plain	2015	213	2	Instinct	135	9392	7360	105.2	44.9	150.1	52.61
Coastal_Plain	2015	214	2	NZone	90	8817	8037	84.6	46.6	131.3	57.92
Coastal_Plain	2015	215	2	UAN	90	7819	7993	82.1	55.2	137.3	64.60
Coastal_Plain	2015	216	2	NZone	180	11715	8880	140.6	59.5	200.1	67.36
Coastal_Plain	2015	217	2	NZone	0	5036	6621	57.9	46.4	104.3	.
Coastal_Plain	2015	218	2	UAN	180	12581	9385	128.3	61.9	190.3	61.88
Coastal_Plain	2015	219	2	UAN	45	5437	8489	50.0	55.2	105.2	57.65
Coastal_Plain	2015	220	2	NZone	45	5411	7382	51.4	48.7	100.1	46.32
Coastal_Plain	2015	221	2	AgrotainPlus	135	11130	10160	111.3	72.1	183.4	77.43
Coastal_Plain	2015	222	2	Instinct	225	12330	8275	146.7	59.6	206.3	56.67
Coastal_Plain	2015	223	2	UAN	135	10882	8812	104.5	62.6	167.0	65.23
Coastal_Plain	2015	224	2	AgrotainPlus	225	14571	10075	167.6	75.6	243.1	73.11
Coastal_Plain	2015	301	3	AgrotainPlus	225	12701	9335	156.2	55.1	211.3	58.90
Coastal_Plain	2015	302	3	NZone	135	10160	7747	116.8	49.6	166.4	64.77
Coastal_Plain	2015	303	3	NZone	180	11980	6951	135.4	21.5	156.9	43.28
Coastal_Plain	2015	304	3	UAN	45	5752	7830	55.2	50.1	105.3	57.94
Coastal_Plain	2015	305	3	NZone	225	11445	7238	144.2	38.4	182.6	46.07
Coastal_Plain	2015	306	3	UAN	225	13054	7547	160.6	48.3	208.9	57.81
Coastal_Plain	2015	307	3	UAN	90	8428	7035	90.2	47.1	137.3	64.66
Coastal_Plain	2015	308	3	AgrotainPlus	180	12815	8702	146.1	52.2	198.3	66.37
Coastal_Plain	2015	309	3	Instinct	225	13568	8914	165.5	52.6	218.1	61.94
Coastal_Plain	2015	310	3	UAN	0	3717	5467	38.7	30.1	68.7	.
Coastal_Plain	2015	311	3	AgrotainPlus	0	4032	6277	38.7	38.9	77.6	.
Coastal_Plain	2015	312	3	NZone	0	3955	8205	42.7	50.1	92.8	.
Coastal_Plain	2015	313	3	NZone	45	4953	7902	50.0	41.1	91.1	26.21
Coastal_Plain	2015	314	3	Instinct	135	9567	9297	92.8	53.0	145.8	49.42
Coastal_Plain	2015	315	3	UAN	135	11444	6338	119.0	34.2	153.2	54.97
Coastal_Plain	2015	316	3	AgrotainPlus	45	6921	9679	67.1	69.7	136.8	128.26
Coastal_Plain	2015	317	3	Instinct	180	12613	8075	138.7	42.0	180.7	56.57
Coastal_Plain	2015	318	3	Instinct	45	4804	7470	44.7	34.4	79.0	.
Coastal_Plain	2015	319	3	Instinct	90	6872	6897	65.3	31.0	96.3	18.92
Coastal_Plain	2015	320	3	UAN	180	12554	8016	139.4	53.7	193.1	63.44
Coastal_Plain	2015	321	3	NZone	90	10511	7147	107.2	44.3	151.5	80.53
Coastal_Plain	2015	322	3	AgrotainPlus	90	7673	7842	70.6	43.9	114.5	39.22
Coastal_Plain	2015	323	3	Instinct	0	3097	6532	34.7	32.0	66.7	.
Coastal_Plain	2015	324	3	AgrotainPlus	135	10392	7883	102.9	68.6	171.5	68.52
Coastal_Plain	2015	401	4	UAN	135	10323	7713	106.3	52.4	158.8	59.08
Coastal_Plain	2015	402	4	AgrotainPlus	225	13723	8128	163.3	49.6	212.9	59.61
Coastal_Plain	2015	403	4	UAN	90	8639	8823	80.3	60.0	140.3	68.04
Coastal_Plain	2015	404	4	Instinct	135	12818	8479	165.4	50.9	216.2	101.83
Coastal_Plain	2015	405	4	UAN	225	13513	10050	143.2	99.5	242.7	72.93
Coastal_Plain	2015	406	4	Instinct	180	12967	8794	140.0	56.3	196.3	65.27

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2015	407	4	AgrotainPlus	0	3733	6591	34.0	44.8	78.8	.
Coastal_Plain	2015	408	4	AgrotainPlus	90	7778	6826	87.9	40.3	128.2	54.46
Coastal_Plain	2015	409	4	AgrotainPlus	135	12528	11080	136.6	66.5	203.0	92.02
Coastal_Plain	2015	410	4	UAN	180	12924	8622	151.2	50.9	202.1	68.48
Coastal_Plain	2015	411	4	NZone	45	5867	6811	55.2	39.5	94.7	34.12
Coastal_Plain	2015	412	4	NZone	0	4474	8923	42.5	53.5	96.0	.
Coastal_Plain	2015	413	4	NZone	135	9068	7717	89.8	48.6	138.4	43.92
Coastal_Plain	2015	414	4	UAN	0	3364	5648	32.0	40.1	72.1	.
Coastal_Plain	2015	415	4	NZone	180	12172	9888	135.1	53.4	188.5	60.90
Coastal_Plain	2015	416	4	AgrotainPlus	45	5035	7396	47.3	43.6	91.0	25.88
Coastal_Plain	2015	417	4	AgrotainPlus	180	10983	7674	116.4	55.3	171.7	51.51
Coastal_Plain	2015	418	4	NZone	225	13486	9448	156.4	65.2	221.6	63.51
Coastal_Plain	2015	419	4	UAN	45	5099	7562	53.5	38.6	92.1	28.44
Coastal_Plain	2015	420	4	NZone	90	7564	6181	86.2	37.7	123.9	49.74
Coastal_Plain	2015	421	4	Instinct	225	14033	9854	181.0	74.9	255.9	78.81
Coastal_Plain	2015	422	4	Instinct	0	3172	6653	32.0	42.6	74.6	.
Coastal_Plain	2015	423	4	Instinct	90	8177	7764	74.4	44.3	118.7	43.86
Coastal_Plain	2015	424	4	Instinct	45	4779	12272	43.0	67.5	110.5	69.51
Mountains	2014	101	1	Instinct	0	10563	10946	87.7	48.2	135.8	.
Mountains	2014	102	1	AgrotainPlus	225	18318	7682	186.8	36.9	223.7	54.37
Mountains	2014	103	1	Instinct	90	17149	10416	147.5	41.7	189.1	97.34
Mountains	2014	104	1	Instinct	45	11457	7815	92.8	29.7	122.5	45.90
Mountains	2014	105	1	NZone	45	11002	10887	88.0	33.8	121.8	44.27
Mountains	2014	106	1	UAN	0	9320	9175	65.2	29.4	94.6	.
Mountains	2014	107	1	NZone	0	8099	7619	62.4	25.1	87.5	.
Mountains	2014	108	1	AgrotainPlus	90	15319	9843	148.6	42.3	190.9	99.31
Mountains	2014	109	1	NZone	90	15646	8082	158.0	33.9	192.0	100.49
Mountains	2014	110	1	UAN	90	16708	10276	157.1	42.1	199.2	108.55
Mountains	2014	111	1	AgrotainPlus	0	12860	9150	110.6	29.3	139.9	.
Mountains	2014	112	1	UAN	135	15657	13671	150.3	38.3	188.6	64.47
Mountains	2014	113	1	NZone	225	19869	11394	198.7	51.3	250.0	66.09
Mountains	2014	114	1	NZone	180	17240	6992	177.6	45.4	223.0	67.57
Mountains	2014	115	1	AgrotainPlus	45	16398	12012	136.1	45.6	181.7	178.16
Mountains	2014	116	1	AgrotainPlus	180	18411	11327	198.8	52.1	250.9	83.15
Mountains	2014	117	1	UAN	225	17988	11640	214.1	68.7	282.7	80.71
Mountains	2014	118	1	AgrotainPlus	135	15676	10545	158.3	53.8	212.1	81.97
Mountains	2014	119	1	Instinct	225	14733	10086	175.3	50.4	225.7	55.27
Mountains	2014	120	1	Instinct	135	16185	8789	160.2	36.0	196.3	70.19
Mountains	2014	121	1	NZone	135	14252	10262	142.5	39.0	181.5	59.21
Mountains	2014	122	1	Instinct	180	16709	10481	170.4	48.2	218.6	65.13
Mountains	2014	123	1	UAN	45	15203	7663	153.6	26.8	180.4	175.09
Mountains	2014	124	1	UAN	180	17649	11554	188.8	60.1	248.9	82.03
Mountains	2014	201	2	Instinct	225	17672	13554	176.7	54.2	230.9	57.59
Mountains	2014	202	2	UAN	180	16472	9999	148.2	46.0	194.2	51.51
Mountains	2014	203	2	UAN	0	9815	11447	68.7	42.4	111.1	.
Mountains	2014	204	2	AgrotainPlus	45	10565	7295	79.2	25.5	104.8	6.32
Mountains	2014	205	2	Instinct	45	13883	9547	104.1	39.1	143.3	92.26
Mountains	2014	206	2	Instinct	225	14935	6560	144.9	30.8	175.7	82.33
Mountains	2014	207	2	NZone	225	15000	8865	144.0	41.7	185.7	37.38
Mountains	2014	208	2	UAN	90	14050	8043	118.0	29.0	147.0	50.27
Mountains	2014	209	2	UAN	135	15608	9977	137.4	50.9	188.2	64.22
Mountains	2014	210	2	AgrotainPlus	180	15451	10692	153.0	44.9	197.9	53.54
Mountains	2014	211	2	NZone	45	14743	10006	113.5	42.0	155.5	119.67
Mountains	2014	212	2	NZone	0	10141	8857	71.0	41.6	112.6	.
Mountains	2014	213	2	Instinct	0	11520	9560	79.5	35.4	114.9	.
Mountains	2014	214	2	Instinct	180	16633	10841	173.0	44.4	217.4	64.45
Mountains	2014	215	2	AgrotainPlus	90	16902	12949	160.6	59.6	220.1	131.92
Mountains	2014	216	2	AgrotainPlus	225	15770	10633	156.1	50.0	206.1	46.50

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Mountains	2014	217	2	AgrotainPlus	0	10057	10603	95.5	37.1	132.6	.
Mountains	2014	218	2	UAN	225	16577	8358	154.2	38.4	192.6	40.48
Mountains	2014	219	2	AgrotainPlus	135	15730	11583	169.9	55.6	225.5	91.92
Mountains	2014	220	2	NZone	180	16398	9938	155.8	54.7	210.4	60.56
Mountains	2014	221	2	UAN	45	14980	11010	116.8	57.3	174.1	161.09
Mountains	2014	222	2	Instinct	135	15646	8431	162.7	48.1	210.8	80.99
Mountains	2014	223	2	NZone	135	16527	10988	162.0	51.6	213.6	83.10
Mountains	2014	224	2	NZone	90	14439	8085	118.4	31.5	149.9	53.57
Mountains	2014	301	3	AgrotainPlus	90	15477	12569	139.3	61.6	200.9	110.43
Mountains	2014	302	3	NZone	225	18082	14287	206.1	80.0	286.1	82.24
Mountains	2014	303	3	UAN	90	16874	16207	172.1	98.9	271.0	188.67
Mountains	2014	304	3	NZone	180	15582	11223	152.7	55.0	207.7	59.02
Mountains	2014	305	3	Instinct	0	8829	8712	68.9	32.2	101.1	.
Mountains	2014	306	3	Instinct	225	13492	10089	143.0	53.5	196.5	42.21
Mountains	2014	307	3	Instinct	180	16469	9969	177.9	62.8	240.7	77.42
Mountains	2014	308	3	AgrotainPlus	135	15806	9716	142.3	48.6	190.8	66.15
Mountains	2014	309	3	AgrotainPlus	45	14043	8408	119.4	37.8	157.2	123.37
Mountains	2014	310	3	Instinct	90	14348	9891	124.8	39.6	164.4	69.71
Mountains	2014	311	3	NZone	45	13229	12078	95.2	74.9	170.1	152.24
Mountains	2014	312	3	AgrotainPlus	0	4572	7480	33.8	26.2	60.0	.
Mountains	2014	313	3	UAN	135	16407	12052	175.6	71.1	246.7	107.69
Mountains	2014	314	3	AgrotainPlus	225	13885	10474	158.3	66.0	224.3	54.62
Mountains	2014	315	3	UAN	225	13611	11679	149.7	54.9	204.6	45.84
Mountains	2014	316	3	NZone	90	14938	9639	165.8	50.1	215.9	127.24
Mountains	2014	317	3	Instinct	45	13859	9843	98.4	40.4	138.8	82.20
Mountains	2014	318	3	UAN	45	15271	11408	146.6	49.1	195.7	209.20
Mountains	2014	319	3	AgrotainPlus	180	17037	12248	175.5	56.3	231.8	72.48
Mountains	2014	320	3	NZone	135	16133	9961	159.7	39.8	199.6	72.64
Mountains	2014	321	3	NZone	0	8377	7256	66.2	26.1	92.3	.
Mountains	2014	322	3	UAN	180	14588	7032	166.3	31.6	197.9	53.58
Mountains	2014	323	3	Instinct	135	17125	11951	171.3	50.2	221.4	88.92
Mountains	2014	324	3	UAN	0	5156	7645	35.6	26.8	62.3	.
Mountains	2014	401	4	NZone	225	7232	7655	84.6	39.0	123.7	9.70
Mountains	2014	402	4	Instinct	225	16182	10855	142.4	59.7	202.1	44.72
Mountains	2014	403	4	AgrotainPlus	135	17343	10739	154.4	46.2	200.5	73.36
Mountains	2014	404	4	UAN	225	17388	8888	168.7	41.8	210.4	48.44
Mountains	2014	405	4	Instinct	135	16419	12976	156.0	66.2	222.2	89.46
Mountains	2014	406	4	Instinct	45	15186	12797	136.7	39.7	176.3	166.10
Mountains	2014	407	4	NZone	135	18385	9853	158.1	37.4	195.6	69.66
Mountains	2014	408	4	AgrotainPlus	45	14455	11961	112.7	45.5	158.2	125.59
Mountains	2014	409	4	NZone	45	14248	9763	108.3	39.1	147.3	101.34
Mountains	2014	410	4	NZone	180	17172	8792	158.0	40.4	198.4	53.85
Mountains	2014	411	4	NZone	0	10257	6117	66.7	20.8	87.5	.
Mountains	2014	412	4	UAN	135	14999	8548	132.0	35.0	167.0	48.44
Mountains	2014	413	4	UAN	90	16216	11942	134.6	66.9	201.5	111.09
Mountains	2014	414	4	Instinct	180	16377	8887	165.4	45.3	210.7	60.71
Mountains	2014	415	4	Instinct	90	20403	11722	179.5	53.9	233.5	146.80
Mountains	2014	416	4	AgrotainPlus	180	17761	12413	181.2	62.1	243.2	78.85
Mountains	2014	417	4	Instinct	0	13434	9134	96.7	29.2	126.0	.
Mountains	2014	418	4	AgrotainPlus	0	11746	10659	76.3	35.2	111.5	.
Mountains	2014	419	4	NZone	90	16150	12042	137.3	40.9	178.2	85.13
Mountains	2014	420	4	AgrotainPlus	90	15314	9858	157.7	37.5	195.2	104.09
Mountains	2014	421	4	AgrotainPlus	225	17476	8646	176.5	45.8	222.3	53.75
Mountains	2014	422	4	UAN	45	14715	7880	141.3	28.4	169.6	151.10
Mountains	2014	423	4	UAN	180	16768	10212	171.0	34.7	205.8	57.94
Mountains	2014	424	4	UAN	0	6274	6630	42.7	18.6	61.2	.
Mountains	2015	101	1	NZone	90	12733	9654	173.2	41.5	214.7	179.74
Mountains	2015	102	1	UAN	135	16751	8039	159.1	38.6	197.7	107.21

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Mountains	2015	103	1	NZone	135	18404	10501	174.8	69.3	244.1	141.75
Mountains	2015	104	1	AgrotainPlus	45	4537	5883	30.4	16.5	46.9	.
Mountains	2015	105	1	Instinct	45	5121	6564	38.9	21.7	60.6	15.50
Mountains	2015	106	1	AgrotainPlus	180	17056	8805	116.0	22.0	138.0	47.07
Mountains	2015	107	1	NZone	45	4829	7642	38.1	26.7	64.9	25.13
Mountains	2015	108	1	UAN	45	5714	5639	40.0	19.7	59.7	13.62
Mountains	2015	109	1	UAN	225	17415	11206	160.2	26.9	187.1	59.59
Mountains	2015	110	1	Instinct	135	12088	8769	94.3	21.0	115.3	45.91
Mountains	2015	111	1	AgrotainPlus	135	12802	9162	93.5	33.9	127.4	54.85
Mountains	2015	112	1	NZone	0	.	8745	.	26.2	.	.
Mountains	2015	113	1	NZone	225	16610	8521	136.2	29.8	166.0	50.17
Mountains	2015	114	1	NZone	180	17307	8205	135.0	34.5	169.5	64.63
Mountains	2015	115	1	AgrotainPlus	0	.	8285	.	32.3	.	.
Mountains	2015	116	1	Instinct	225	15847	10539	126.8	33.7	160.5	47.71
Mountains	2015	117	1	AgrotainPlus	90	11521	7621	84.1	29.7	113.8	67.17
Mountains	2015	118	1	Instinct	90	9460	7739	68.1	20.1	88.2	38.61
Mountains	2015	119	1	UAN	180	18230	8558	169.5	20.5	190.1	76.14
Mountains	2015	120	1	AgrotainPlus	225	20069	9717	176.6	36.9	213.5	71.38
Mountains	2015	121	1	UAN	0	4431	3765	35.4	21.5	56.9	.
Mountains	2015	122	1	UAN	90	8299	7184	57.3	23.0	80.3	29.70
Mountains	2015	123	1	Instinct	180	18176	7980	109.1	27.1	136.2	46.07
Mountains	2015	124	1	Instinct	0	5465	5946	39.3	25.0	64.3	.
Mountains	2015	201	2	Instinct	90	10096	7747	68.6	20.1	88.8	39.23
Mountains	2015	202	2	UAN	225	17679	8182	143.2	49.1	192.3	61.90
Mountains	2015	203	2	Instinct	225	20100	9572	186.9	58.4	245.3	85.57
Mountains	2015	204	2	AgrotainPlus	225	18163	7448	158.0	35.0	193.0	62.22
Mountains	2015	205	2	AgrotainPlus	90	8924	.	72.3	.	.	.
Mountains	2015	206	2	NZone	225	15264	10757	111.4	36.6	148.0	42.13
Mountains	2015	207	2	NZone	45	5682	8028	40.3	32.9	73.3	43.79
Mountains	2015	208	2	NZone	90	8957	7163	74.3	27.9	102.3	54.28
Mountains	2015	209	2	UAN	45	6872	8087	46.0	32.3	78.4	55.24
Mountains	2015	210	2	NZone	135	14776	12230	106.4	66.0	172.4	88.39
Mountains	2015	211	2	UAN	135	16750	10020	129.0	39.1	168.1	85.13
Mountains	2015	212	2	NZone	0	5096	6360	38.7	28.0	66.7	.
Mountains	2015	213	2	Instinct	135	13541	10193	94.8	40.8	135.6	60.96
Mountains	2015	214	2	UAN	90	10450	9430	72.1	46.2	118.3	72.18
Mountains	2015	215	2	UAN	0	6959	6057	50.8	22.4	73.2	.
Mountains	2015	216	2	Instinct	0	2192	2728	15.3	11.7	27.1	.
Mountains	2015	217	2	Instinct	45	3981	7854	35.8	19.6	55.5	4.08
Mountains	2015	218	2	UAN	180	16672	13269	118.4	59.7	178.1	69.44
Mountains	2015	219	2	AgrotainPlus	180	16334	9310	142.1	27.9	170.0	64.95
Mountains	2015	220	2	Instinct	180	14745	13294	95.8	58.5	154.3	56.20
Mountains	2015	221	2	AgrotainPlus	0	1818	2444	16.5	9.0	25.6	.
Mountains	2015	222	2	NZone	180	14137	9170	107.4	38.5	146.0	51.52
Mountains	2015	223	2	AgrotainPlus	45	5043	5692	33.3	20.5	53.8	0.31
Mountains	2015	224	2	AgrotainPlus	135	13808	10448	100.8	41.8	142.6	66.19
Mountains	2015	301	3	UAN	45	5057	7201	42.0	28.1	70.1	36.65
Mountains	2015	302	3	Instinct	45	4890	5289	40.1	15.3	55.4	4.01
Mountains	2015	303	3	UAN	90	13448	8433	108.9	28.7	137.6	93.71
Mountains	2015	304	3	Instinct	90	9675	9654	80.3	40.5	120.9	75.02
Mountains	2015	305	3	UAN	180	17190	9363	144.4	53.4	197.8	80.43
Mountains	2015	306	3	UAN	0	1471	3259	14.4	16.3	30.7	.
Mountains	2015	307	3	NZone	135	14283	12829	112.8	42.3	155.2	75.55
Mountains	2015	308	3	NZone	90	9981	8765	78.9	25.4	104.3	56.51
Mountains	2015	309	3	UAN	225	17394	11964	161.8	46.7	208.4	69.10
Mountains	2015	310	3	Instinct	180	15700	10550	133.4	51.7	185.1	73.38
Mountains	2015	311	3	NZone	225	18061	8741	151.7	19.2	170.9	52.37
Mountains	2015	312	3	AgrotainPlus	0	5408	5604	42.7	23.0	65.7	.

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Mountains	2015	313	3	Instinct	0	4048	4038	32.4	15.3	47.7	.
Mountains	2015	314	3	NZone	180	11347	.	96.4	.	.	.
Mountains	2015	315	3	NZone	0	7114	5746	57.6	26.4	84.1	.
Mountains	2015	316	3	Instinct	135	11563	8904	92.5	31.2	123.7	52.11
Mountains	2015	317	3	AgrotainPlus	180	15149	8670	131.8	29.5	161.3	60.07
Mountains	2015	318	3	AgrotainPlus	225	18936	9673	178.0	33.9	211.9	70.63
Mountains	2015	319	3	NZone	45	4856	6219	36.9	18.7	55.6	4.30
Mountains	2015	320	3	Instinct	225	16384	14683	131.1	60.2	191.3	61.44
Mountains	2015	321	3	AgrotainPlus	45	5533	8200	42.6	17.2	59.8	13.82
Mountains	2015	322	3	AgrotainPlus	90	6443	9051	52.2	26.2	78.4	27.68
Mountains	2015	323	3	AgrotainPlus	135	11230	10288	91.0	34.0	124.9	53.03
Mountains	2015	324	3	UAN	135	14523	12425	117.6	41.0	158.6	78.12
Mountains	2015	401	4	NZone	45	5860	6098	45.7	15.2	60.9	16.32
Mountains	2015	402	4	AgrotainPlus	180	16551	13837	134.1	48.4	182.5	71.91
Mountains	2015	403	4	UAN	225	17066	9664	148.5	39.6	188.1	60.03
Mountains	2015	404	4	NZone	180	15914	8884	138.5	27.5	166.0	62.70
Mountains	2015	405	4	AgrotainPlus	225	7354	10623	61.0	29.7	90.8	16.58
Mountains	2015	406	4	AgrotainPlus	0	4474	3904	37.6	16.4	54.0	.
Mountains	2015	407	4	AgrotainPlus	45	4861	4858	38.9	10.7	49.6	.
Mountains	2015	408	4	UAN	0	4227	5414	37.2	18.9	56.1	.
Mountains	2015	409	4	Instinct	0	4856	4316	42.2	12.9	55.2	.
Mountains	2015	410	4	NZone	90	9561	8474	69.8	22.0	91.8	42.63
Mountains	2015	411	4	UAN	90	7184	9779	55.3	32.3	87.6	37.89
Mountains	2015	412	4	Instinct	135	12436	7993	110.7	26.4	137.1	62.07
Mountains	2015	413	4	NZone	0	3181	2620	27.4	11.8	39.1	.
Mountains	2015	414	4	Instinct	45	3953	3764	28.9	12.8	41.7	.
Mountains	2015	415	4	UAN	135	9186	7254	64.3	31.2	95.5	31.14
Mountains	2015	416	4	UAN	180	12078	8883	90.6	24.9	115.5	34.50
Mountains	2015	417	4	Instinct	90	11496	7478	96.6	18.7	115.3	68.78
Mountains	2015	418	4	Instinct	180	13286	4066	122.2	16.3	138.5	47.36
Mountains	2015	419	4	AgrotainPlus	135	12044	9469	122.8	32.2	155.0	75.45
Mountains	2015	420	4	AgrotainPlus	90	11445	14266	114.4	54.2	168.7	128.37
Mountains	2015	421	4	NZone	135	19309	14300	177.6	75.8	253.4	148.66
Mountains	2015	422	4	NZone	225	15685	10619	166.3	31.9	198.1	64.50
Mountains	2015	423	4	UAN	45	5383	6205	41.4	26.7	68.1	32.35
Mountains	2015	424	4	Instinct	225	18588	7892	180.3	22.9	203.2	66.76
Piedmont	2014	101	1	NZone	180	9820	7455	127.7	47.0	174.6	53.28
Piedmont	2014	102	1	UAN	135	10410	7568	128.0	40.9	168.9	66.78
Piedmont	2014	103	1	NZone	45	7682	7589	68.4	33.4	101.8	50.45
Piedmont	2014	104	1	NZone	135	11383	8541	127.5	39.3	166.8	65.19
Piedmont	2014	105	1	Instinct	135	10522	7223	130.5	33.2	163.7	62.90
Piedmont	2014	106	1	Instinct	180	10530	10743	122.2	48.3	170.5	50.97
Piedmont	2014	107	1	Instinct	45	6623	8717	61.6	38.4	100.0	46.41
Piedmont	2014	108	1	UAN	225	9171	8948	121.1	53.7	174.8	42.68
Piedmont	2014	109	1	UAN	45	5675	6028	51.1	27.7	78.8	-0.79
Piedmont	2014	110	1	AgrotainPlus	0	4773	6405	43.0	26.3	69.2	.
Piedmont	2014	111	1	UAN	90	7183	9384	82.6	46.0	128.6	55.17
Piedmont	2014	112	1	UAN	0	5900	6698	51.3	32.8	84.1	.
Piedmont	2014	113	1	AgrotainPlus	135	9734	6926	118.8	33.2	152.0	54.20
Piedmont	2014	114	1	AgrotainPlus	225	9559	9536	126.2	51.5	177.7	43.98
Piedmont	2014	115	1	Instinct	90	9623	7846	93.3	32.2	125.5	51.73
Piedmont	2014	116	1	NZone	0	6493	7525	55.2	31.6	86.8	.
Piedmont	2014	117	1	Instinct	225	10261	6577	122.1	41.4	163.5	37.67
Piedmont	2014	118	1	AgrotainPlus	180	9452	8151	126.7	39.9	166.6	48.80
Piedmont	2014	119	1	AgrotainPlus	90	9087	6087	89.0	27.4	116.4	41.61
Piedmont	2014	120	1	NZone	225	8083	6930	114.8	45.7	160.5	36.32
Piedmont	2014	121	1	NZone	90	8954	7451	109.2	33.5	142.8	70.99
Piedmont	2014	122	1	UAN	180	8762	8202	133.2	46.8	179.9	56.23

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Piedmont	2014	123	1	Instinct	0	5536	5563	55.4	25.0	80.4	.
Piedmont	2014	124	1	AgrotainPlus	45	7198	5557	62.6	27.2	89.9	23.87
Piedmont	2014	201	2	Instinct	135	10927	8874	121.3	44.4	165.7	64.36
Piedmont	2014	202	2	UAN	180	10018	7825	130.2	43.8	174.1	52.96
Piedmont	2014	203	2	UAN	135	10701	8337	132.7	39.2	171.9	68.99
Piedmont	2014	204	2	Instinct	0	5942	7359	52.9	29.4	82.3	.
Piedmont	2014	205	2	UAN	225	11803	7773	145.2	43.5	188.7	48.90
Piedmont	2014	206	2	NZone	225	12958	7857	174.9	43.2	218.1	62.05
Piedmont	2014	207	2	Instinct	90	8009	7372	76.1	35.4	111.5	36.06
Piedmont	2014	208	2	UAN	0	3894	5242	34.3	20.4	54.7	.
Piedmont	2014	209	2	NZone	45	6857	6465	63.1	25.9	88.9	21.84
Piedmont	2014	210	2	NZone	90	8399	9680	94.9	49.4	144.3	72.68
Piedmont	2014	211	2	AgrotainPlus	45	6399	4824	58.9	24.1	83.0	8.55
Piedmont	2014	212	2	AgrotainPlus	225	10429	8323	156.4	52.4	208.9	57.91
Piedmont	2014	213	2	AgrotainPlus	180	10365	6197	132.7	35.3	168.0	49.57
Piedmont	2014	214	2	Instinct	225	7908	7842	101.2	61.2	162.4	37.16
Piedmont	2014	215	2	AgrotainPlus	135	12633	8062	154.1	43.5	197.7	88.17
Piedmont	2014	216	2	NZone	180	13608	7311	170.1	37.3	207.4	71.56
Piedmont	2014	217	2	NZone	135	12795	6523	163.8	29.4	193.1	84.80
Piedmont	2014	218	2	NZone	0	7188	5866	64.7	22.9	87.6	.
Piedmont	2014	219	2	Instinct	180	11396	8077	152.7	44.4	197.1	65.83
Piedmont	2014	220	2	AgrotainPlus	90	10009	7372	108.1	26.5	134.6	61.92
Piedmont	2014	221	2	AgrotainPlus	0	5702	7256	54.2	26.8	81.0	.
Piedmont	2014	222	2	UAN	45	7409	8241	72.6	30.5	103.1	53.45
Piedmont	2014	223	2	UAN	90	11236	6477	120.2	27.9	148.1	76.91
Piedmont	2014	224	2	Instinct	45	8751	5858	88.4	27.5	115.9	82.04
Piedmont	2014	301	3	UAN	90	8217	8114	94.5	36.5	131.0	57.86
Piedmont	2014	302	3	Instinct	90	10965	6563	125.0	35.4	160.4	90.72
Piedmont	2014	303	3	AgrotainPlus	135	13306	7930	166.3	40.4	206.8	94.95
Piedmont	2014	304	3	Instinct	180	13736	8136	199.2	54.5	253.7	97.39
Piedmont	2014	305	3	AgrotainPlus	90	11957	5747	133.9	29.3	163.2	93.82
Piedmont	2014	306	3	NZone	180	.	6518	.	30.0	.	.
Piedmont	2014	307	3	Instinct	225	11835	6673	170.4	42.0	212.5	59.51
Piedmont	2014	308	3	UAN	225	10919	7988	147.4	43.9	191.3	50.08
Piedmont	2014	309	3	AgrotainPlus	225	11959	8264	165.0	57.8	222.9	64.16
Piedmont	2014	310	3	AgrotainPlus	45	9206	5773	91.1	26.6	117.7	86.03
Piedmont	2014	311	3	NZone	90	11138	8104	116.9	37.3	154.2	83.78
Piedmont	2014	312	3	Instinct	0	7542	7240	73.2	33.3	106.5	.
Piedmont	2014	313	3	AgrotainPlus	180	5607	5909	95.3	38.4	133.7	30.45
Piedmont	2014	314	3	NZone	135	11202	4937	117.6	38.0	155.6	56.91
Piedmont	2014	315	3	UAN	180	9052	6395	120.4	32.6	153.0	41.21
Piedmont	2014	316	3	NZone	45	8907	6129	104.2	26.4	130.6	114.74
Piedmont	2014	317	3	NZone	225	12665	9365	165.9	54.3	220.2	62.98
Piedmont	2014	318	3	UAN	45	10294	5860	95.7	23.4	119.2	89.32
Piedmont	2014	319	3	AgrotainPlus	0	7306	6624	63.6	22.5	86.1	.
Piedmont	2014	320	3	Instinct	45	6872	7113	55.0	25.6	80.6	3.18
Piedmont	2014	321	3	NZone	0	5521	6491	49.1	24.0	73.2	.
Piedmont	2014	322	3	UAN	0	6117	6959	47.7	24.4	72.1	.
Piedmont	2014	323	3	Instinct	135	10815	8296	100.6	34.8	135.4	41.86
Piedmont	2014	324	3	UAN	135	11754	7732	137.5	37.1	174.6	71.04
Piedmont	2014	401	4	AgrotainPlus	135	8684	7746	115.5	52.7	168.2	66.23
Piedmont	2014	402	4	UAN	180	7642	6308	107.0	32.2	139.2	33.48
Piedmont	2014	403	4	AgrotainPlus	45	7951	7029	73.9	34.4	108.4	65.24
Piedmont	2014	404	4	UAN	225	9964	10088	130.5	84.7	215.3	60.76
Piedmont	2014	405	4	NZone	90	11897	7518	111.8	34.6	146.4	75.07
Piedmont	2014	406	4	NZone	0	4575	4369	42.1	16.2	58.3	.
Piedmont	2014	407	4	NZone	135	9842	8874	99.4	40.8	140.2	45.44
Piedmont	2014	408	4	Instinct	0	5031	4286	41.8	12.4	54.2	.

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Piedmont	2014	409	4	Instinct	225	13778	8496	151.6	46.7	198.3	53.18
Piedmont	2014	410	4	AgrotainPlus	225	11135	9481	135.8	73.0	208.8	57.90
Piedmont	2014	411	4	Instinct	135	10944	7469	125.9	32.1	158.0	58.64
Piedmont	2014	412	4	UAN	0	6390	5157	53.7	16.5	70.2	.
Piedmont	2014	413	4	UAN	45	7301	10988	68.6	53.8	122.5	96.67
Piedmont	2014	414	4	UAN	135	10415	7731	128.1	46.4	174.5	70.93
Piedmont	2014	415	4	UAN	90	9434	9244	92.5	41.6	134.1	61.26
Piedmont	2014	416	4	Instinct	180	11314	8763	118.8	42.1	160.9	45.59
Piedmont	2014	417	4	NZone	180	12435	8538	136.8	40.1	176.9	54.55
Piedmont	2014	418	4	NZone	45	7472	4576	74.0	16.5	90.4	25.19
Piedmont	2014	419	4	NZone	225	12922	8672	175.7	58.1	233.8	69.05
Piedmont	2014	420	4	Instinct	90	10590	9252	105.9	39.8	145.7	74.25
Piedmont	2014	421	4	AgrotainPlus	90	10329	6413	104.3	32.7	137.0	64.59
Piedmont	2014	422	4	Instinct	45	9225	8763	84.9	35.1	119.9	90.99
Piedmont	2014	423	4	AgrotainPlus	180	13443	6881	172.1	35.1	207.2	71.43
Piedmont	2014	424	4	AgrotainPlus	0	8214	10106	71.5	48.5	120.0	.
Piedmont	2015	101	1	NZone	135	5270	2575	58.0	9.5	67.5	22.98
Piedmont	2015	102	1	UAN	45	3554	2006	34.1	7.0	41.1	10.11
Piedmont	2015	103	1	NZone	180	4048	3385	44.9	19.0	63.9	15.22
Piedmont	2015	104	1	AgrotainPlus	90	4431	3632	47.9	18.2	66.0	32.83
Piedmont	2015	105	1	Instinct	180	3057	1997	39.7	16.6	56.3	11.00
Piedmont	2015	106	1	NZone	225	3647	2789	51.4	18.4	69.8	14.83
Piedmont	2015	107	1	UAN	135	3322	3258	44.5	21.2	65.7	21.64
Piedmont	2015	108	1	UAN	0	2354	2243	26.8	9.4	36.3	.
Piedmont	2015	109	1	NZone	0	1854	1957	21.7	10.2	31.9	.
Piedmont	2015	110	1	Instinct	0	2318	2297	22.9	10.6	33.5	.
Piedmont	2015	111	1	AgrotainPlus	225	4085	3770	50.6	21.1	71.8	15.69
Piedmont	2015	112	1	Instinct	90	4288	.	45.0	.	.	.
Piedmont	2015	113	1	AgrotainPlus	0	2563	2886	24.9	13.9	38.7	.
Piedmont	2015	114	1	UAN	180	4463	1929	54.0	14.1	68.1	17.57
Piedmont	2015	115	1	AgrotainPlus	135	4071	2264	49.7	7.0	56.7	14.94
Piedmont	2015	116	1	Instinct	225	6879	236	81.9	1.5	83.4	20.88
Piedmont	2015	117	1	UAN	225	6394	3142	73.5	22.9	96.5	26.72
Piedmont	2015	118	1	UAN	90	5318	2740	54.8	12.3	67.1	34.04
Piedmont	2015	119	1	Instinct	45	3080	3055	27.4	12.2	39.6	6.75
Piedmont	2015	120	1	AgrotainPlus	45	3543	2038	34.7	8.4	43.1	14.44
Piedmont	2015	121	1	AgrotainPlus	180	3285	2053	39.8	16.4	56.2	10.92
Piedmont	2015	122	1	Instinct	135	4925	3026	52.7	16.3	69.0	24.13
Piedmont	2015	123	1	NZone	90	4373	2469	48.5	9.4	57.9	23.79
Piedmont	2015	124	1	NZone	45	3579	3854	35.1	15.8	50.9	31.84
Piedmont	2015	201	2	Instinct	135	5377	3252	60.8	14.0	74.8	28.38
Piedmont	2015	202	2	Instinct	90	3573	.	39.7	.	.	.
Piedmont	2015	203	2	AgrotainPlus	0	2117	1600	22.0	7.0	29.1	.
Piedmont	2015	204	2	NZone	45	3869	2929	39.8	12.0	51.9	34.05
Piedmont	2015	205	2	AgrotainPlus	180	4080	3462	48.6	31.5	80.1	24.25
Piedmont	2015	206	2	AgrotainPlus	45	4099	2778	36.9	12.2	49.1	27.92
Piedmont	2015	207	2	NZone	0	1901	2795	17.5	12.0	29.5	.
Piedmont	2015	208	2	Instinct	180	5273	3820	62.2	22.9	85.1	27.09
Piedmont	2015	209	2	UAN	0	2111	2530	20.5	10.6	31.1	.
Piedmont	2015	210	2	AgrotainPlus	135	3948	2536	44.2	17.0	61.2	18.31
Piedmont	2015	211	2	Instinct	45	2288	2219	26.5	8.2	34.7	.
Piedmont	2015	212	2	Instinct	0	3263	1636	30.0	6.9	36.9	.
Piedmont	2015	213	2	UAN	90	4674	3737	47.2	14.2	61.4	27.68
Piedmont	2015	214	2	NZone	225	4918	2788	61.0	20.4	81.3	19.97
Piedmont	2015	215	2	NZone	135	4853	3717	56.8	35.3	92.1	41.28
Piedmont	2015	216	2	NZone	90	908	3304	9.9	19.8	29.7	.
Piedmont	2015	217	2	AgrotainPlus	225	4779	.	59.7	.	.	.
Piedmont	2015	218	2	UAN	135	6503	4666	70.9	17.3	88.1	38.35

Table B1 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Stover Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Stover N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Piedmont	2015	219	2	UAN	45	2931	2755	29.0	11.3	40.3	8.27
Piedmont	2015	220	2	UAN	225	4814	4047	61.6	39.3	100.9	28.69
Piedmont	2015	221	2	NZone	180	4186	3069	47.3	17.5	64.8	15.73
Piedmont	2015	222	2	Instinct	225	4191	2598	52.0	27.8	79.8	19.27
Piedmont	2015	223	2	UAN	180	3329	2131	41.3	16.4	57.7	11.76
Piedmont	2015	224	2	AgrotainPlus	90	4457	1919	47.2	10.6	57.8	23.66
Piedmont	2015	301	3	AgrotainPlus	135	4281	2325	49.2	17.9	67.1	22.71
Piedmont	2015	302	3	UAN	135	4124	2181	48.2	13.7	62.0	18.89
Piedmont	2015	303	3	NZone	0	2232	1826	21.9	6.9	28.8	.
Piedmont	2015	304	3	AgrotainPlus	45	3339	2288	30.7	12.1	42.8	13.92
Piedmont	2015	305	3	NZone	180	4597	3407	53.3	17.0	70.4	18.84
Piedmont	2015	306	3	UAN	90	4535	2156	48.1	13.4	61.4	27.71
Piedmont	2015	307	3	UAN	180	6622	3389	78.8	22.4	101.2	36.03
Piedmont	2015	308	3	UAN	45	5005	2431	52.5	10.0	62.5	57.83
Piedmont	2015	309	3	NZone	90	4989	3669	49.9	18.3	68.2	35.30
Piedmont	2015	310	3	AgrotainPlus	90	5562	3218	59.0	12.6	71.5	38.95
Piedmont	2015	311	3	AgrotainPlus	0	2825	3140	27.1	15.7	42.8	.
Piedmont	2015	312	3	NZone	225	7488	3182	83.1	18.5	101.6	29.00
Piedmont	2015	313	3	NZone	45	3537	1920	35.0	7.5	42.5	13.15
Piedmont	2015	314	3	Instinct	90	4175	2746	38.0	11.5	49.5	14.42
Piedmont	2015	315	3	AgrotainPlus	225	6085	2133	70.0	11.1	81.1	19.85
Piedmont	2015	316	3	AgrotainPlus	180	7997	2609	88.0	13.6	101.5	36.23
Piedmont	2015	317	3	Instinct	180	5678	2853	60.2	16.5	76.7	22.39
Piedmont	2015	318	3	Instinct	45	4531	4071	44.9	13.0	57.9	47.49
Piedmont	2015	319	3	UAN	0	2706	2843	25.7	14.2	39.9	.
Piedmont	2015	320	3	Instinct	135	6701	2504	61.6	13.5	75.2	28.69
Piedmont	2015	321	3	Instinct	0	2947	1584	28.0	5.7	33.7	.
Piedmont	2015	322	3	NZone	135	6504	2437	57.9	10.2	68.1	23.45
Piedmont	2015	323	3	Instinct	225	7695	5110	90.8	19.9	110.7	33.09
Piedmont	2015	324	3	UAN	225	7608	4005	85.2	30.0	115.2	35.11
Piedmont	2015	401	4	NZone	90	4346	2943	42.6	19.4	62.0	28.35
Piedmont	2015	402	4	NZone	225	6113	3097	65.4	19.2	84.6	21.43
Piedmont	2015	403	4	AgrotainPlus	90	4724	4809	48.7	21.6	70.3	37.60
Piedmont	2015	404	4	Instinct	225	8275	4941	77.0	31.6	108.6	32.13
Piedmont	2015	405	4	AgrotainPlus	180	7452	3000	92.4	17.1	109.5	40.68
Piedmont	2015	406	4	AgrotainPlus	135	7756	5003	84.5	43.5	128.1	68.05
Piedmont	2015	407	4	Instinct	45	3850	2975	35.0	13.7	48.7	27.03
Piedmont	2015	408	4	UAN	180	7928	5822	80.9	21.0	101.8	36.39
Piedmont	2015	409	4	Instinct	90	4617	3756	42.5	15.4	57.9	23.74
Piedmont	2015	410	4	Instinct	180	7099	4969	77.4	38.8	116.1	44.38
Piedmont	2015	411	4	Instinct	0	2392	4760	18.9	25.2	44.1	.
Piedmont	2015	412	4	AgrotainPlus	225	6908	5278	69.8	32.7	102.5	29.41
Piedmont	2015	413	4	AgrotainPlus	0	3849	1898	40.8	9.3	50.1	.
Piedmont	2015	414	4	NZone	0	3789	1437	34.9	6.3	41.2	.
Piedmont	2015	415	4	UAN	0	3048	2175	28.3	9.8	38.1	.
Piedmont	2015	416	4	NZone	45	4631	5421	44.9	24.4	69.3	73.00
Piedmont	2015	417	4	NZone	180	6229	2899	66.0	15.9	82.0	25.31
Piedmont	2015	418	4	UAN	90	7408	4917	64.4	28.0	92.5	62.35
Piedmont	2015	419	4	UAN	135	5187	2998	59.7	16.8	76.4	29.64
Piedmont	2015	420	4	AgrotainPlus	45	5543	2575	52.7	12.6	65.3	63.99
Piedmont	2015	421	4	UAN	45	4379	3049	46.9	12.8	59.7	51.46
Piedmont	2015	422	4	UAN	225	7785	4337	95.0	22.6	117.5	36.13
Piedmont	2015	423	4	NZone	135	5882	3622	59.4	17.4	76.8	29.91
Piedmont	2015	424	4	Instinct	135	7579	4632	80.3	31.5	111.8	55.97

Table B2 - Wheat N rate & product field trials raw data by site year.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2014	101	1	NZone	135	6348	2602	115.7	14.3	130.1	61.6
Coastal_Plain	2014	102	1	UAN	90	5624	3049	96.9	13.7	110.7	70.8
Coastal_Plain	2014	103	1	UAN	180	6839	4350	124.7	24.8	149.5	57.0
Coastal_Plain	2014	104	1	NZone	0	3194	2033	53.5	10.8	64.2	.
Coastal_Plain	2014	105	1	NZone	90	5535	3374	93.2	17.9	111.1	71.2
Coastal_Plain	2014	106	1	Instinct	180	7094	4675	130.8	24.3	155.1	60.2
Coastal_Plain	2014	107	1	Instinct	135	6794	4391	117.8	22.8	140.6	69.5
Coastal_Plain	2014	109	1	Instinct	0	2732	1586	47.6	9.2	56.8	.
Coastal_Plain	2014	110	1	UAN	45	3936	2480	65.1	13.1	78.2	69.2
Coastal_Plain	2014	111	1	NZone	45	4399	3049	69.7	13.7	83.4	80.7
Coastal_Plain	2014	112	1	UAN	135	6566	4594	109.9	20.2	130.1	61.6
Coastal_Plain	2014	116	1	Instinct	90	6493	4025	112.6	23.7	136.3	99.4
Coastal_Plain	2014	117	1	UAN	0	2540	1138	47.3	7.6	54.9	.
Coastal_Plain	2014	118	1	Instinct	45	4242	2643	74.0	16.4	90.3	96.2
Coastal_Plain	2014	119	1	NZone	180	7286	5245	140.8	30.4	171.3	69.2
Coastal_Plain	2014	201	2	NZone	0	2491	1057	44.4	6.1	50.6	.
Coastal_Plain	2014	203	2	Instinct	45	3830	2887	64.5	14.7	79.2	71.3
Coastal_Plain	2014	204	2	Instinct	135	6722	4635	123.9	23.2	147.1	74.3
Coastal_Plain	2014	205	2	NZone	180	6914	4350	124.7	24.4	149.0	56.8
Coastal_Plain	2014	208	2	Instinct	90	5910	3334	105.4	18.0	123.4	85.0
Coastal_Plain	2014	210	2	UAN	0	2110	1382	36.4	10.2	46.6	.
Coastal_Plain	2014	211	2	NZone	45	4046	2439	67.3	10.2	77.6	67.7
Coastal_Plain	2014	212	2	UAN	135	6190	3700	104.8	26.6	131.5	62.7
Coastal_Plain	2014	213	2	UAN	180	6720	3578	126.5	19.7	146.2	55.2
Coastal_Plain	2014	214	2	Instinct	180	7209	4553	155.1	36.4	191.6	80.5
Coastal_Plain	2014	215	2	NZone	90	5452	2765	94.5	15.5	110.0	70.0
Coastal_Plain	2014	217	2	Instinct	0	2857	1342	52.1	8.5	60.5	.
Coastal_Plain	2014	218	2	UAN	90	5324	2724	92.3	13.3	105.6	65.2
Coastal_Plain	2014	219	2	NZone	135	6340	3862	111.2	21.2	132.4	63.4
Coastal_Plain	2014	220	2	UAN	45	4019	2439	68.5	11.7	80.2	73.5
Coastal_Plain	2014	304	3	NZone	0	2238	1504	38.3	8.1	46.5	.
Coastal_Plain	2014	305	3	NZone	45	3592	2846	54.4	11.7	66.1	42.0
Coastal_Plain	2014	306	3	Instinct	180	7221	4635	136.7	25.5	162.2	64.1
Coastal_Plain	2014	307	3	UAN	0	1866	1098	31.4	7.2	38.7	.
Coastal_Plain	2014	308	3	UAN	45	3214	2033	51.5	10.6	62.1	33.2
Coastal_Plain	2014	309	3	NZone	90	5463	3659	88.7	19.0	107.7	67.5
Coastal_Plain	2014	310	3	NZone	135	6328	4147	111.0	18.7	129.6	61.3
Coastal_Plain	2014	311	3	UAN	180	7147	4594	141.7	28.0	169.7	68.3
Coastal_Plain	2014	313	3	UAN	90	4987	3009	75.5	12.9	88.5	46.0
Coastal_Plain	2014	314	3	Instinct	135	6933	4025	123.0	21.3	144.3	72.2
Coastal_Plain	2014	315	3	NZone	180	7348	3781	147.9	20.4	168.3	67.6
Coastal_Plain	2014	316	3	UAN	135	6849	3822	122.1	20.3	142.4	70.8
Coastal_Plain	2014	317	3	Instinct	45	3476	2317	51.6	11.1	62.7	34.5
Coastal_Plain	2014	319	3	Instinct	90	5455	3496	87.0	18.9	105.8	65.4
Coastal_Plain	2014	320	3	Instinct	0	2565	1220	44.2	5.9	50.1	.
Coastal_Plain	2014	403	4	NZone	90	5060	3252	88.2	19.8	108.1	67.9
Coastal_Plain	2014	404	4	UAN	180	6001	4228	116.0	24.5	140.5	52.0
Coastal_Plain	2014	406	4	Instinct	0	1352	650	23.8	5.5	29.4	.
Coastal_Plain	2014	407	4	NZone	0	1484	447	24.5	3.3	27.8	.
Coastal_Plain	2014	408	4	Instinct	90	5103	3334	75.8	14.7	90.4	48.2
Coastal_Plain	2014	410	4	Instinct	180	6538	4432	136.1	27.0	163.2	64.7
Coastal_Plain	2014	411	4	NZone	180	6265	4391	126.1	24.1	150.2	57.5
Coastal_Plain	2014	412	4	UAN	90	4887	2927	72.1	12.0	84.1	41.1
Coastal_Plain	2014	413	4	UAN	45	3014	1748	47.1	7.2	54.3	15.8
Coastal_Plain	2014	414	4	UAN	135	5773	3131	97.2	22.5	119.7	53.9
Coastal_Plain	2014	416	4	NZone	135	5886	3334	105.0	19.7	124.6	57.6
Coastal_Plain	2014	417	4	Instinct	45	2958	1667	45.7	7.7	53.3	13.6
Coastal_Plain	2014	418	4	Instinct	135	5510	3131	97.2	16.6	113.7	49.5

Table B2 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2014	419	4	NZone	45	2957	1830	43.9	8.0	51.9	10.5
Coastal_Plain	2014	420	4	UAN	0	1934	1179	32.4	8.6	41.0	.
Coastal_Plain	2015	101	1	Instinct	180	7645	4635	138.7	29.2	167.9	41.6
Coastal_Plain	2015	102	1	UAN	90	6422	4371	109.4	23.6	133.0	44.4
Coastal_Plain	2015	103	1	Instinct	45	4912	3191	102.8	17.9	120.7	61.2
Coastal_Plain	2015	106	1	Instinct	0	3812	2033	67.6	14.0	81.6	.
Coastal_Plain	2015	107	1	NZone	0	3908	2073	68.5	13.3	81.8	.
Coastal_Plain	2015	108	1	Instinct	90	6664	4330	107.4	22.5	129.9	40.9
Coastal_Plain	2015	109	1	UAN	0	4542	2419	82.8	15.2	98.1	.
Coastal_Plain	2015	110	1	NZone	135	7621	4838	140.5	33.9	174.3	60.3
Coastal_Plain	2015	111	1	NZone	180	7552	4858	160.2	38.9	199.1	59.1
Coastal_Plain	2015	112	1	UAN	180	7684	5428	143.9	30.9	174.9	45.5
Coastal_Plain	2015	113	1	NZone	45	5497	3781	92.0	24.2	116.2	51.2
Coastal_Plain	2015	114	1	NZone	90	6263	4513	107.9	22.6	130.5	41.6
Coastal_Plain	2015	117	1	UAN	135	6292	3944	114.7	19.7	134.4	30.6
Coastal_Plain	2015	118	1	UAN	45	3805	2561	69.4	14.6	84.0	0.0
Coastal_Plain	2015	119	1	Instinct	135	6648	3801	138.1	27.0	165.1	53.4
Coastal_Plain	2015	201	2	NZone	135	7260	4472	119.3	29.1	148.4	41.0
Coastal_Plain	2015	202	2	UAN	0	3867	2561	64.3	13.3	77.7	.
Coastal_Plain	2015	204	2	NZone	0	3522	1870	61.1	11.8	72.8	.
Coastal_Plain	2015	205	2	Instinct	180	7520	5021	149.5	45.7	195.2	56.9
Coastal_Plain	2015	206	2	UAN	45	5627	4045	97.0	22.2	119.2	58.0
Coastal_Plain	2015	208	2	UAN	90	6929	4879	119.4	26.8	146.3	59.1
Coastal_Plain	2015	209	2	NZone	45	5900	3781	100.5	29.9	130.4	82.9
Coastal_Plain	2015	210	2	NZone	180	8481	6159	162.2	45.0	207.2	63.6
Coastal_Plain	2015	211	2	UAN	180	8210	6180	158.7	43.9	202.6	61.0
Coastal_Plain	2015	212	2	UAN	135	7123	4696	126.3	26.3	152.6	44.2
Coastal_Plain	2015	214	2	Instinct	0	4531	3151	90.8	15.1	105.9	.
Coastal_Plain	2015	217	2	NZone	90	6368	4432	114.8	22.2	137.0	48.8
Coastal_Plain	2015	218	2	Instinct	45	5770	4371	106.5	27.5	134.0	91.0
Coastal_Plain	2015	219	2	Instinct	135	7493	5082	140.4	36.6	177.0	62.3
Coastal_Plain	2015	220	2	Instinct	90	6998	5123	125.4	31.8	157.2	71.4
Coastal_Plain	2015	301	3	UAN	135	7429	5367	128.8	36.0	164.7	53.2
Coastal_Plain	2015	302	3	NZone	90	6719	5021	107.8	28.6	136.4	48.1
Coastal_Plain	2015	303	3	NZone	180	8203	5123	154.5	38.4	192.9	55.6
Coastal_Plain	2015	304	3	UAN	0	4277	2561	75.4	14.9	90.3	.
Coastal_Plain	2015	306	3	Instinct	180	8436	5875	163.2	30.5	193.8	56.1
Coastal_Plain	2015	308	3	UAN	90	7198	5143	122.6	24.7	147.3	60.3
Coastal_Plain	2015	311	3	Instinct	0	4851	3049	89.5	14.6	104.2	.
Coastal_Plain	2015	312	3	Instinct	135	7798	4960	140.3	30.8	171.1	57.9
Coastal_Plain	2015	313	3	UAN	45	6629	4208	115.6	19.8	135.4	94.0
Coastal_Plain	2015	314	3	Instinct	45	6176	4371	114.3	33.2	147.5	121.0
Coastal_Plain	2015	315	3	Instinct	90	8023	5407	121.5	35.1	156.7	70.8
Coastal_Plain	2015	317	3	NZone	0	4696	3049	82.3	17.7	100.0	.
Coastal_Plain	2015	318	3	UAN	180	8254	5367	163.6	35.4	199.1	59.0
Coastal_Plain	2015	319	3	NZone	135	7601	4310	138.6	19.8	158.4	48.5
Coastal_Plain	2015	320	3	NZone	45	6337	4432	112.4	21.3	133.6	90.1
Coastal_Plain	2015	401	4	NZone	90	6798	4614	109.7	29.1	138.8	50.8
Coastal_Plain	2015	403	4	Instinct	0	5373	3374	75.5	30.4	105.9	.
Coastal_Plain	2015	404	4	Instinct	45	5930	4147	100.9	19.9	120.8	61.5
Coastal_Plain	2015	406	4	UAN	135	7935	5102	135.2	33.7	168.9	56.2
Coastal_Plain	2015	407	4	UAN	180	8438	6363	158.9	40.7	199.6	59.3
Coastal_Plain	2015	408	4	Instinct	180	8476	6159	171.2	53.6	224.8	73.4
Coastal_Plain	2015	409	4	UAN	45	7052	5489	126.5	32.9	159.4	147.6
Coastal_Plain	2015	411	4	UAN	90	7484	5123	140.9	31.8	172.7	88.6
Coastal_Plain	2015	412	4	NZone	0	4636	2602	77.6	11.4	89.0	.
Coastal_Plain	2015	413	4	Instinct	135	8093	5062	139.3	32.4	171.7	58.4
Coastal_Plain	2015	414	4	NZone	45	6291	4045	106.6	19.4	126.0	73.0

Table B2 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Coastal_Plain	2015	417	4	NZone	135	7522	4594	140.1	31.7	171.8	58.5
Coastal_Plain	2015	418	4	NZone	180	7843	5285	151.6	37.0	188.6	53.2
Coastal_Plain	2015	419	4	UAN	0	5098	3009	92.4	14.7	107.2	.
Coastal_Plain	2015	420	4	Instinct	90	7202	5082	151.1	26.9	178.0	94.6
Piedmont	2015	101	1	Instinct	0	4726	3122	73.9	8.1	82.0	.
Piedmont	2014	103	1	Instinct	45	4512	2635	67.0	7.4	74.3	.
Piedmont	2014	105	1	NZone	180	5306	2960	94.1	9.8	103.9	13.0
Piedmont	2014	106	1	NZone	45	4608	2960	72.5	8.3	80.8	0.5
Piedmont	2014	108	1	UAN	0	5120	2992	82.6	8.1	90.7	.
Piedmont	2014	109	1	NZone	135	6418	6472	110.6	22.0	132.6	38.7
Piedmont	2014	111	1	NZone	0	4806	2960	73.7	8.0	81.7	.
Piedmont	2014	112	1	UAN	180	6353	3903	112.7	12.1	124.8	24.6
Piedmont	2014	114	1	UAN	45	5227	3155	83.3	7.9	91.2	23.7
Piedmont	2014	115	1	Instinct	135	6873	3838	121.9	13.8	135.7	41.0
Piedmont	2014	116	1	UAN	135	7325	4196	136.5	18.5	154.9	55.3
Piedmont	2014	117	1	NZone	90	6259	3935	103.5	10.6	114.1	37.4
Piedmont	2014	118	1	UAN	90	6833	7611	136.2	30.4	166.6	96.0
Piedmont	2014	119	1	Instinct	90	5738	3935	94.9	11.0	105.9	28.2
Piedmont	2014	120	1	Instinct	180	6390	3740	119.0	16.1	135.1	30.4
Piedmont	2014	202	2	UAN	45	5346	2895	77.2	7.5	84.8	9.2
Piedmont	2014	203	2	UAN	0	4547	2212	66.6	6.4	73.0	.
Piedmont	2014	204	2	NZone	135	6452	3513	108.6	10.5	119.2	28.7
Piedmont	2014	205	2	UAN	90	5296	2960	78.6	11.8	90.5	11.0
Piedmont	2014	206	2	UAN	180	6568	3675	107.3	11.0	118.3	21.1
Piedmont	2014	207	2	NZone	180	6429	3350	112.7	10.1	122.8	23.5
Piedmont	2014	208	2	NZone	0	4934	2667	73.2	6.9	80.2	.
Piedmont	2014	209	2	Instinct	135	6925	4131	120.0	14.5	134.5	40.1
Piedmont	2014	210	2	UAN	135	6779	3740	118.9	15.3	134.2	39.9
Piedmont	2014	212	2	Instinct	0	4154	1919	60.4	5.0	65.4	.
Piedmont	2014	214	2	Instinct	180	7737	4521	149.5	17.6	167.2	48.3
Piedmont	2014	215	2	NZone	90	6670	4228	105.7	12.7	118.3	42.1
Piedmont	2014	217	2	Instinct	45	5563	3643	84.8	10.9	95.7	33.8
Piedmont	2014	218	2	Instinct	90	7286	4553	135.7	16.4	152.1	79.8
Piedmont	2014	219	2	NZone	45	4553	2700	69.9	7.6	77.4	.
Piedmont	2014	301	3	UAN	135	6164	4098	106.2	20.1	126.3	34.0
Piedmont	2014	303	3	NZone	180	6768	3318	115.3	13.3	128.6	26.8
Piedmont	2014	304	3	UAN	0	4979	2569	69.9	7.2	77.1	.
Piedmont	2014	305	3	Instinct	0	4678	2537	66.2	6.3	72.5	.
Piedmont	2014	307	3	Instinct	180	7207	4423	137.9	16.4	154.2	41.1
Piedmont	2014	308	3	NZone	90	6569	3513	106.0	9.8	115.9	39.3
Piedmont	2014	310	3	UAN	45	5919	3415	90.8	8.9	99.7	42.6
Piedmont	2014	312	3	Instinct	90	6244	3383	96.4	10.1	106.6	29.0
Piedmont	2014	313	3	NZone	135	6660	3903	112.1	11.7	123.8	32.2
Piedmont	2014	314	3	UAN	180	7892	4976	138.4	19.4	157.8	43.1
Piedmont	2014	315	3	Instinct	135	7822	8099	135.6	30.0	165.6	63.2
Piedmont	2014	316	3	UAN	90	7845	4749	132.9	16.6	149.5	76.9
Piedmont	2014	318	3	NZone	0	5339	3448	95.7	11.0	106.8	.
Piedmont	2014	319	3	NZone	45	5350	3057	85.3	7.6	92.9	27.5
Piedmont	2014	320	3	Instinct	45	4772	3155	78.0	7.6	85.5	11.0
Piedmont	2014	401	4	Instinct	180	6523	3513	120.2	12.3	132.5	29.0
Piedmont	2014	402	4	NZone	90	6683	4196	111.9	11.7	123.6	48.0
Piedmont	2014	403	4	Instinct	0	4739	2212	71.8	6.2	78.0	.
Piedmont	2014	404	4	Instinct	90	6522	3383	103.3	11.8	115.2	38.6
Piedmont	2014	405	4	NZone	45	5265	2960	85.0	8.3	93.3	28.2
Piedmont	2014	407	4	Instinct	45	5117	2667	80.0	6.7	86.7	13.6
Piedmont	2014	408	4	NZone	180	7102	3643	128.1	13.5	141.6	34.0
Piedmont	2014	411	4	UAN	135	6276	3773	106.3	17.0	123.3	31.7
Piedmont	2014	413	4	NZone	135	6366	3740	108.5	11.6	120.1	29.3

Table B2 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Piedmont	2014	414	4	UAN	180	6716	3448	127.8	11.4	139.2	32.7
Piedmont	2014	415	4	UAN	45	5372	3187	93.1	13.4	106.5	57.8
Piedmont	2014	416	4	Instinct	135	7573	4066	141.9	15.4	157.3	57.1
Piedmont	2014	418	4	UAN	0	4337	2212	73.5	6.0	79.4	.
Piedmont	2014	419	4	NZone	0	4094	2439	73.8	6.6	80.4	.
Piedmont	2014	420	4	UAN	90	5744	3740	97.3	11.2	108.5	31.1
Piedmont	2015	101	1	UAN	90	5969	2943	104.3	23.6	127.9	53.1
Piedmont	2015	105	1	Instinct	0	5818	2960	59.2	14.0	73.2	.
Piedmont	2015	106	1	UAN	180	7380	3480	137.0	30.9	168.0	48.9
Piedmont	2015	107	1	NZone	45	6137	3252	85.4	24.2	109.6	65.5
Piedmont	2015	108	1	NZone	180	7458	2537	139.2	38.9	178.1	54.5
Piedmont	2015	109	1	Instinct	45	6343	3415	88.4	17.9	106.3	57.9
Piedmont	2015	110	1	NZone	90	6717	3513	100.5	22.6	123.0	47.7
Piedmont	2015	111	1	UAN	135	6337	3090	104.7	19.7	124.4	32.8
Piedmont	2015	112	1	UAN	45	5799	3285	57.6	14.6	72.2	0.0
Piedmont	2015	114	1	UAN	0	6132	3529	67.0	15.2	82.2	.
Piedmont	2015	115	1	NZone	0	5526	2992	55.3	13.3	68.6	.
Piedmont	2015	116	1	Instinct	135	6898	3740	116.0	27.0	143.0	46.7
Piedmont	2015	117	1	NZone	135	6827	3627	126.0	33.9	159.9	59.2
Piedmont	2015	118	1	Instinct	180	6801	3496	132.0	29.2	161.2	45.1
Piedmont	2015	119	1	Instinct	90	6376	3204	88.9	22.5	111.4	34.7
Piedmont	2015	201	2	UAN	0	4077	1919	55.1	13.3	68.4	.
Piedmont	2015	203	2	NZone	90	6181	3187	100.9	22.2	123.0	47.7
Piedmont	2015	205	2	Instinct	90	6465	2943	112.8	31.8	144.5	71.7
Piedmont	2015	206	2	Instinct	135	6565	3155	125.9	36.6	162.5	61.2
Piedmont	2015	208	2	UAN	180	6318	3252	143.1	43.9	187.0	59.6
Piedmont	2015	209	2	NZone	180	6715	3204	142.8	45.0	187.8	60.0
Piedmont	2015	210	2	Instinct	180	6036	2700	128.7	45.7	174.4	52.5
Piedmont	2015	211	2	NZone	135	6108	2358	121.5	29.1	150.6	52.3
Piedmont	2015	212	2	Instinct	0	4297	2114	74.8	15.1	89.9	.
Piedmont	2015	213	2	UAN	90	6054	3187	107.7	26.8	134.5	60.5
Piedmont	2015	216	2	UAN	45	5646	2878	90.8	22.2	113.1	73.2
Piedmont	2015	217	2	Instinct	45	5476	3009	85.2	27.5	112.7	72.4
Piedmont	2015	218	2	NZone	0	4599	2179	48.1	11.8	59.9	.
Piedmont	2015	219	2	NZone	45	5063	2504	85.8	29.9	115.7	79.0
Piedmont	2015	220	2	UAN	135	5456	2732	110.0	26.3	136.3	41.7
Piedmont	2015	301	3	Instinct	90	4999	2667	106.8	35.1	142.0	68.9
Piedmont	2015	303	3	UAN	90	5655	2927	112.6	24.7	137.3	63.6
Piedmont	2015	305	3	NZone	0	4304	1984	66.4	17.7	84.1	.
Piedmont	2015	306	3	NZone	45	5133	2260	89.0	21.3	110.3	66.9
Piedmont	2015	307	3	UAN	45	5296	2618	89.8	19.8	109.6	65.4
Piedmont	2015	308	3	UAN	180	6813	3561	148.0	35.4	183.4	57.6
Piedmont	2015	309	3	Instinct	135	6269	1951	132.2	30.8	163.0	61.5
Piedmont	2015	310	3	NZone	180	6064	2765	135.7	38.4	174.1	52.3
Piedmont	2015	313	3	UAN	135	6443	3383	115.5	36.0	151.4	52.9
Piedmont	2015	314	3	Instinct	45	5627	3057	102.6	33.2	135.8	124.0
Piedmont	2015	316	3	Instinct	0	4983	2309	74.6	14.6	89.2	.
Piedmont	2015	317	3	Instinct	180	7449	4066	149.0	30.5	179.5	55.4
Piedmont	2015	318	3	NZone	90	6367	3220	109.8	28.6	138.4	64.8
Piedmont	2015	319	3	UAN	0	4834	2309	58.4	14.9	73.2	.
Piedmont	2015	320	3	NZone	135	6385	3122	123.4	19.8	143.3	46.8
Piedmont	2015	402	4	Instinct	90	5046	2407	122.0	18.3	140.3	66.9
Piedmont	2015	403	4	UAN	45	4897	2342	101.2	32.9	134.1	120.1
Piedmont	2015	404	4	UAN	180	6638	3285	137.0	40.7	177.8	54.4
Piedmont	2015	405	4	NZone	135	6344	2813	122.2	31.7	153.9	54.7
Piedmont	2015	407	4	Instinct	135	6839	3773	130.4	32.4	162.8	61.4
Piedmont	2015	408	4	UAN	135	6603	3968	129.7	33.7	163.3	61.8
Piedmont	2015	411	4	Instinct	0	3596	1594	63.5	30.4	93.9	.

Table B2 - Continued.

Site	Year	Plot	Rep	Treatment	N Rate (kg ha^{-1})	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})	NUE %
Piedmont	2015	412	4	Instinct	180	5729	2367	127.3	53.6	180.9	56.2
Piedmont	2015	413	4	UAN	0	4318	1830	72.1	14.7	86.9	.
Piedmont	2015	414	4	UAN	90	5800	2817	111.8	31.8	143.6	70.6
Piedmont	2015	415	4	NZone	90	6138	2730	102.3	29.1	131.3	57.0
Piedmont	2015	416	4	NZone	0	4589	1931	63.7	11.4	75.2	.
Piedmont	2015	417	4	NZone	180	7037	3252	141.4	28.5	170.0	50.0
Piedmont	2015	418	4	NZone	45	4761	2802	93.4	19.4	112.8	72.6
Piedmont	2015	419	4	Instinct	45	5735	2585	91.1	19.9	111.0	68.5
Coastal_Plain	2015	104	1	AgrotainPlus	90	6194	3740	101.2	19.4	120.7	30.57
Coastal_Plain	2015	105	1	AgrotainPlus	0	3833	1667	68.0	8.3	76.3	.
Coastal_Plain	2015	115	1	AgrotainPlus	45	6035	4005	99.2	19.2	118.4	56.17
Coastal_Plain	2015	116	1	AgrotainPlus	135	7372	4635	130.7	25.0	155.8	46.51
Coastal_Plain	2015	120	1	AgrotainPlus	180	7484	4391	142.4	25.5	167.9	41.64
Coastal_Plain	2015	203	2	AgrotainPlus	135	7660	5489	143.5	36.8	180.2	64.72
Coastal_Plain	2015	207	2	AgrotainPlus	180	8023	5468	150.3	33.9	184.2	50.74
Coastal_Plain	2015	213	2	AgrotainPlus	90	7074	4635	120.5	24.6	145.1	57.83
Coastal_Plain	2015	215	2	AgrotainPlus	0	5362	3395	86.5	16.3	102.8	.
Coastal_Plain	2015	216	2	AgrotainPlus	45	6108	4492	103.5	19.3	122.8	65.87
Coastal_Plain	2015	305	3	AgrotainPlus	90	6703	5021	113.5	28.1	141.6	53.99
Coastal_Plain	2015	307	3	AgrotainPlus	180	8401	5570	158.2	39.5	197.7	58.30
Coastal_Plain	2015	309	3	AgrotainPlus	135	8094	6180	159.7	41.4	201.1	80.21
Coastal_Plain	2015	310	3	AgrotainPlus	45	6867	4269	119.0	22.6	141.7	108.06
Coastal_Plain	2015	316	3	AgrotainPlus	0	5349	3618	89.0	17.7	106.7	.
Coastal_Plain	2015	402	4	AgrotainPlus	135	8131	5936	142.6	36.8	179.4	64.07
Coastal_Plain	2015	405	4	AgrotainPlus	0	4651	3009	75.5	16.2	91.8	.
Coastal_Plain	2015	410	4	AgrotainPlus	90	7898	6566	140.1	33.5	173.6	89.61
Coastal_Plain	2015	415	4	AgrotainPlus	180	8636	6017	168.6	40.3	209.0	64.56
Coastal_Plain	2015	416	4	AgrotainPlus	45	6137	4330	106.4	29.4	135.8	95.03
Piedmont	2015	102	1	AgrotainPlus	0	5296	2846	58.4	8.3	66.8	.
Piedmont	2015	103	1	AgrotainPlus	135	7205	3952	130.7	25.0	155.8	56.15
Piedmont	2015	104	1	AgrotainPlus	180	7974	4261	138.7	25.5	164.2	46.79
Piedmont	2015	113	1	AgrotainPlus	90	6494	3383	98.1	19.4	117.6	41.59
Piedmont	2015	120	1	AgrotainPlus	45	4891	1756	84.2	19.2	103.4	51.55
Piedmont	2015	202	2	AgrotainPlus	180	6785	3431	151.1	33.9	185.0	58.41
Piedmont	2015	204	2	AgrotainPlus	90	6418	3318	114.9	24.6	139.4	66.00
Piedmont	2015	207	2	AgrotainPlus	135	6494	3578	123.6	36.8	160.4	59.60
Piedmont	2015	214	2	AgrotainPlus	45	5818	3155	92.5	19.3	111.8	70.35
Piedmont	2015	215	2	AgrotainPlus	0	5079	2391	79.1	16.3	95.4	.
Piedmont	2015	302	3	AgrotainPlus	180	6089	3139	143.1	39.5	182.7	57.13
Piedmont	2015	304	3	AgrotainPlus	90	6042	3041	106.2	28.1	134.3	60.26
Piedmont	2015	311	3	AgrotainPlus	0	4318	2228	81.0	17.7	98.7	.
Piedmont	2015	312	3	AgrotainPlus	45	4918	2374	104.7	22.6	127.3	104.92
Piedmont	2015	315	3	AgrotainPlus	135	7043	3838	137.9	41.4	179.3	73.66
Piedmont	2015	401	4	AgrotainPlus	45	.	1138	88.0	20.4	108.4	62.71
Piedmont	2015	406	4	AgrotainPlus	90	6223	3122	123.5	33.5	157.0	85.63
Piedmont	2015	409	4	AgrotainPlus	180	7161	4066	146.3	40.3	186.6	59.31
Piedmont	2015	410	4	AgrotainPlus	135	6675	3220	133.7	36.8	170.5	67.08
Piedmont	2015	420	4	AgrotainPlus	0	4488	1854	63.0	16.2	79.3	.

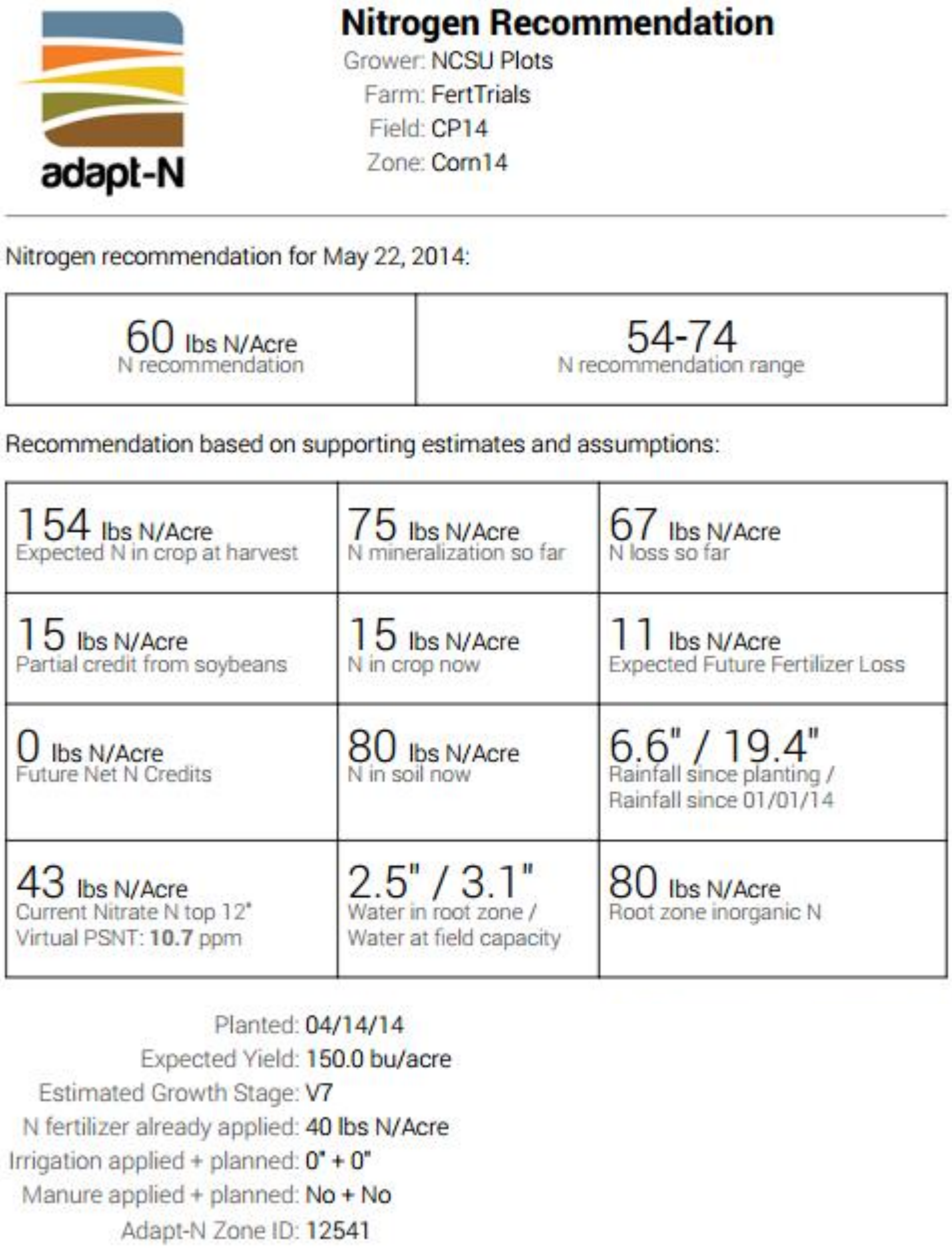
Table B3 – Wheat ESN field trials raw data by site year.

Site	Year	Plot	Rep	Treatment	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})
Coastal_Plain	2014	103	1	J100E	4417	2399	74.7	14.2	88.8
Coastal_Plain	2014	203	2	J100E	4038	2114	69.0	11.4	80.5
Coastal_Plain	2014	304	3	J100E	3624	2358	59.8	12.5	72.3
Coastal_Plain	2014	404	4	J100E	3513	2033	55.9	11.0	66.8
Coastal_Plain	2014	102	1	J50A/M50U	5174	3252	84.9	18.5	103.4
Coastal_Plain	2014	205	2	J50A/M50U	4905	2358	79.9	11.1	91.0
Coastal_Plain	2014	302	3	J50A/M50U	5195	3537	79.0	15.9	94.9
Coastal_Plain	2014	406	4	J50A/M50U	4684	2846	77.3	13.7	90.9
Coastal_Plain	2014	105	1	J50E/50A	4843	3131	80.4	13.1	93.5
Coastal_Plain	2014	206	2	J50E/50A	4296	2480	67.9	13.6	81.5
Coastal_Plain	2014	303	3	J50E/50A	4416	2968	71.1	15.7	86.8
Coastal_Plain	2014	403	4	J50E/50A	4115	2521	61.7	10.3	72.1
Coastal_Plain	2014	106	1	J75E/25A	4357	2805	72.3	13.2	85.5
Coastal_Plain	2014	202	2	J75E/25A	4560	2602	73.9	11.7	85.6
Coastal_Plain	2014	301	3	J75E/25A	4023	2480	64.0	9.9	73.9
Coastal_Plain	2014	402	4	J75E/25A	4071	2358	62.3	10.4	72.7
Coastal_Plain	2014	104	1	M50E/50A	5115	2643	87.0	11.9	98.8
Coastal_Plain	2014	204	2	M50E/50A	4950	2561	81.7	15.4	97.0
Coastal_Plain	2014	306	3	M50E/50A	4473	2683	76.0	13.1	89.2
Coastal_Plain	2014	405	4	M50E/50A	4645	2480	77.1	13.4	90.5
Coastal_Plain	2014	101	1	M50U/50A	5625	3578	96.2	19.7	115.9
Coastal_Plain	2014	201	2	M50U/50A	5626	3252	88.9	14.3	103.2
Coastal_Plain	2014	305	3	M50U/50A	5052	3537	87.4	14.1	101.5
Coastal_Plain	2014	401	4	M50U/50A	4955	2927	76.8	12.9	89.7
Coastal_Plain	2015	508	1	J100E	7646	5570	137.6	30.6	168.3
Coastal_Plain	2015	603	2	J100E	7278	6322	131.0	27.8	158.8
Coastal_Plain	2015	703	3	J100E	7951	4797	147.9	30.7	178.6
Coastal_Plain	2015	801	4	J100E	7607	5082	136.9	36.1	173.0
Coastal_Plain	2015	506	1	J50A/M50U	7989	5590	143.8	27.4	171.2
Coastal_Plain	2015	608	2	J50A/M50U	8136	3070	149.7	16.0	165.7
Coastal_Plain	2015	702	3	J50A/M50U	7838	6830	144.2	34.2	178.4
Coastal_Plain	2015	803	4	J50A/M50U	6940	4797	120.8	24.9	145.7
Coastal_Plain	2015	505	1	J50E/50A	7775	5976	137.6	33.5	171.1
Coastal_Plain	2015	607	2	J50E/50A	7307	4960	134.5	22.8	157.3
Coastal_Plain	2015	704	3	J50E/50A	7755	4960	145.0	39.2	184.2
Coastal_Plain	2015	807	4	J50E/50A	6714	4350	120.2	25.7	145.8
Coastal_Plain	2015	501	1	J75E/25A	7715	5306	140.4	41.4	181.8
Coastal_Plain	2015	601	2	J75E/25A	6934	5732	131.7	32.1	163.8
Coastal_Plain	2015	706	3	J75E/25A	7881	4513	139.5	27.5	167.0
Coastal_Plain	2015	804	4	J75E/25A	6964	4858	115.6	32.1	147.7
Coastal_Plain	2015	507	1	M50E/50A	7928	5326	145.1	31.4	176.5
Coastal_Plain	2015	602	2	M50E/50A	7752	5001	142.6	31.7	174.3
Coastal_Plain	2015	705	3	M50E/50A	7455	5082	143.1	34.0	177.2
Coastal_Plain	2015	802	4	M50E/50A	7006	3191	138.7	24.6	163.3
Coastal_Plain	2015	502	1	M50U/50A	7822	5631	145.5	33.2	178.7
Coastal_Plain	2015	604	2	M50U/50A	6577	3822	113.1	16.4	129.6
Coastal_Plain	2015	701	3	M50U/50A	7987	5854	143.0	34.5	177.5
Coastal_Plain	2015	808	4	M50U/50A	6592	3862	118.7	25.1	143.8
Piedmont	2014	105	1	J100E	6867	5074	119.5	16.7	136.2
Piedmont	2014	201	2	J100E	5438	2830	90.3	10.5	100.7
Piedmont	2014	303	3	J100E	6068	3935	98.9	14.2	113.1
Piedmont	2014	403	4	J100E	5386	3350	87.8	11.7	99.5
Piedmont	2014	104	1	J50A/M50U	5985	4944	102.9	20.8	123.7
Piedmont	2014	203	2	J50A/M50U	5115	3643	79.8	10.9	90.7
Piedmont	2014	304	3	J50A/M50U	5407	4423	90.8	14.2	105.0
Piedmont	2014	401	4	J50A/M50U	5216	3935	84.5	11.8	96.3
Piedmont	2014	103	1	J50E/50A	5985	4521	98.8	16.3	115.0

Table B3 - Continued.

Site	Year	Plot	Rep	Treatment	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain N (kg ha^{-1})	Straw N (kg ha^{-1})	Total N (kg ha^{-1})
Piedmont	2014	206	2	J50E/50A	5251	3675	80.9	10.7	91.5
Piedmont	2014	302	3	J50E/50A	4472	3838	71.1	12.3	83.4
Piedmont	2014	402	4	J50E/50A	4665	3090	76.0	9.9	85.9
Piedmont	2014	106	1	J75E/25A	6181	7351	111.9	20.6	132.5
Piedmont	2014	205	2	J75E/25A	5323	3513	85.2	10.2	95.3
Piedmont	2014	301	3	J75E/25A	5228	3708	82.1	11.5	93.6
Piedmont	2014	406	4	J75E/25A	5394	3187	94.4	9.6	104.0
Piedmont	2014	101	1	M50E/50A	5552	3870	85.5	11.6	97.1
Piedmont	2014	204	2	M50E/50A	5804	4391	95.8	14.9	110.7
Piedmont	2014	305	3	M50E/50A	6291	4131	114.5	14.9	129.4
Piedmont	2014	404	4	M50E/50A	5574	3578	97.6	14.0	111.5
Piedmont	2014	102	1	M50U/50A	4512	3155	70.8	8.5	79.4
Piedmont	2014	202	2	M50U/50A	4432	2797	68.2	8.1	76.4
Piedmont	2014	306	3	M50U/50A	5649	4293	100.0	13.7	113.7
Piedmont	2015	506	1	J100E	5996	3074	104.3	17.2	121.5
Piedmont	2015	605	2	J100E	6636	3903	111.5	17.2	128.7
Piedmont	2015	705	3	J100E	5286	1268	89.3	7.9	97.2
Piedmont	2015	802	4	J100E	6282	3480	108.1	23.3	131.4
Piedmont	2015	507	1	J50A/M50U	6361	3399	104.3	21.5	125.8
Piedmont	2015	604	2	J50A/M50U	6443	3480	106.3	21.6	127.9
Piedmont	2015	701	3	J50A/M50U	5509	2212	91.4	11.1	102.5
Piedmont	2015	805	4	J50A/M50U	6280	3675	101.7	19.1	120.8
Piedmont	2015	505	1	J50E/50A	6241	2423	107.3	10.4	117.8
Piedmont	2015	602	2	J50E/50A	6812	3789	117.2	20.8	138.0
Piedmont	2015	707	3	J50E/50A	6157	2895	108.4	19.1	127.5
Piedmont	2015	808	4	J50E/50A	6890	4179	125.4	24.7	150.1
Piedmont	2015	503	1	J75E/25A	6424	3041	109.8	23.7	133.6
Piedmont	2015	606	2	J75E/25A	6517	3870	116.0	21.7	137.7
Piedmont	2015	703	3	J75E/25A	5739	2830	98.1	17.3	115.4
Piedmont	2015	803	4	J75E/25A	6075	3285	97.8	26.0	123.8
Piedmont	2015	501	1	M50E/50A	6067	2830	106.2	16.7	122.9
Piedmont	2015	603	2	M50E/50A	6602	3480	110.9	18.1	129.0
Piedmont	2015	706	3	M50E/50A	5811	1854	105.2	11.9	117.0
Piedmont	2015	807	4	M50E/50A	6872	3383	121.6	26.0	147.7
Piedmont	2015	504	1	M50U/50A	6583	3659	108.6	21.6	130.2
Piedmont	2015	601	2	M50U/50A	6433	3627	104.2	16.7	120.9
Piedmont	2015	702	3	M50U/50A	5460	2504	87.9	14.8	102.7
Piedmont	2015	806	4	M50U/50A	6469	3496	106.7	22.7	129.5

APPENDIX C – Adapt-N Output



adapt-N

Nitrogen Recommendation

Grower: NCSU Plots
Farm: FertTrials
Field: CP14
Zone: Corn14

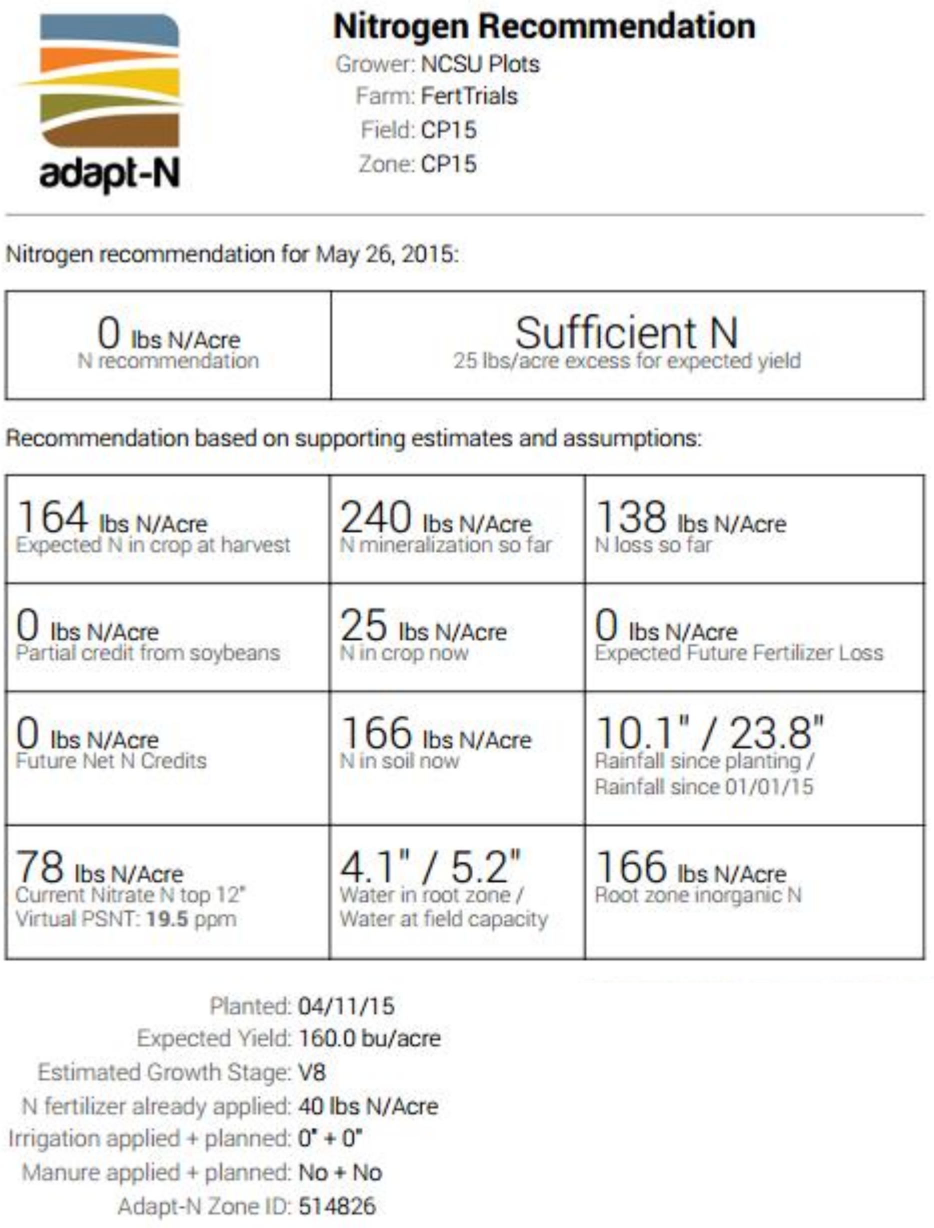
Nitrogen recommendation for May 22, 2014:

60 lbs N/Acre N recommendation	54-74 N recommendation range

Recommendation based on supporting estimates and assumptions:

154 lbs N/Acre Expected N in crop at harvest	75 lbs N/Acre N mineralization so far	67 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	15 lbs N/Acre N in crop now	11 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	80 lbs N/Acre N in soil now	6.6" / 19.4" Rainfall since planting / Rainfall since 01/01/14
43 lbs N/Acre Current Nitrate N top 12" Virtual PSNT: **10.7** ppm	2.5" / 3.1" Water in root zone / Water at field capacity	80 lbs N/Acre Root zone inorganic N

Planted: 04/14/14
Expected Yield: 150.0 bu/acre
Estimated Growth Stage: V7
N fertilizer already applied: 40 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No
Adapt-N Zone ID: 12541



adapt-N

Nitrogen Recommendation

Grower: NCSU Plots
Farm: FertTrials
Field: CP15
Zone: CP15

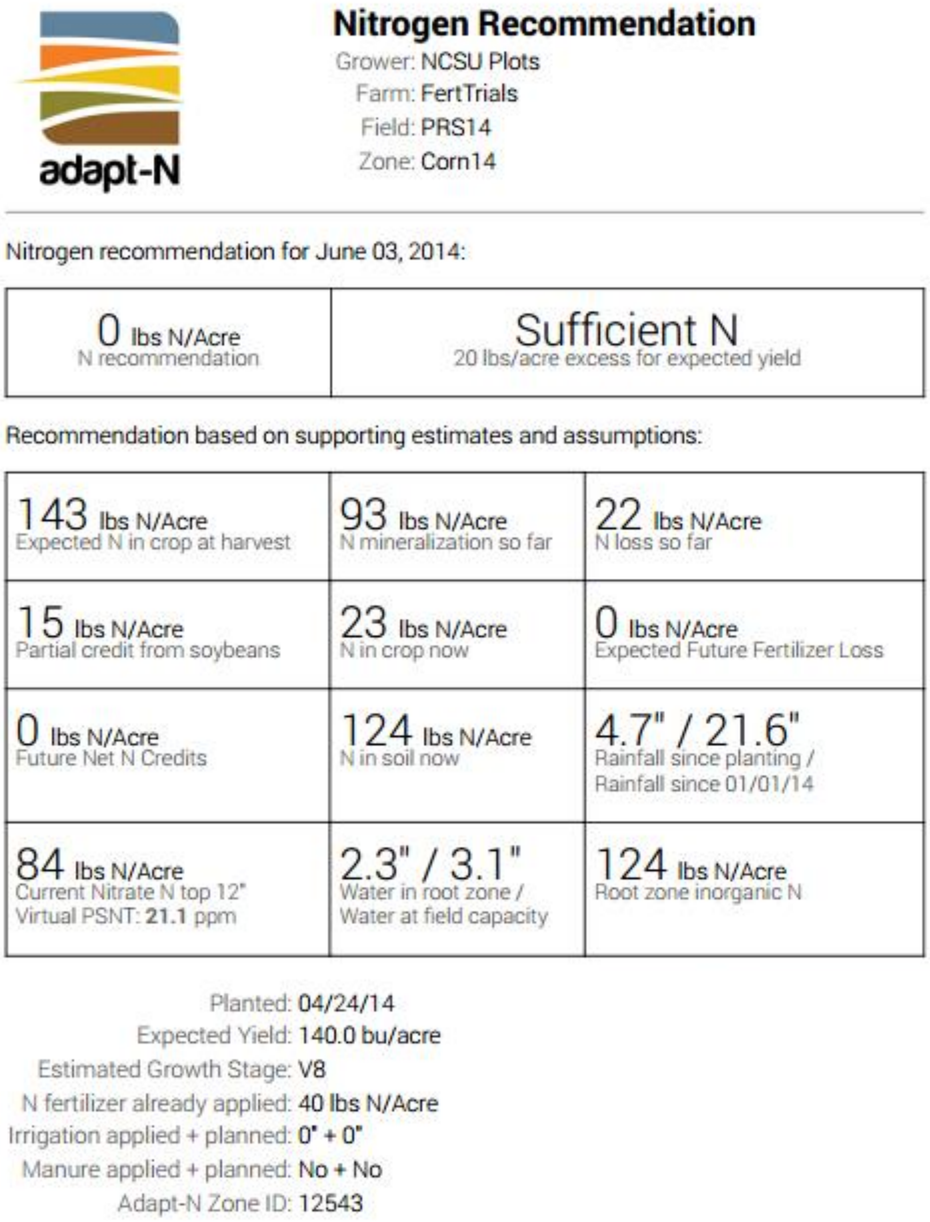
Nitrogen recommendation for May 26, 2015:

0 lbs N/Acre N recommendation	Sufficient N 25 lbs/acre excess for expected yield

Recommendation based on supporting estimates and assumptions:

164 lbs N/Acre Expected N in crop at harvest	240 lbs N/Acre N mineralization so far	138 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	25 lbs N/Acre N in crop now	0 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	166 lbs N/Acre N in soil now	10.1" / 23.8" Rainfall since planting / Rainfall since 01/01/15
78 lbs N/Acre Current Nitrate N top 12" Virtual PSNT: **19.5** ppm	4.1" / 5.2" Water in root zone / Water at field capacity	166 lbs N/Acre Root zone inorganic N

Planted: 04/11/15
Expected Yield: 160.0 bu/acre
Estimated Growth Stage: V8
N fertilizer already applied: 40 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No
Adapt-N Zone ID: 514826



adapt-N

Nitrogen Recommendation

Grower: **NCSU Plots**
Farm: **FertTrials**
Field: **PRS14**
Zone: **Corn14**

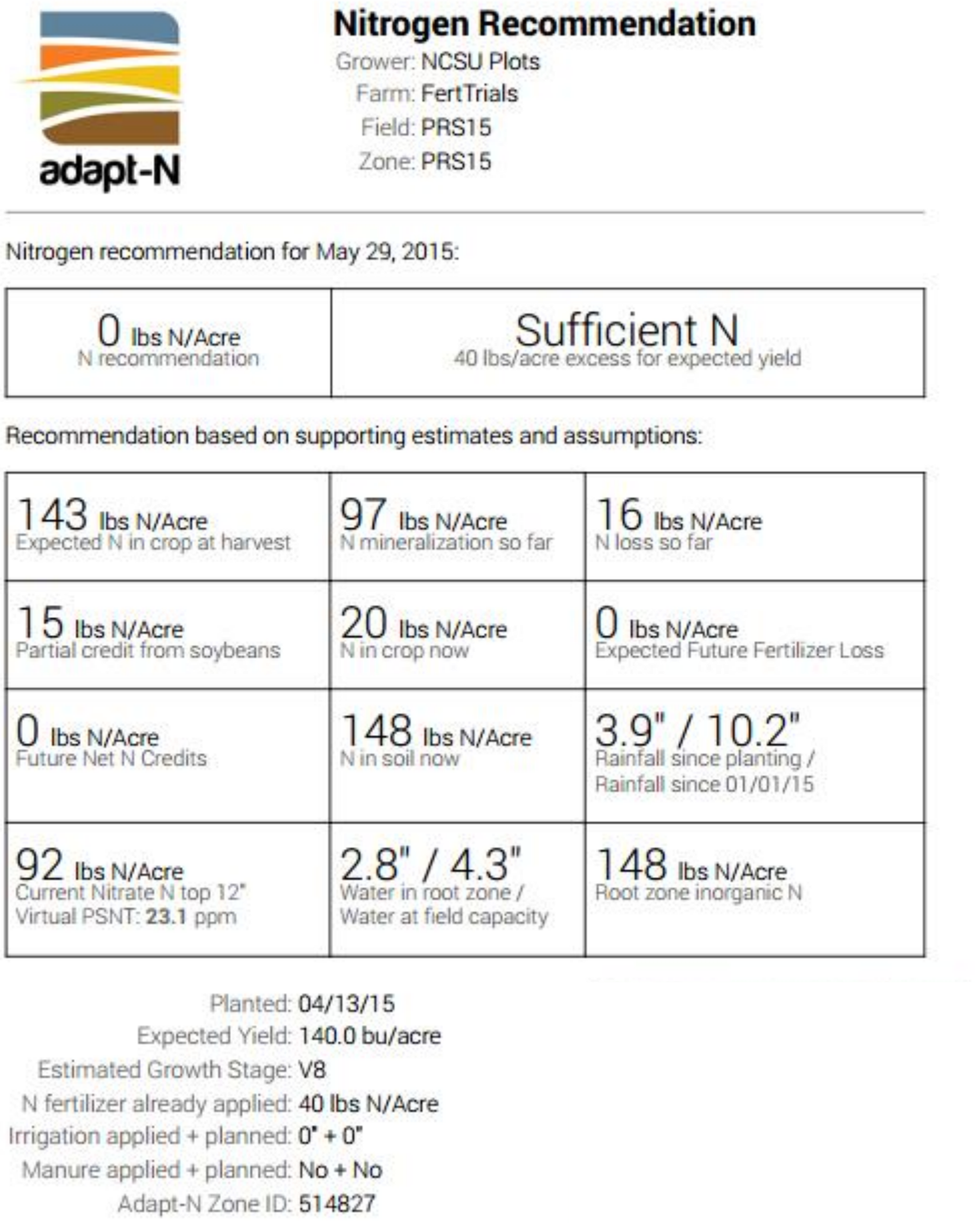
Nitrogen recommendation for June 03, 2014:

0 lbs N/Acre N recommendation	Sufficient N 20 lbs/acre excess for expected yield

Recommendation based on supporting estimates and assumptions:

143 lbs N/Acre Expected N in crop at harvest	93 lbs N/Acre N mineralization so far	22 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	23 lbs N/Acre N in crop now	0 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	124 lbs N/Acre N in soil now	4.7" / 21.6" Rainfall since planting / Rainfall since 01/01/14
84 lbs N/Acre Current Nitrate N top 12" Virtual PSNT: **21.1** ppm	2.3" / 3.1" Water in root zone / Water at field capacity	124 lbs N/Acre Root zone inorganic N

Planted: **04/24/14**
Expected Yield: **140.0 bu/acre**
Estimated Growth Stage: **V8**
N fertilizer already applied: **40 lbs N/Acre**
Irrigation applied + planned: **0" + 0"**
Manure applied + planned: **No + No**
Adapt-N Zone ID: **12543**



Nitrogen Recommendation

Grower: **NCSU Plots**
Farm: **FertTrials**
Field: **PRS15**
Zone: **PRS15**

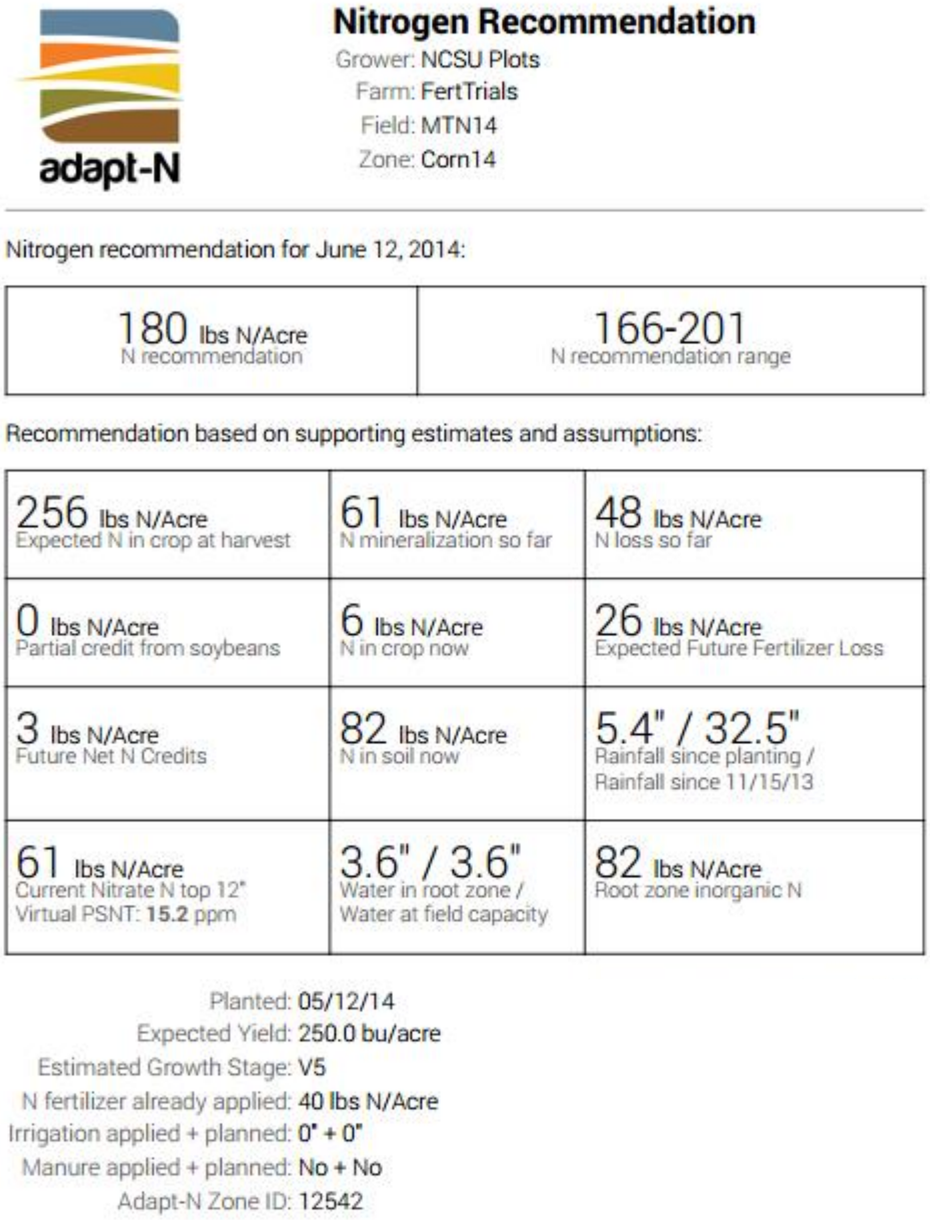
Nitrogen recommendation for May 29, 2015:

0 lbs N/Acre N recommendation	Sufficient N 40 lbs/acre excess for expected yield

Recommendation based on supporting estimates and assumptions:

143 lbs N/Acre Expected N in crop at harvest	97 lbs N/Acre N mineralization so far	16 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	20 lbs N/Acre N in crop now	0 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	148 lbs N/Acre N in soil now	3.9" / 10.2" Rainfall since planting / Rainfall since 01/01/15
92 lbs N/Acre Current Nitrate N top 12" Virtual PSNT: **23.1** ppm	2.8" / 4.3" Water in root zone / Water at field capacity	148 lbs N/Acre Root zone inorganic N

Planted: 04/13/15
Expected Yield: 140.0 bu/acre
Estimated Growth Stage: V8
N fertilizer already applied: 40 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No
Adapt-N Zone ID: 514827



adapt-N

Nitrogen Recommendation

Grower: **NCSU Plots**
Farm: **FertTrials**
Field: **MTN14**
Zone: **Corn14**

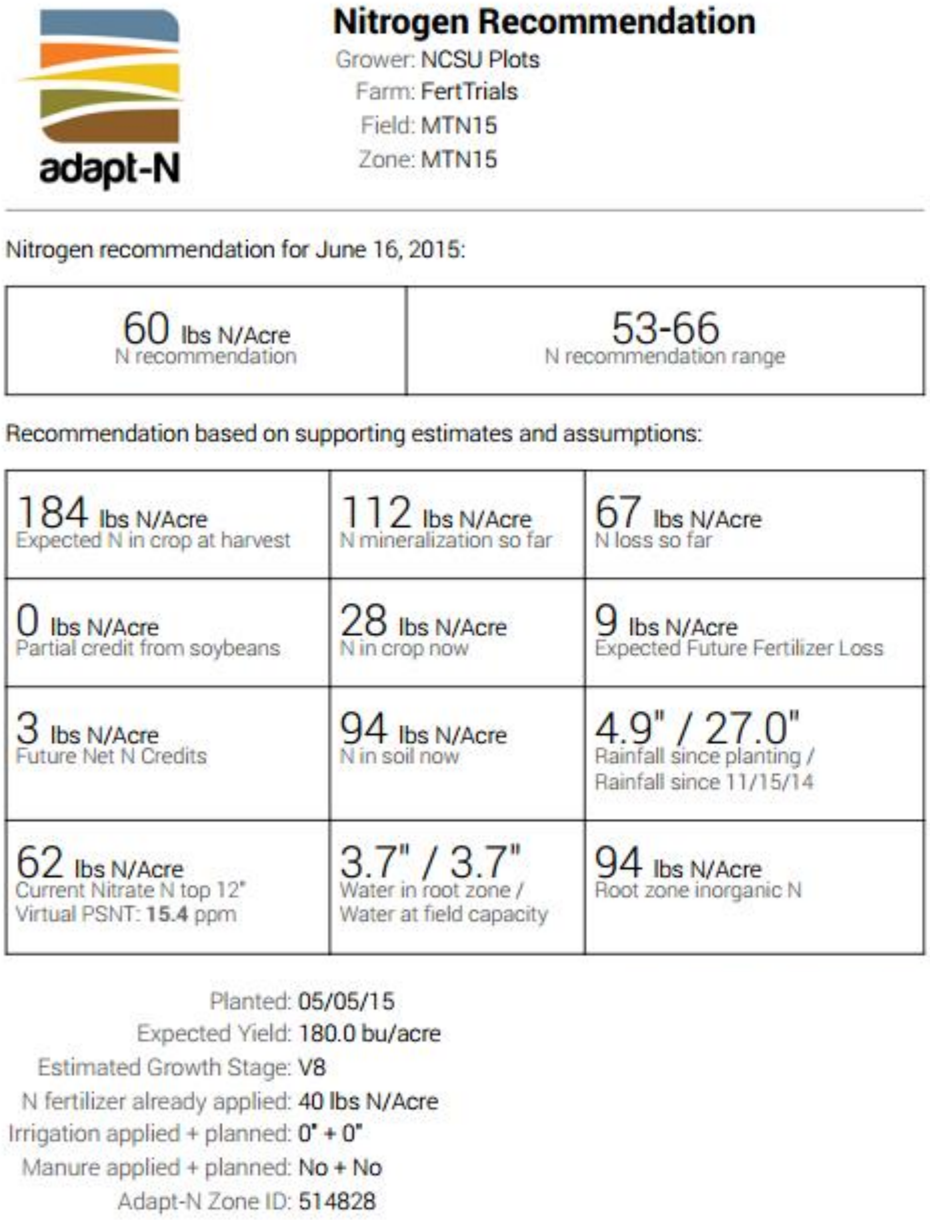
Nitrogen recommendation for June 12, 2014:

180 lbs N/Acre N recommendation	166-201 N recommendation range

Recommendation based on supporting estimates and assumptions:

256 lbs N/Acre Expected N in crop at harvest	61 lbs N/Acre N mineralization so far	48 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	6 lbs N/Acre N in crop now	26 lbs N/Acre Expected Future Fertilizer Loss
3 lbs N/Acre Future Net N Credits	82 lbs N/Acre N in soil now	5.4" / 32.5" Rainfall since planting / Rainfall since 11/15/13
61 lbs N/Acre Current Nitrate N top 12" Virtual PSNT: **15.2** ppm	3.6" / 3.6" Water in root zone / Water at field capacity	82 lbs N/Acre Root zone inorganic N

Planted: **05/12/14**
Expected Yield: **250.0 bu/acre**
Estimated Growth Stage: **V5**
N fertilizer already applied: **40 lbs N/Acre**
Irrigation applied + planned: **0" + 0"**
Manure applied + planned: **No + No**
Adapt-N Zone ID: **12542**



Nitrogen Recommendation

Grower: NCSU Plots
Farm: FertTrials
Field: MTN15
Zone: MTN15

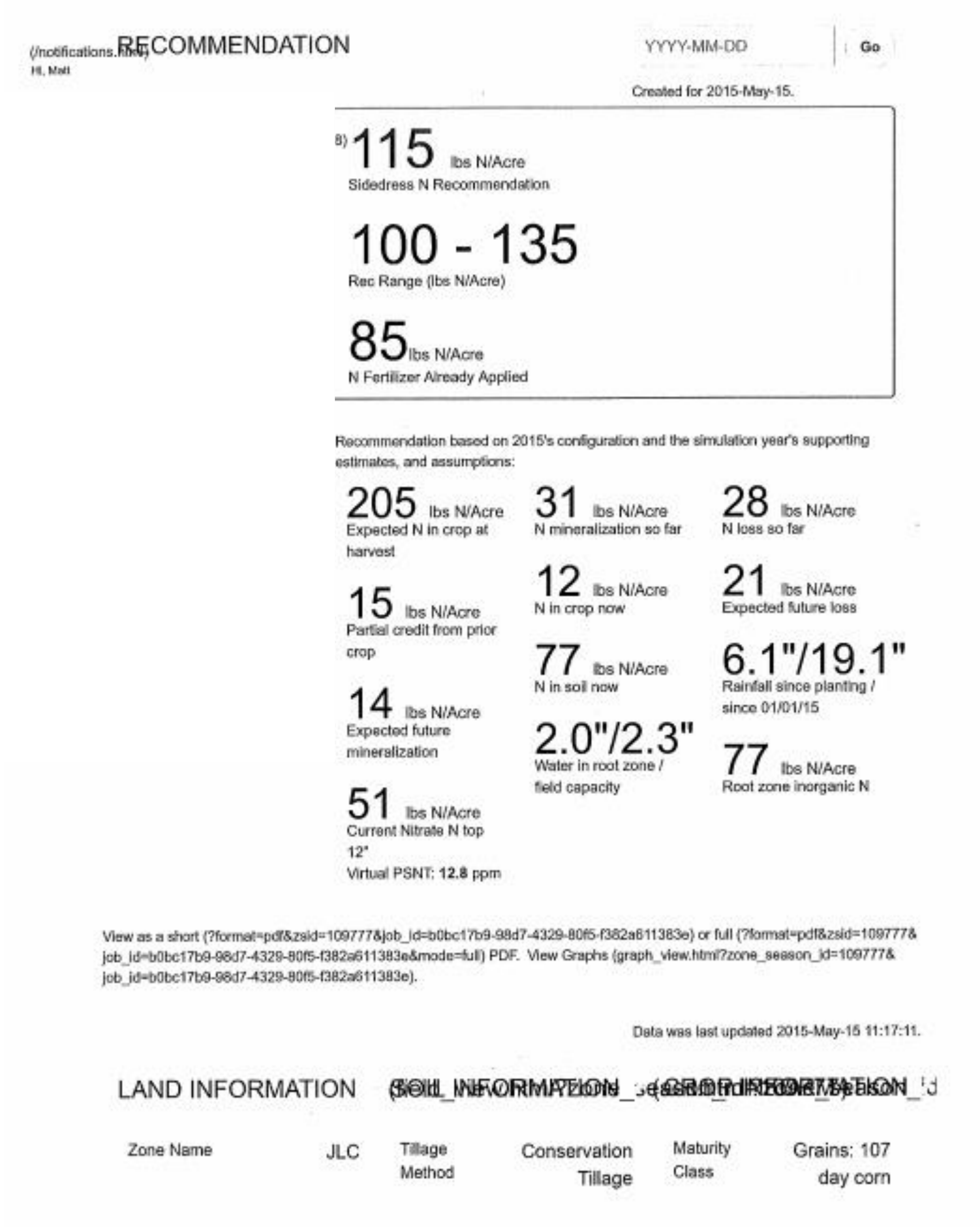
Nitrogen recommendation for June 16, 2015:

60 lbs N/Acre N recommendation	53-66 N recommendation range

Recommendation based on supporting estimates and assumptions:

184 lbs N/Acre Expected N in crop at harvest	112 lbs N/Acre N mineralization so far	67 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	28 lbs N/Acre N in crop now	9 lbs N/Acre Expected Future Fertilizer Loss
3 lbs N/Acre Future Net N Credits	94 lbs N/Acre N in soil now	4.9" / 27.0" Rainfall since planting / Rainfall since 11/15/14
62 lbs N/Acre Current Nitrate N top 12" Virtual PSNT: **15.4** ppm	3.7" / 3.7" Water in root zone / Water at field capacity	94 lbs N/Acre Root zone inorganic N

Planted: 05/05/15
Expected Yield: 180.0 bu/acre
Estimated Growth Stage: V8
N fertilizer already applied: 40 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No
Adapt-N Zone ID: 514828



(/notifications.html) RECOMMENDATION

Hi, Matt

YYYY-MM-DD Go

Created for 2015-May-15.

8) 115 lbs N/Acre
Sidedress N Recommendation

100 - 135
Rec Range (lbs N/Acre)

85 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

205 lbs N/Acre
Expected N in crop at harvest

15 lbs N/Acre
Partial credit from prior crop

14 lbs N/Acre
Expected future mineralization

51 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **12.8** ppm

31 lbs N/Acre
N mineralization so far

12 lbs N/Acre
N in crop now

77 lbs N/Acre
N in soil now

2.0"/2.3"
Water in root zone / field capacity

28 lbs N/Acre
N loss so far

21 lbs N/Acre
Expected future loss

6.1"/19.1"
Rainfall since planting / since 01/01/15

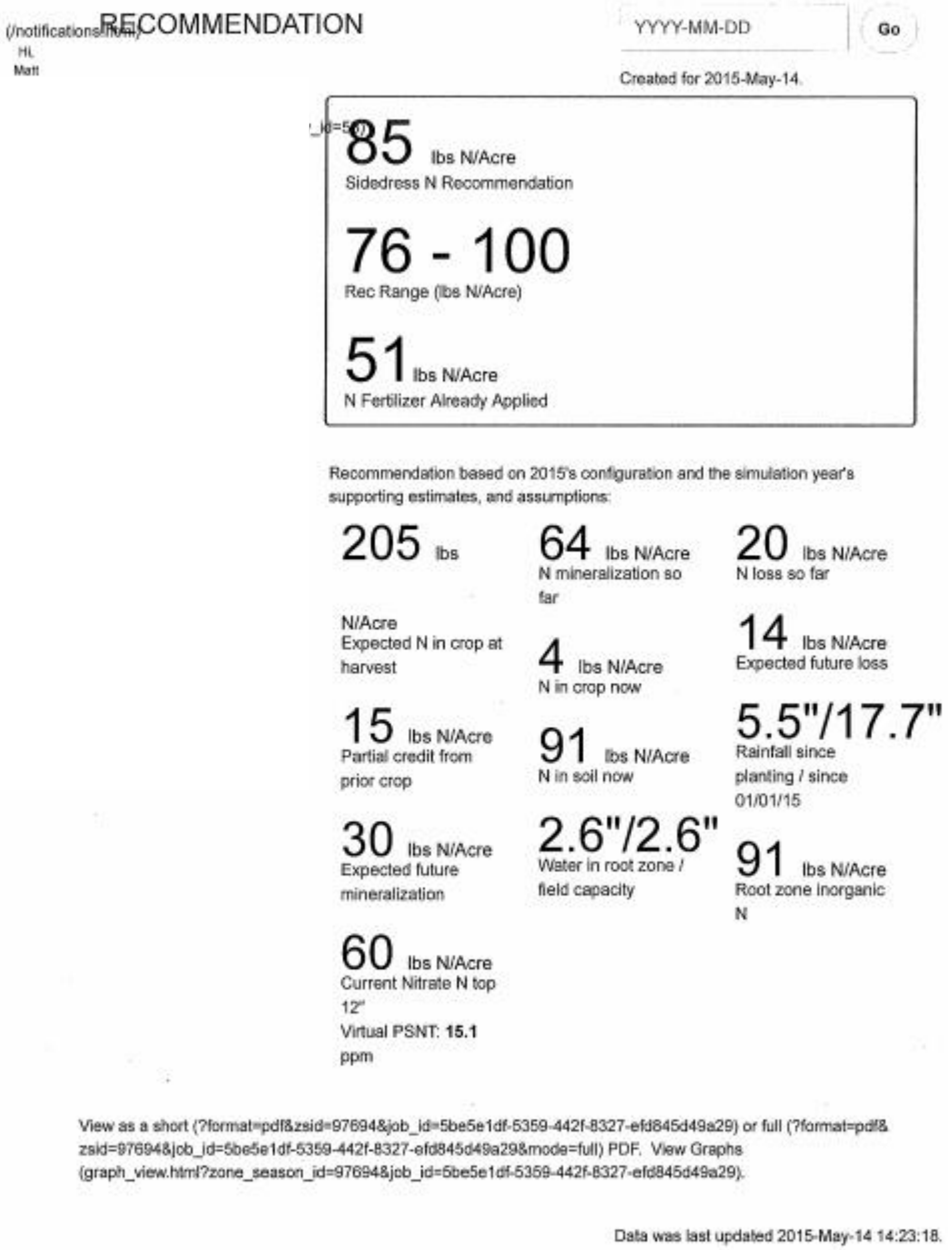
77 lbs N/Acre
Root zone inorganic N

View as a short (?format=pdf&zsid=109777&job_id=b0bc17b9-98d7-4329-80f5-f382a611383e) or full (?format=pdf&zsid=109777&job_id=b0bc17b9-98d7-4329-80f5-f382a611383e&mode=full) PDF. View Graphs (graph_view.html?zone_season_id=109777&job_id=b0bc17b9-98d7-4329-80f5-f382a611383e).

Data was last updated 2015-May-15 11:17:11.

LAND INFORMATION SOIL INFORMATION CROP INFORMATION

Zone Name	JLC	Tillage Method	Conservation Tillage	Maturity Class	Grains: 107 day corn



(/notifications.html) RECOMMENDATION

Hi, Matt

Created for 2015-May-14.

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85 lbs N/Acre
Sidedress N Recommendation

76 - 100
Rec Range (lbs N/Acre)

51 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

205 lbs N/Acre
Expected N in crop at harvest

15 lbs N/Acre
Partial credit from prior crop

30 lbs N/Acre
Expected future mineralization

60 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **15.1** ppm

64 lbs N/Acre
N mineralization so far

4 lbs N/Acre
N in crop now

91 lbs N/Acre
N in soil now

2.6"/2.6"
Water in root zone / field capacity

20 lbs N/Acre
N loss so far

14 lbs N/Acre
Expected future loss

5.5"/17.7"
Rainfall since planting / since 01/01/15

91 lbs N/Acre
Root zone inorganic N

View as a short (?format=pdf&zsid=97694&job_id=5be5e1df-5359-442f-8327-efd845d49a29) or full (?format=pdf&zsid=97694&job_id=5be5e1df-5359-442f-8327-efd845d49a29&mode=full) PDF. View Graphs (graph_view.html?zone_season_id=97694&job_id=5be5e1df-5359-442f-8327-efd845d49a29).

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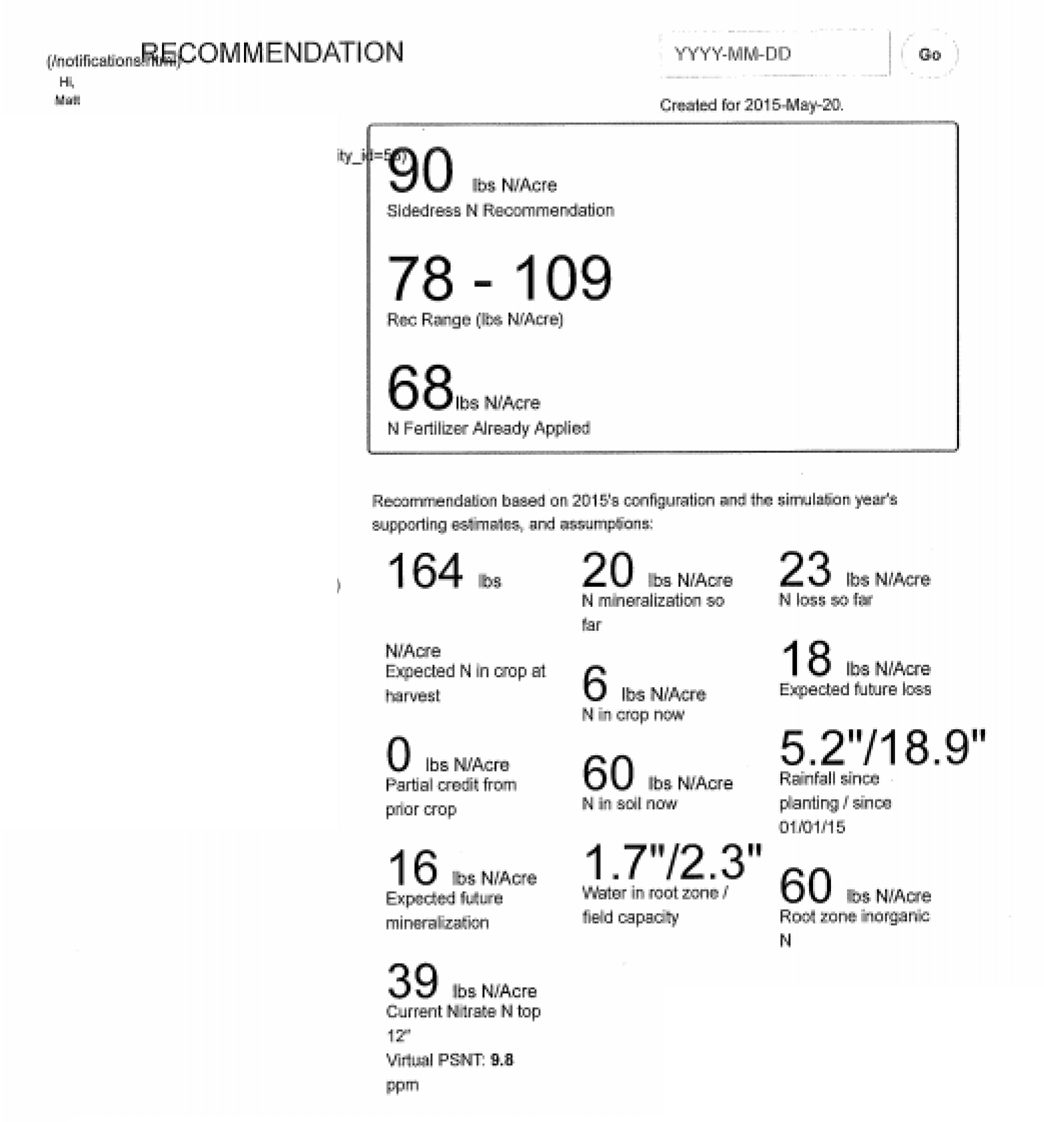

(/notifications.html) RECOMMENDATION

Hi,
Matt

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Created for 2015-May-20.

ity_id=56)

90 lbs N/Acre
Sidedress N Recommendation

78 - 109
Rec Range (lbs N/Acre)

68 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

164 lbs N/Acre
Expected N in crop at harvest

0 lbs N/Acre
Partial credit from prior crop

16 lbs N/Acre
Expected future mineralization

39 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **9.8** ppm

20 lbs N/Acre
N mineralization so far

6 lbs N/Acre
N in crop now

60 lbs N/Acre
N in soil now

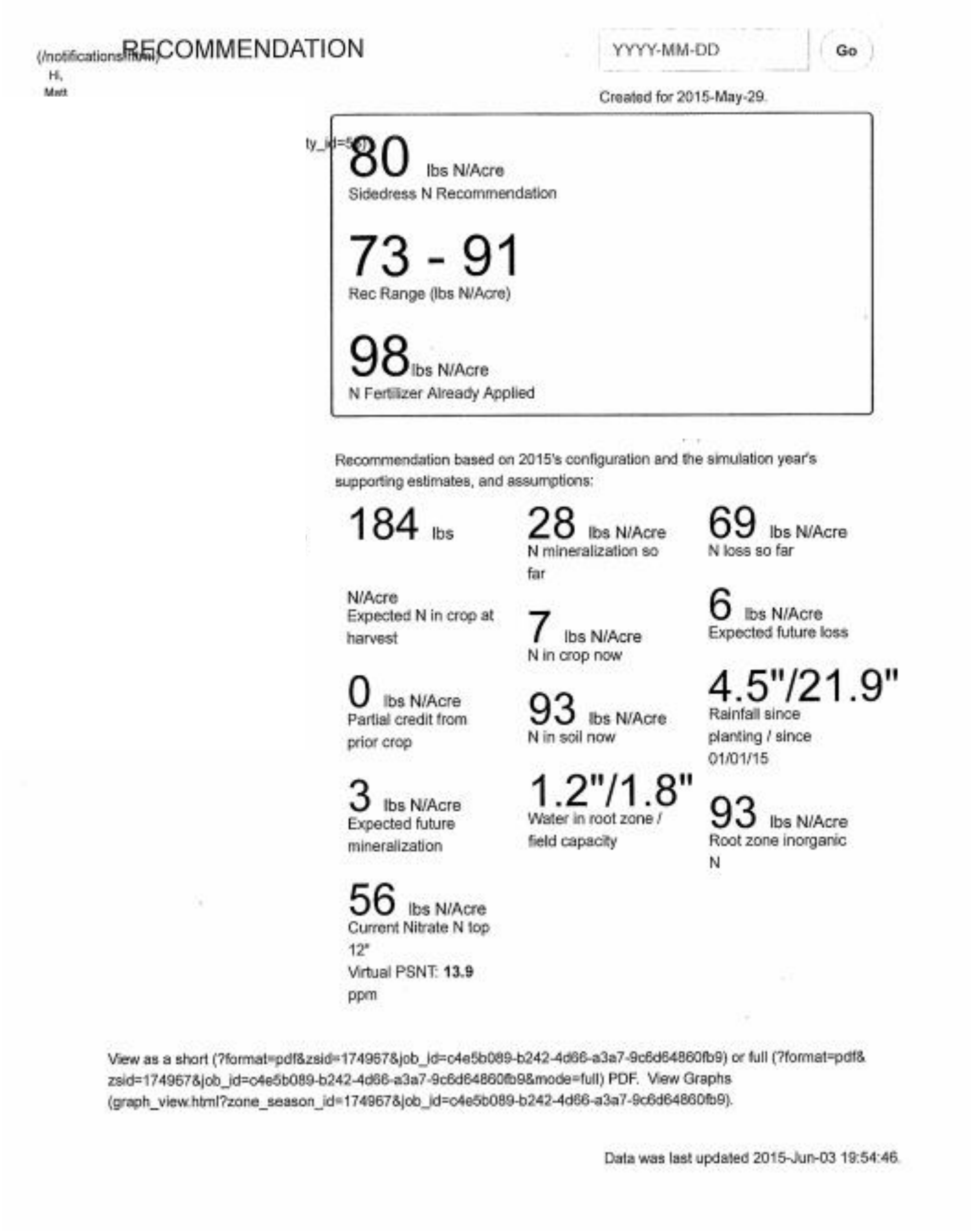
1.7"/2.3"
Water in root zone / field capacity

23 lbs N/Acre
N loss so far

18 lbs N/Acre
Expected future loss

5.2"/18.9"
Rainfall since planting / since 01/01/15

60 lbs N/Acre
Root zone inorganic N



(/notificationshtml)RECOMMENDATION

Hi,
Matt

Created for 2015-May-29.

ty_id=5

80 lbs N/Acre
Sidedress N Recommendation

73 - 91
Rec Range (lbs N/Acre)

98 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

184 lbs N/Acre
Expected N in crop at harvest

0 lbs N/Acre
Partial credit from prior crop

3 lbs N/Acre
Expected future mineralization

56 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **13.9** ppm

28 lbs N/Acre
N mineralization so far

7 lbs N/Acre
N in crop now

93 lbs N/Acre
N in soil now

1.2"/1.8"
Water in root zone / field capacity

69 lbs N/Acre
N loss so far

6 lbs N/Acre
Expected future loss

4.5"/21.9"
Rainfall since planting / since 01/01/15

93 lbs N/Acre
Root zone inorganic N

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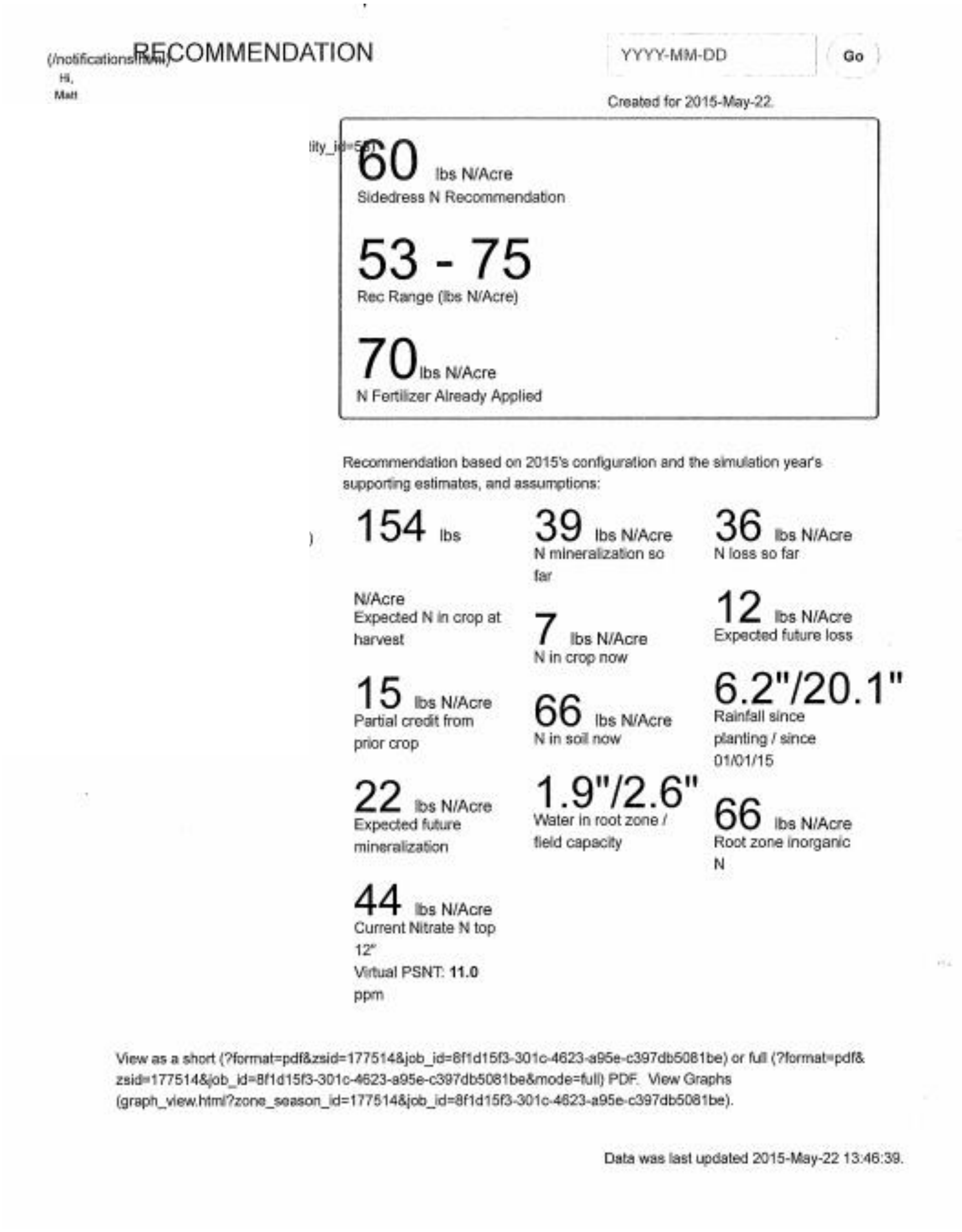

(/notifications[illegible]) RECOMMENDATION

Hi,
Matt

Created for 2015-May-22.

tity_id=5[illegible]

60 lbs N/Acre
Sidedress N Recommendation

53 - 75
Rec Range (lbs N/Acre)

70 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

)

154 lbs N/Acre
Expected N in crop at harvest

15 lbs N/Acre
Partial credit from prior crop

22 lbs N/Acre
Expected future mineralization

44 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **11.0** ppm

39 lbs N/Acre
N mineralization so far

7 lbs N/Acre
N in crop now

66 lbs N/Acre
N in soil now

1.9"/2.6"
Water in root zone / field capacity

36 lbs N/Acre
N loss so far

12 lbs N/Acre
Expected future loss

6.2"/20.1"
Rainfall since planting / since 01/01/15

66 lbs N/Acre
Root zone inorganic N

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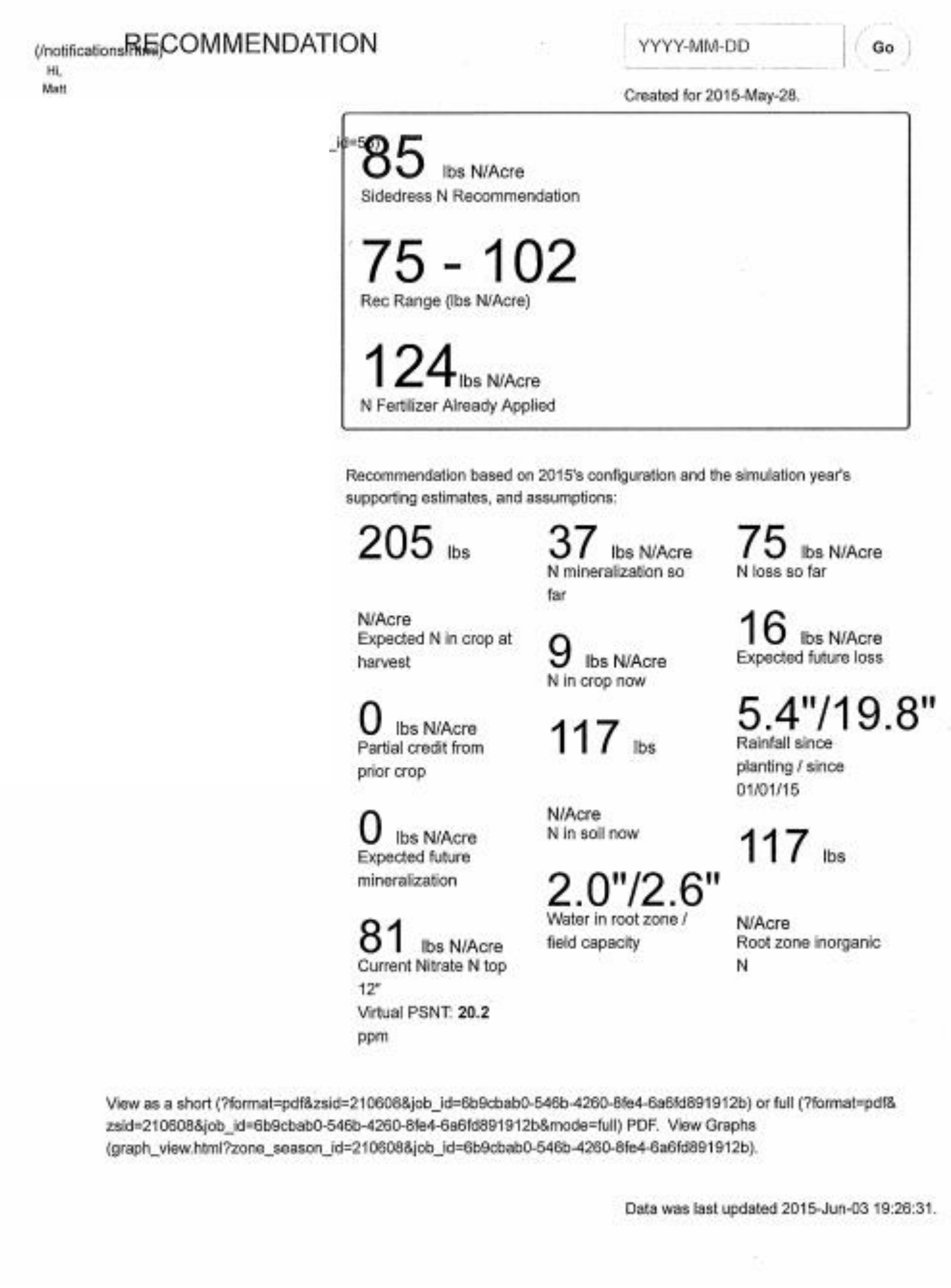
(/notifications[illegible]) RECOMMENDATION

Hi,
Matt

YYYY-MM-DD Go

Created for 2015-May-28.

_id=5[illegible])

85 lbs N/Acre
Sidedress N Recommendation

75 - 102
Rec Range (lbs N/Acre)

124 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

205 lbs N/Acre
Expected N in crop at harvest

0 lbs N/Acre
Partial credit from prior crop

0 lbs N/Acre
Expected future mineralization

81 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **20.2** ppm

37 lbs N/Acre
N mineralization so far

9 lbs N/Acre
N in crop now

117 lbs N/Acre
N in soil now

2.0"/2.6"
Water in root zone / field capacity

75 lbs N/Acre
N loss so far

16 lbs N/Acre
Expected future loss

5.4"/19.8"
Rainfall since planting / since 01/01/15

117 lbs N/Acre
Root zone inorganic N

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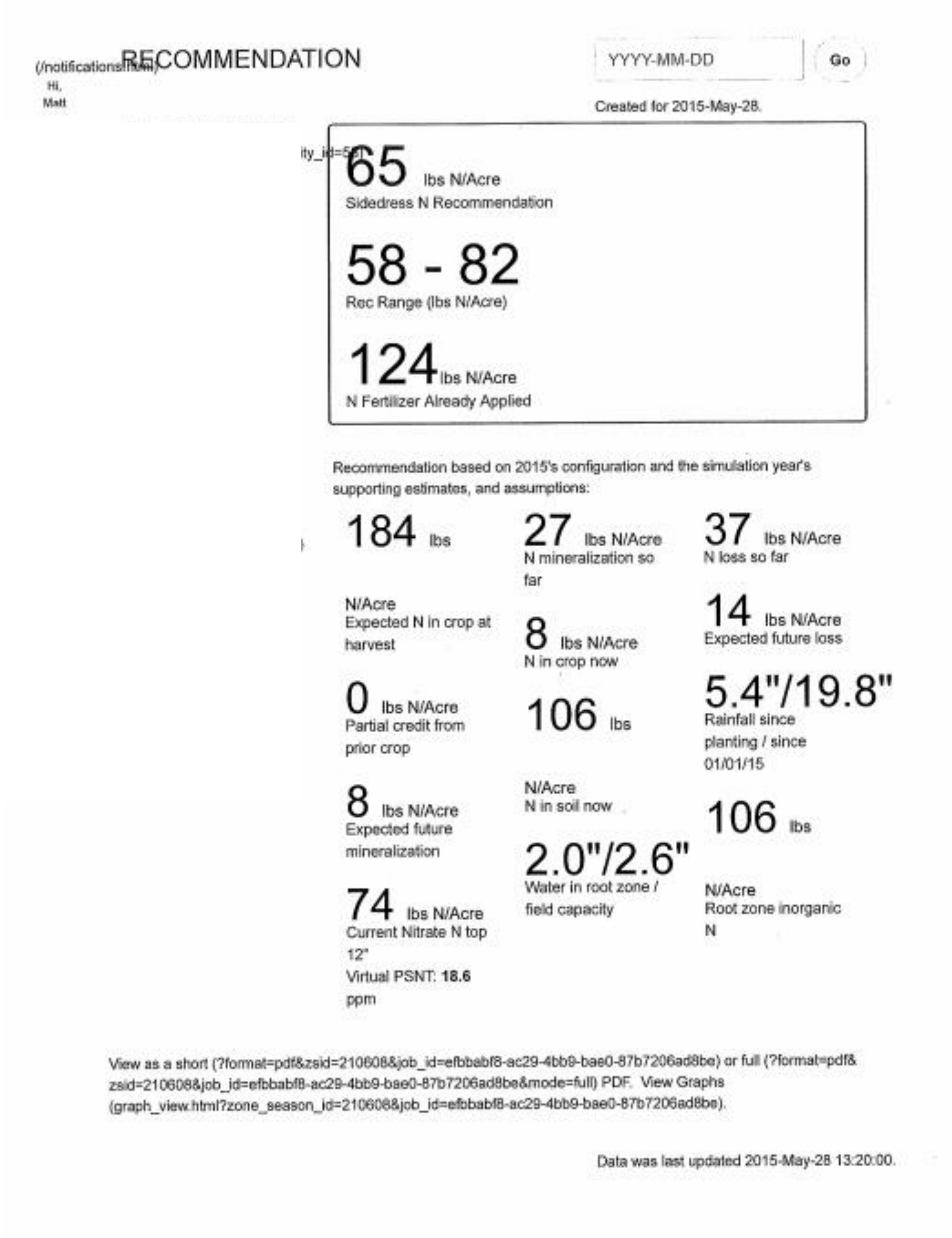

(/notifications.html) RECOMMENDATION

Hi,
Matt

YYYY-MM-DD

Created for 2015-May-28.

ity_id=58)

65 lbs N/Acre
Sidedress N Recommendation

58 - 82
Rec Range (lbs N/Acre)

124 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

184 lbs N/Acre
Expected N in crop at harvest

0 lbs N/Acre
Partial credit from prior crop

8 lbs N/Acre
Expected future mineralization

74 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **18.6** ppm

27 lbs N/Acre
N mineralization so far

8 lbs N/Acre
N in crop now

106 lbs N/Acre
N in soil now

2.0"/2.6"
Water in root zone / field capacity

37 lbs N/Acre
N loss so far

14 lbs N/Acre
Expected future loss

5.4"/19.8"
Rainfall since planting / since 01/01/15

106 lbs N/Acre
Root zone inorganic N

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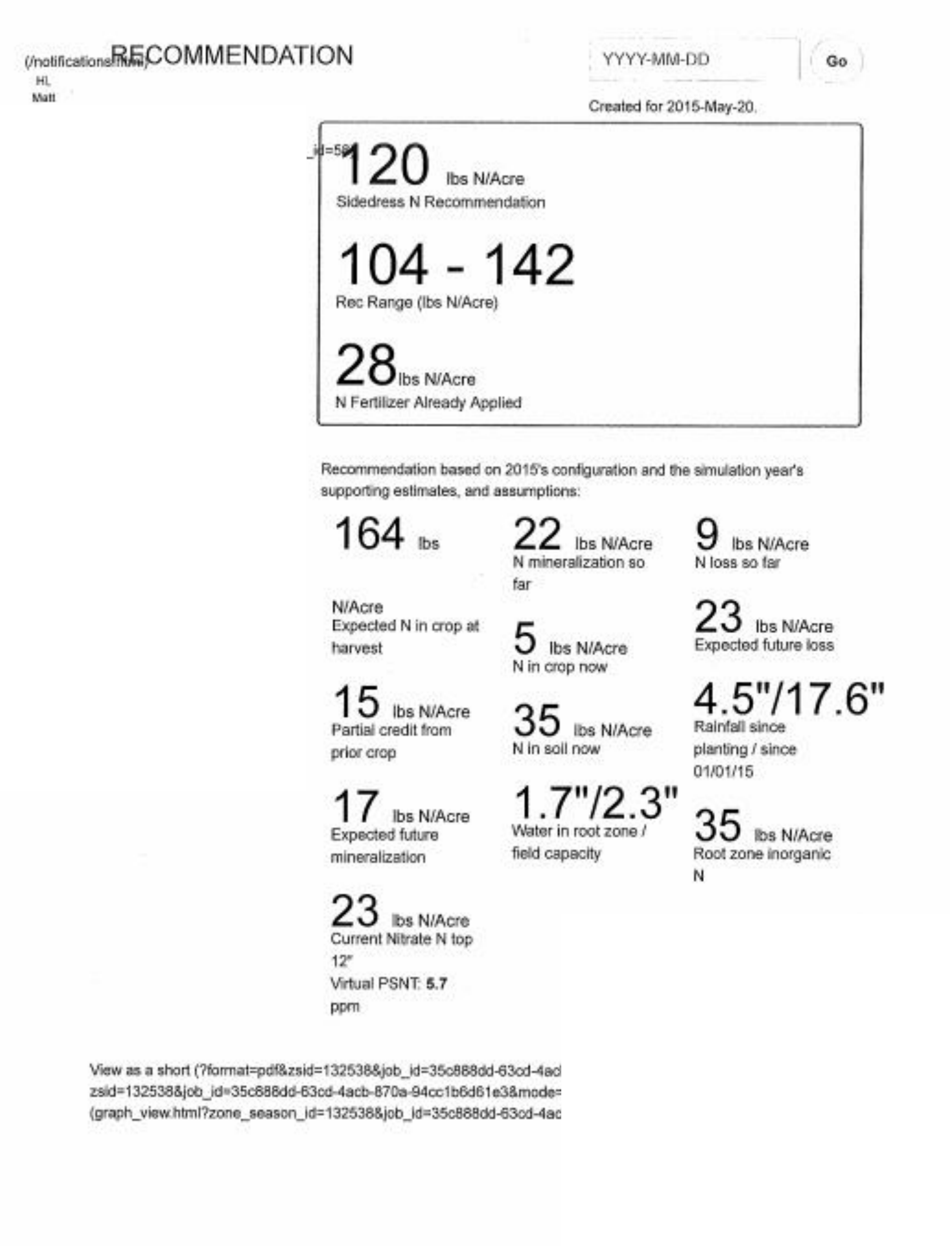

(/notifications.html) RECOMMENDATION

Hi,
Matt

Created for 2015-May-20.

_id=58

120 lbs N/Acre
Sidedress N Recommendation

104 - 142
Rec Range (lbs N/Acre)

28 lbs N/Acre
N Fertilizer Already Applied

Recommendation based on 2015's configuration and the simulation year's supporting estimates, and assumptions:

164 lbs N/Acre
Expected N in crop at harvest

22 lbs N/Acre
N mineralization so far

9 lbs N/Acre
N loss so far

5 lbs N/Acre
N in crop now

23 lbs N/Acre
Expected future loss

15 lbs N/Acre
Partial credit from prior crop

35 lbs N/Acre
N in soil now

4.5"/17.6"
Rainfall since planting / since 01/01/15

17 lbs N/Acre
Expected future mineralization

1.7"/2.3"
Water in root zone / field capacity

35 lbs N/Acre
Root zone inorganic N

23 lbs N/Acre
Current Nitrate N top 12"
Virtual PSNT: **5.7** ppm

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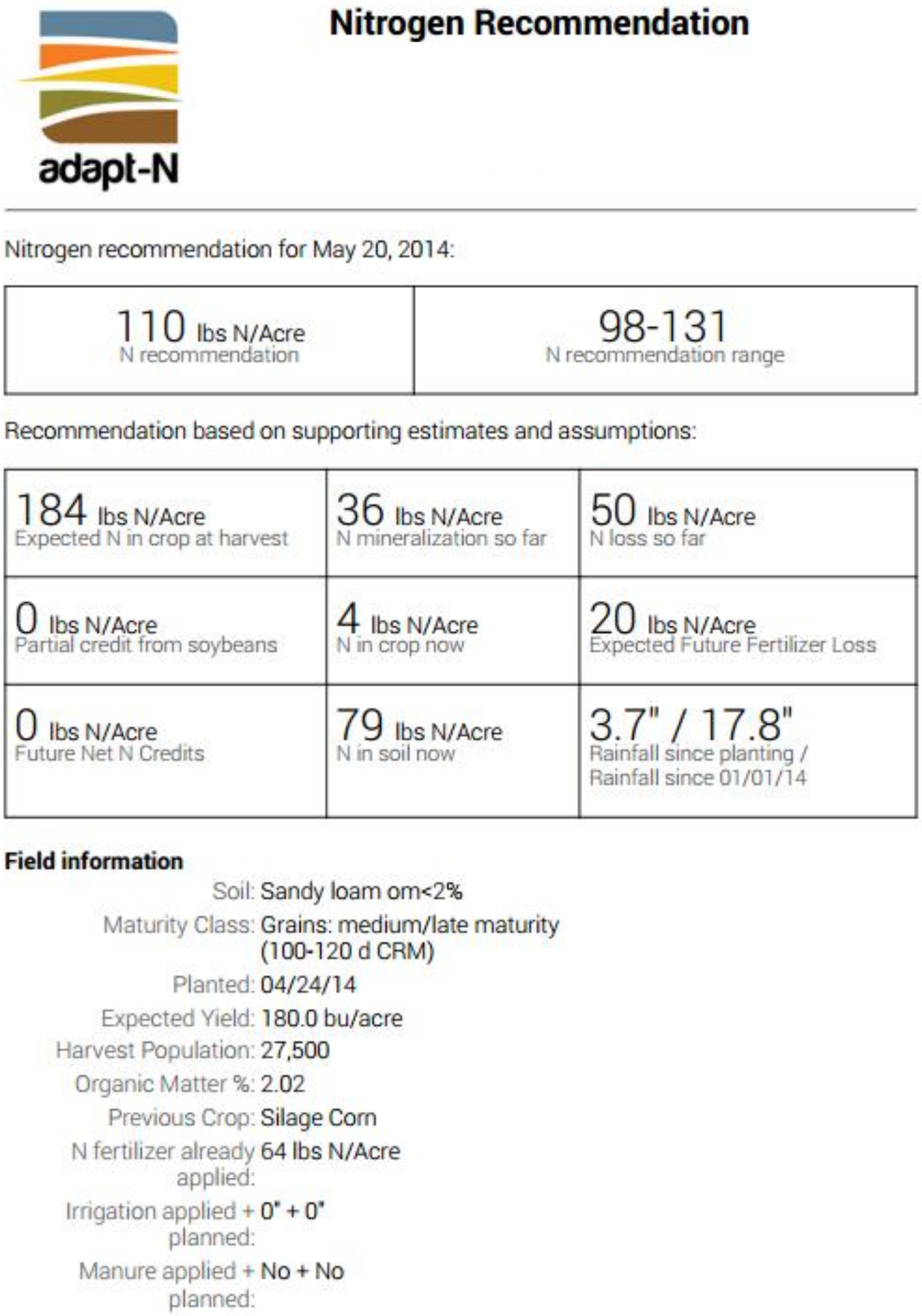


Nitrogen Recommendation

adapt-N

Nitrogen recommendation for May 20, 2014:

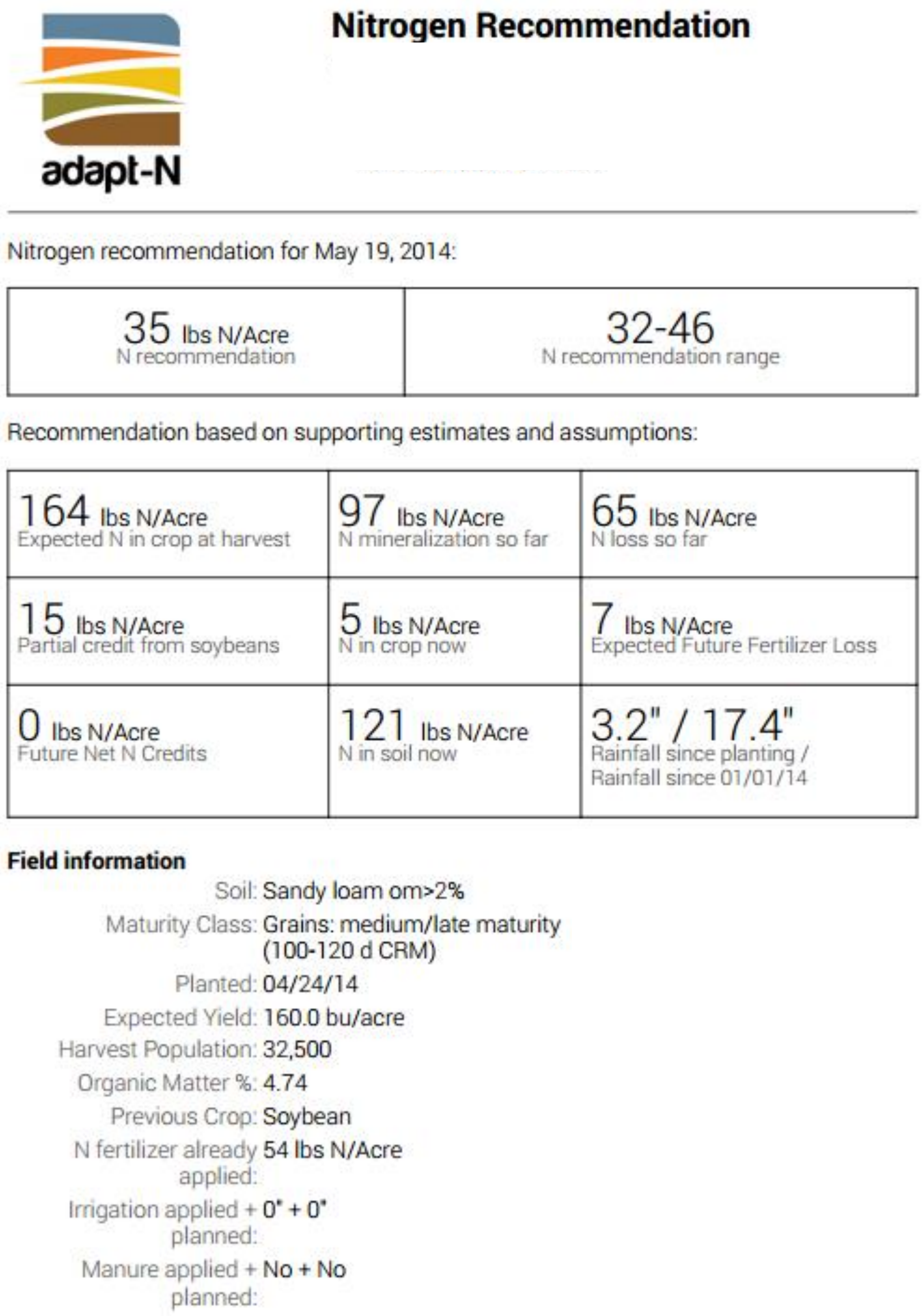
110 lbs N/Acre N recommendation	98-131 N recommendation range

Recommendation based on supporting estimates and assumptions:

184 lbs N/Acre Expected N in crop at harvest	36 lbs N/Acre N mineralization so far	50 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	4 lbs N/Acre N in crop now	20 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	79 lbs N/Acre N in soil now	3.7" / 17.8" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil:	Sandy loam om<2%
Maturity Class:	Grains: medium/late maturity (100-120 d CRM)
Planted:	04/24/14
Expected Yield:	180.0 bu/acre
Harvest Population:	27,500
Organic Matter %:	2.02
Previous Crop:	Silage Corn
N fertilizer already applied:	64 lbs N/Acre
Irrigation applied + planned:	0" + 0"
Manure applied + planned:	No + No



adapt-N

Nitrogen Recommendation

Nitrogen recommendation for May 19, 2014:

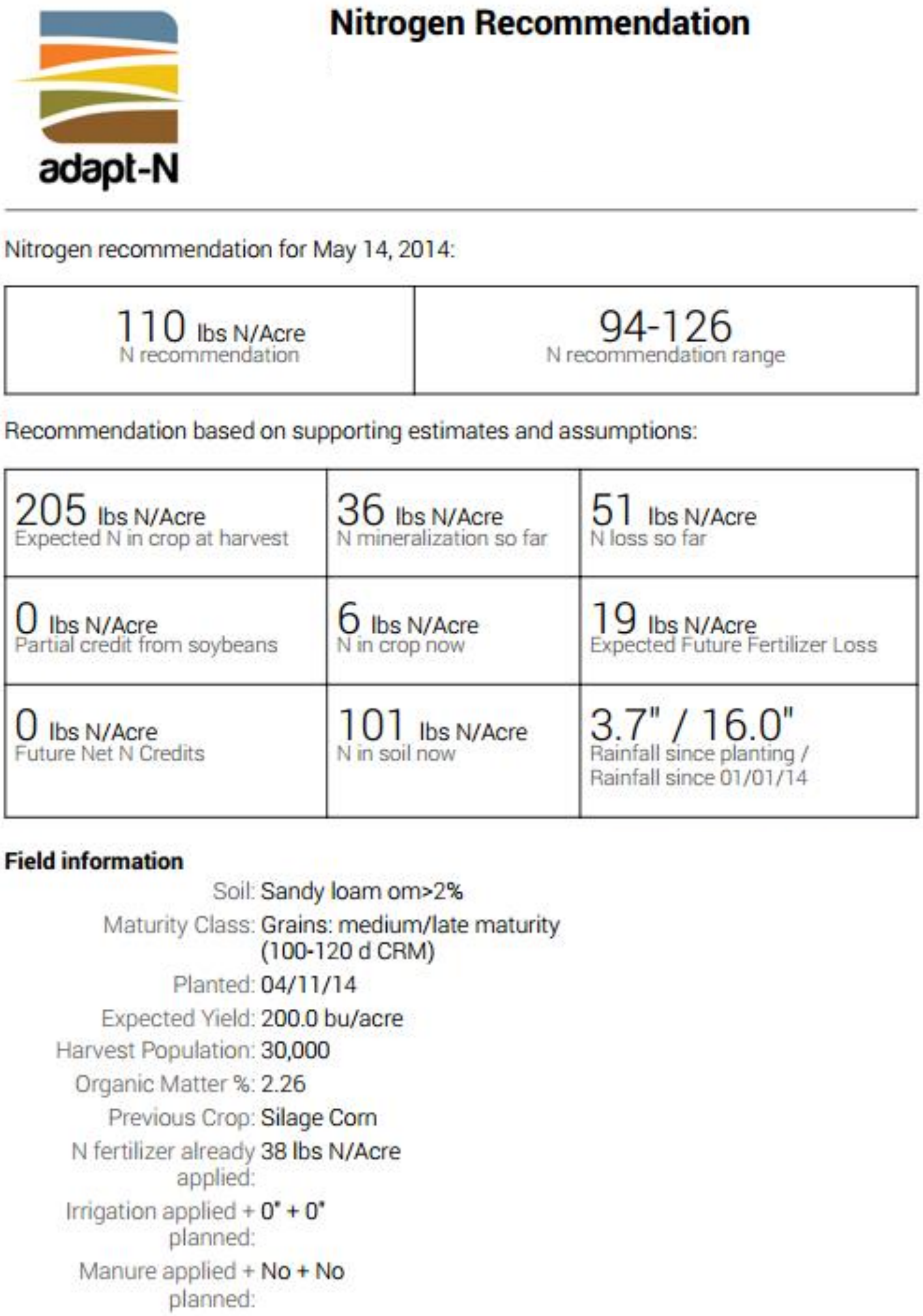
35 lbs N/Acre N recommendation	32-46 N recommendation range

Recommendation based on supporting estimates and assumptions:

164 lbs N/Acre Expected N in crop at harvest	97 lbs N/Acre N mineralization so far	65 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	5 lbs N/Acre N in crop now	7 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	121 lbs N/Acre N in soil now	3.2" / 17.4" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil:	Sandy loam om>2%
Maturity Class:	Grains: medium/late maturity (100-120 d CRM)
Planted:	04/24/14
Expected Yield:	160.0 bu/acre
Harvest Population:	32,500
Organic Matter %:	4.74
Previous Crop:	Soybean
N fertilizer already applied:	54 lbs N/Acre
Irrigation applied + planned:	0" + 0"
Manure applied + planned:	No + No



adapt-N

Nitrogen Recommendation

Nitrogen recommendation for May 14, 2014:

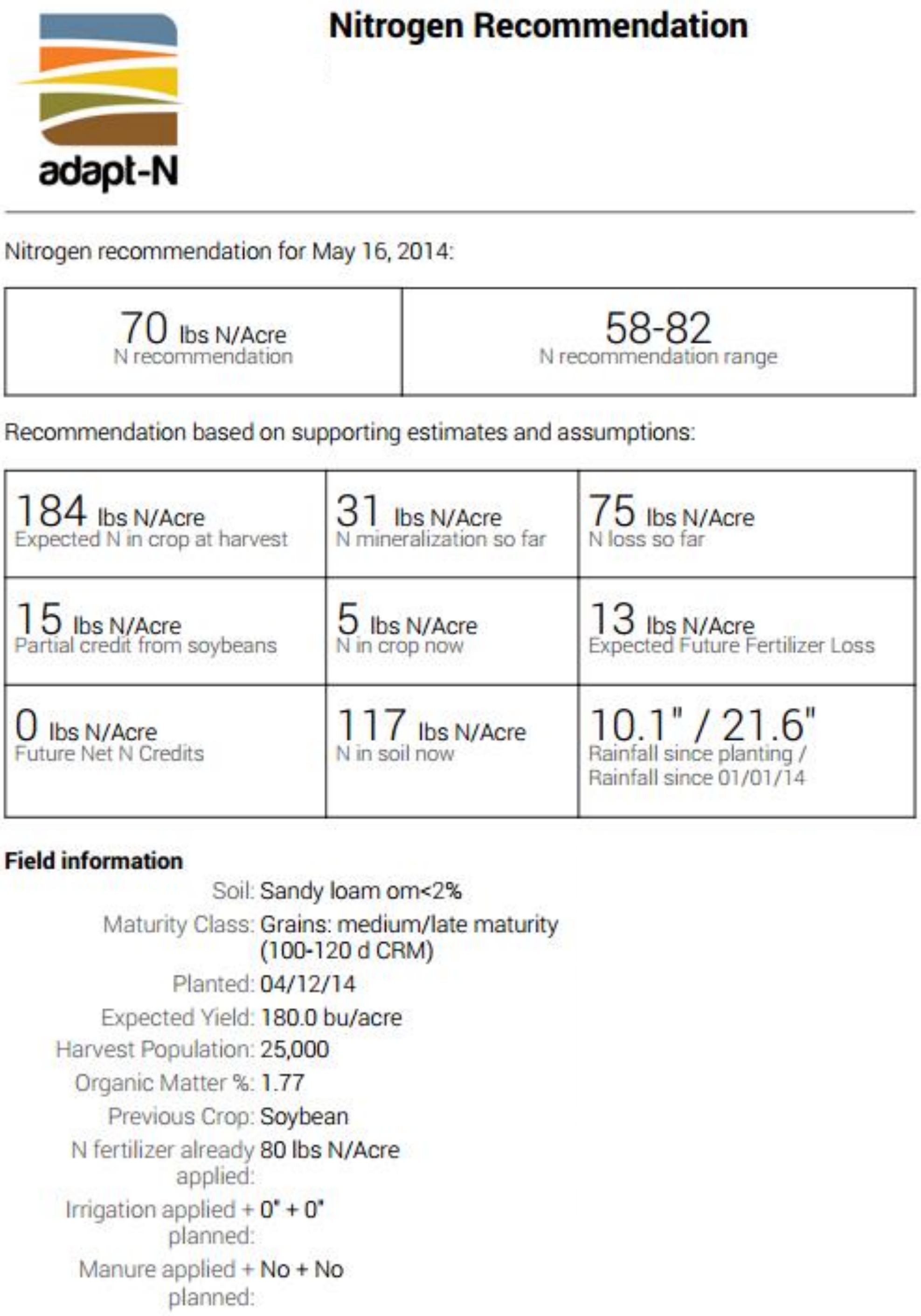
110 lbs N/Acre N recommendation	94-126 N recommendation range

Recommendation based on supporting estimates and assumptions:

205 lbs N/Acre Expected N in crop at harvest	36 lbs N/Acre N mineralization so far	51 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	6 lbs N/Acre N in crop now	19 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	101 lbs N/Acre N in soil now	3.7" / 16.0" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil: Sandy loam om>2%
Maturity Class: Grains: medium/late maturity (100-120 d CRM)
Planted: 04/11/14
Expected Yield: 200.0 bu/acre
Harvest Population: 30,000
Organic Matter %: 2.26
Previous Crop: Silage Corn
N fertilizer already applied: 38 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No



Nitrogen Recommendation

Nitrogen recommendation for May 16, 2014:

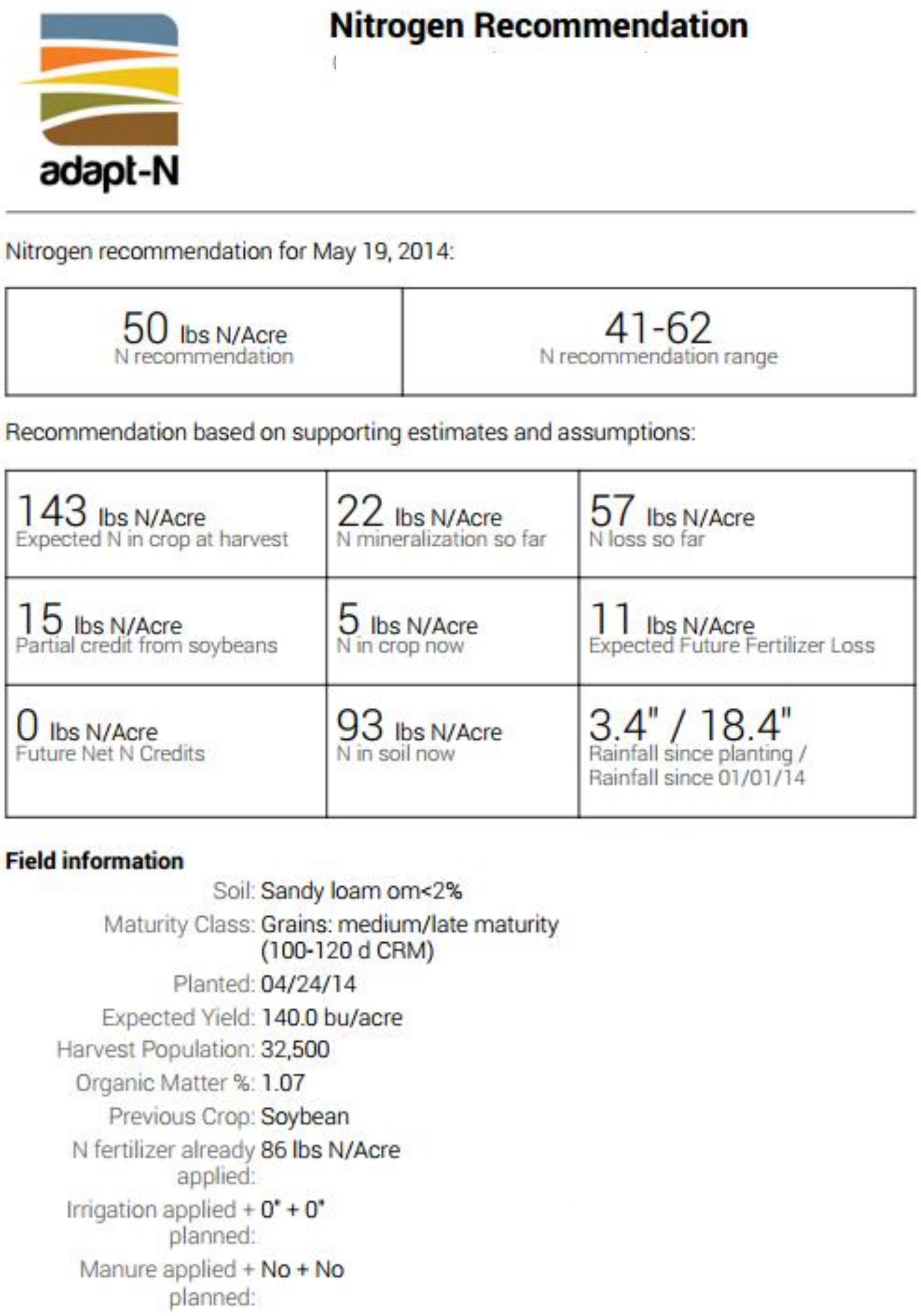
70 lbs N/Acre N recommendation	58-82 N recommendation range

Recommendation based on supporting estimates and assumptions:

184 lbs N/Acre Expected N in crop at harvest	31 lbs N/Acre N mineralization so far	75 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	5 lbs N/Acre N in crop now	13 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	117 lbs N/Acre N in soil now	10.1" / 21.6" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil:	Sandy loam om<2%
Maturity Class:	Grains: medium/late maturity (100-120 d CRM)
Planted:	04/12/14
Expected Yield:	180.0 bu/acre
Harvest Population:	25,000
Organic Matter %:	1.77
Previous Crop:	Soybean
N fertilizer already applied:	80 lbs N/Acre
Irrigation applied + planned:	0" + 0"
Manure applied + planned:	No + No



adapt-N

Nitrogen Recommendation

Nitrogen recommendation for May 19, 2014:

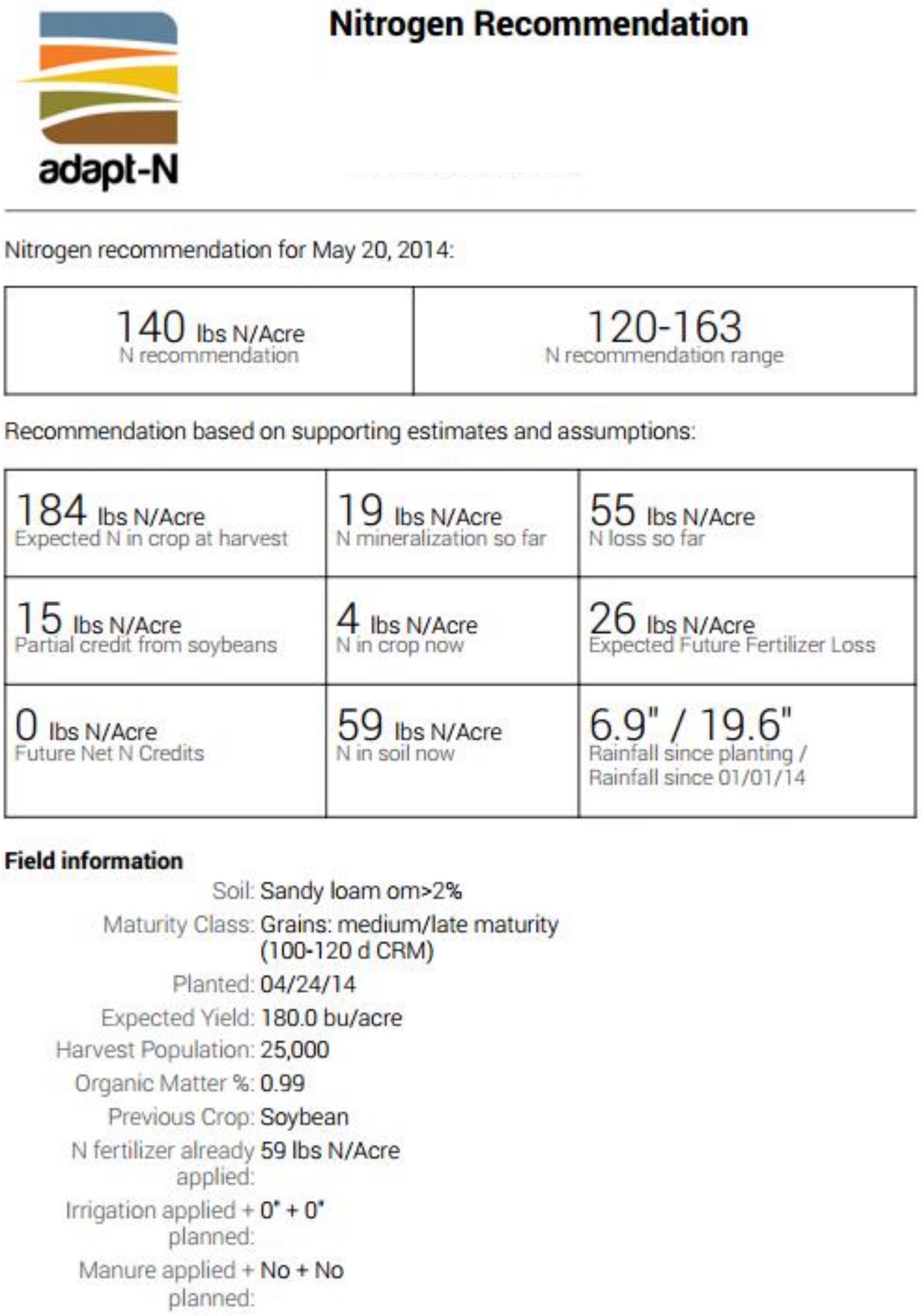
50 lbs N/Acre N recommendation	41-62 N recommendation range

Recommendation based on supporting estimates and assumptions:

143 lbs N/Acre Expected N in crop at harvest	22 lbs N/Acre N mineralization so far	57 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	5 lbs N/Acre N in crop now	11 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	93 lbs N/Acre N in soil now	3.4" / 18.4" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil:	Sandy loam om<2%
Maturity Class:	Grains: medium/late maturity (100-120 d CRM)
Planted:	04/24/14
Expected Yield:	140.0 bu/acre
Harvest Population:	32,500
Organic Matter %:	1.07
Previous Crop:	Soybean
N fertilizer already applied:	86 lbs N/Acre
Irrigation applied + planned:	0" + 0"
Manure applied + planned:	No + No



adapt-N

Nitrogen Recommendation

Nitrogen recommendation for May 20, 2014:

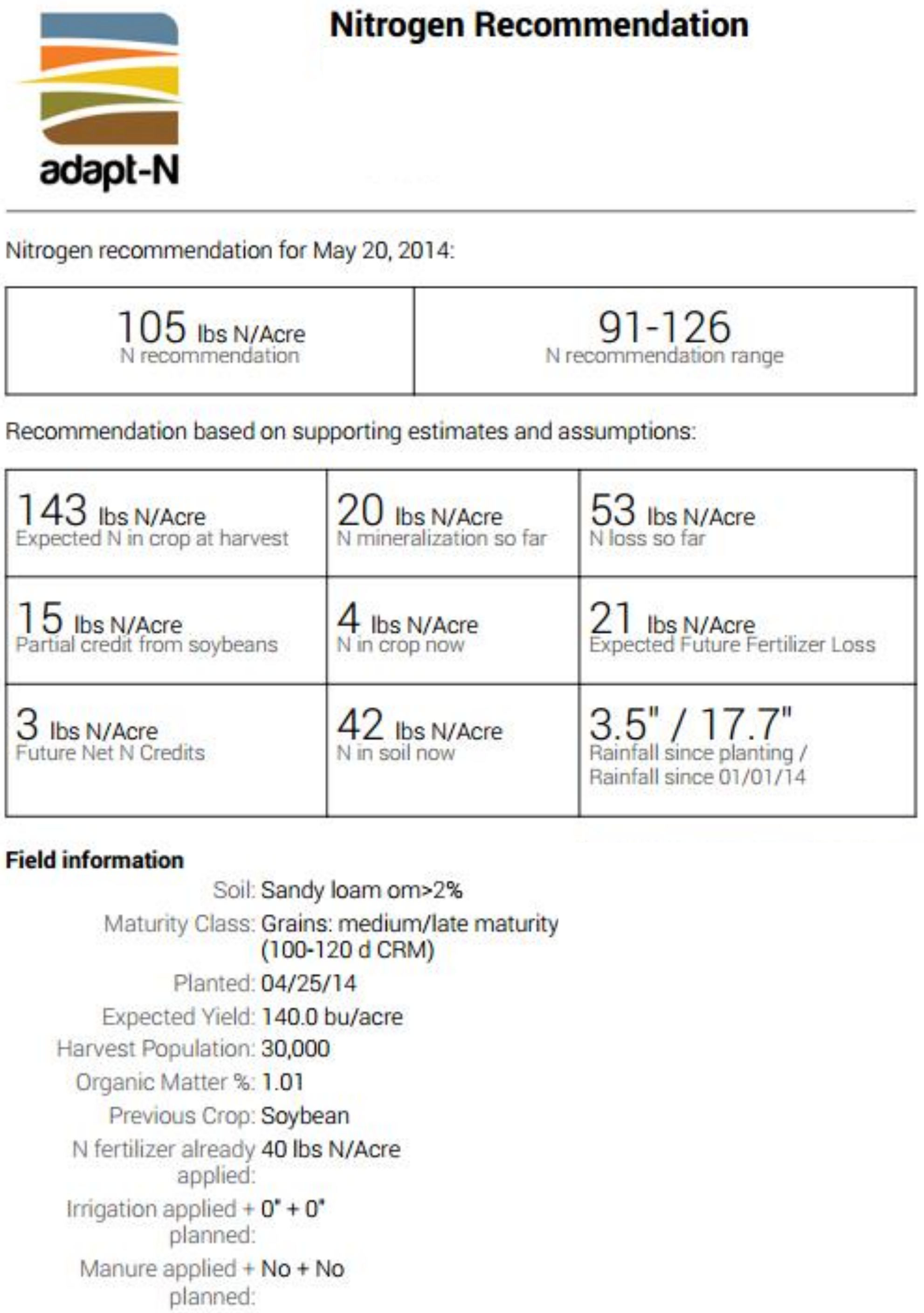
140 lbs N/Acre N recommendation	120-163 N recommendation range

Recommendation based on supporting estimates and assumptions:

184 lbs N/Acre Expected N in crop at harvest	19 lbs N/Acre N mineralization so far	55 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	4 lbs N/Acre N in crop now	26 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	59 lbs N/Acre N in soil now	6.9" / 19.6" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil:	Sandy loam om>2%
Maturity Class:	Grains: medium/late maturity (100-120 d CRM)
Planted:	04/24/14
Expected Yield:	180.0 bu/acre
Harvest Population:	25,000
Organic Matter %:	0.99
Previous Crop:	Soybean
N fertilizer already applied:	59 lbs N/Acre
Irrigation applied + planned:	0" + 0"
Manure applied + planned:	No + No



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Nitrogen Recommendation

Nitrogen recommendation for May 20, 2014:

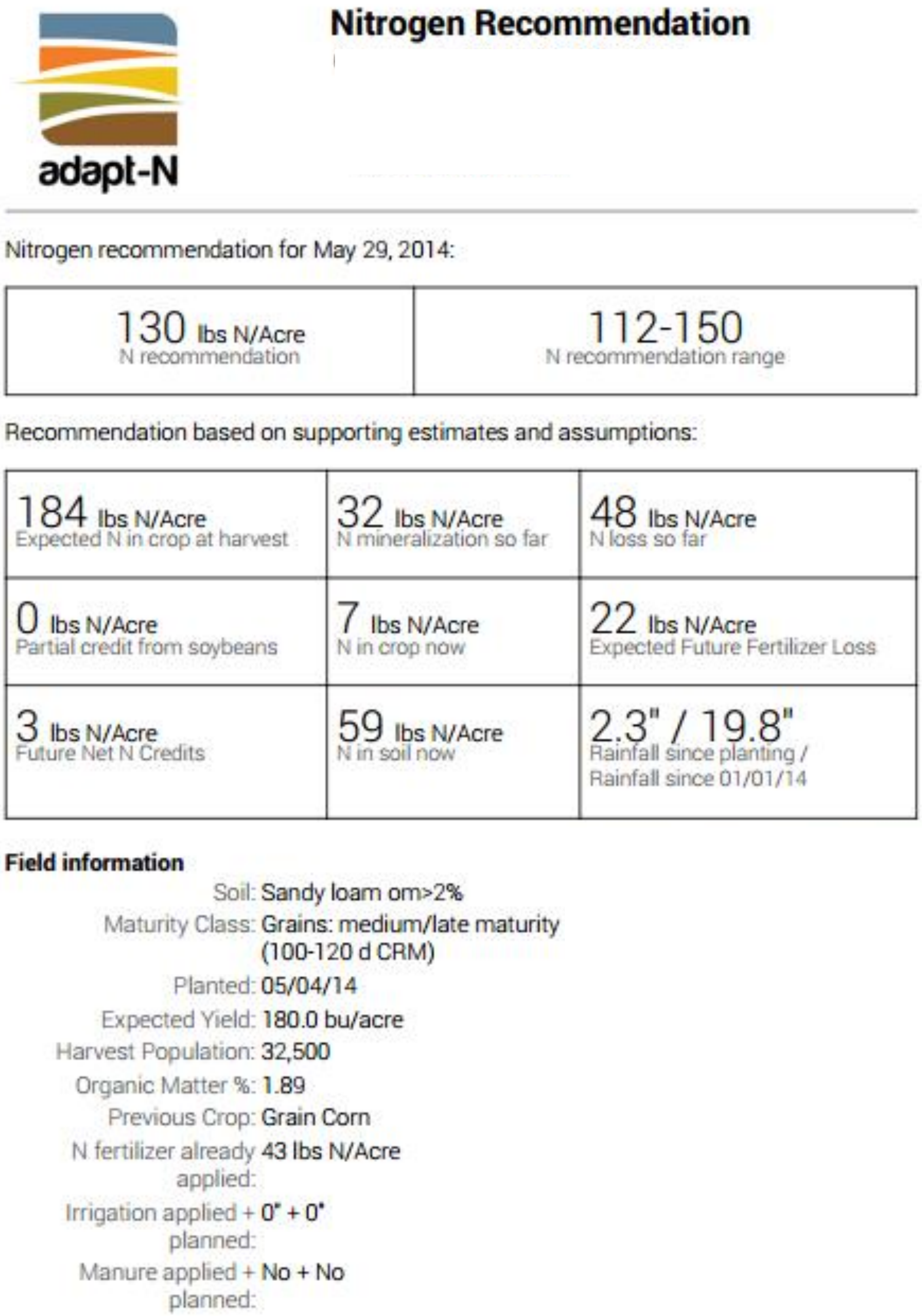
105 lbs N/Acre N recommendation	91-126 N recommendation range

Recommendation based on supporting estimates and assumptions:

143 lbs N/Acre Expected N in crop at harvest	20 lbs N/Acre N mineralization so far	53 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	4 lbs N/Acre N in crop now	21 lbs N/Acre Expected Future Fertilizer Loss
3 lbs N/Acre Future Net N Credits	42 lbs N/Acre N in soil now	3.5" / 17.7" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil: Sandy loam om>2%
Maturity Class: Grains: medium/late maturity (100-120 d CRM)
Planted: 04/25/14
Expected Yield: 140.0 bu/acre
Harvest Population: 30,000
Organic Matter %: 1.01
Previous Crop: Soybean
N fertilizer already applied: 40 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No



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Nitrogen Recommendation

Nitrogen recommendation for May 29, 2014:

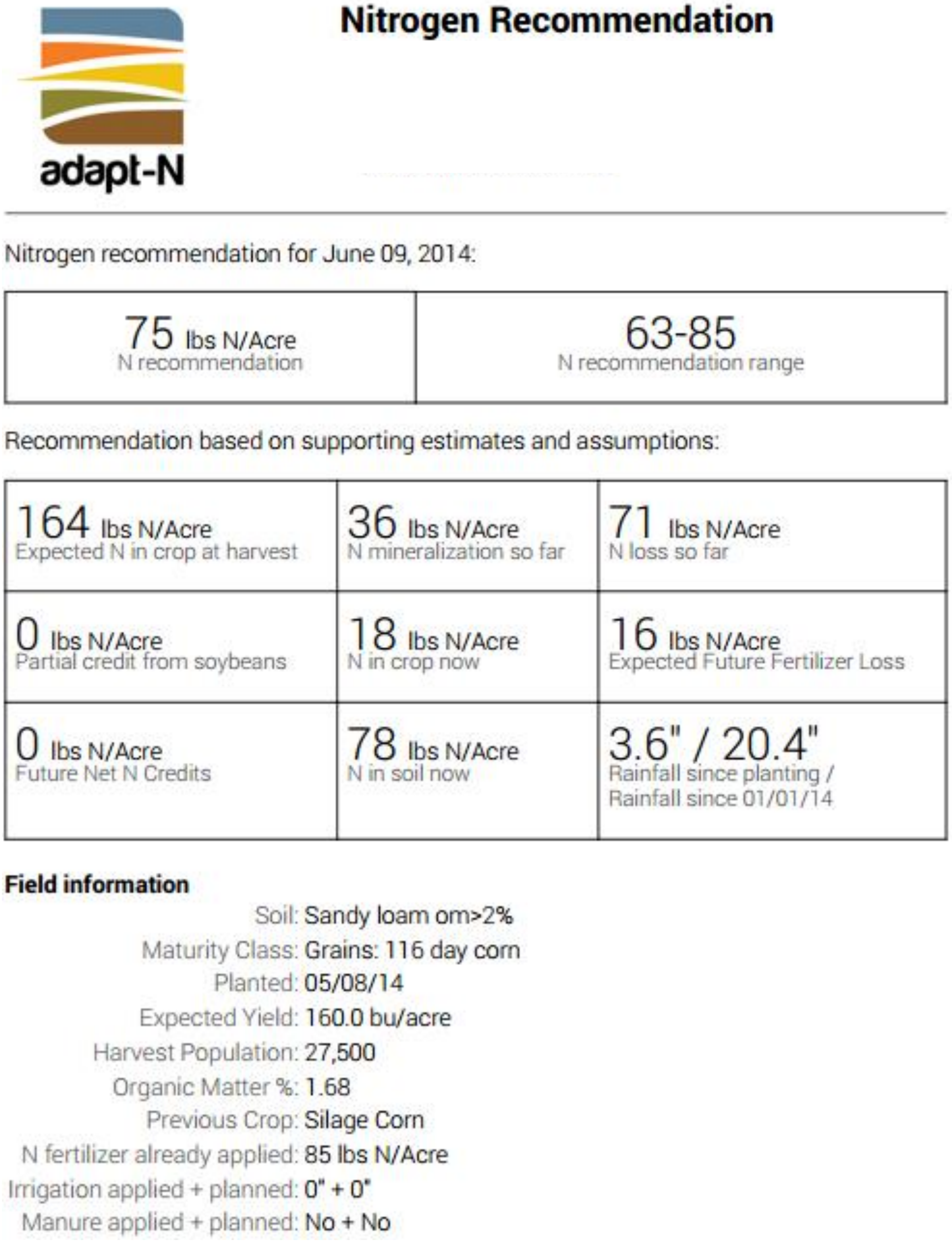
130 lbs N/Acre N recommendation	112-150 N recommendation range

Recommendation based on supporting estimates and assumptions:

184 lbs N/Acre Expected N in crop at harvest	32 lbs N/Acre N mineralization so far	48 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	7 lbs N/Acre N in crop now	22 lbs N/Acre Expected Future Fertilizer Loss
3 lbs N/Acre Future Net N Credits	59 lbs N/Acre N in soil now	2.3" / 19.8" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil:	Sandy loam om>2%
Maturity Class:	Grains: medium/late maturity (100-120 d CRM)
Planted:	05/04/14
Expected Yield:	180.0 bu/acre
Harvest Population:	32,500
Organic Matter %:	1.89
Previous Crop:	Grain Corn
N fertilizer already applied:	43 lbs N/Acre
Irrigation applied + planned:	0" + 0"
Manure applied + planned:	No + No



Nitrogen Recommendation

Nitrogen recommendation for June 09, 2014:

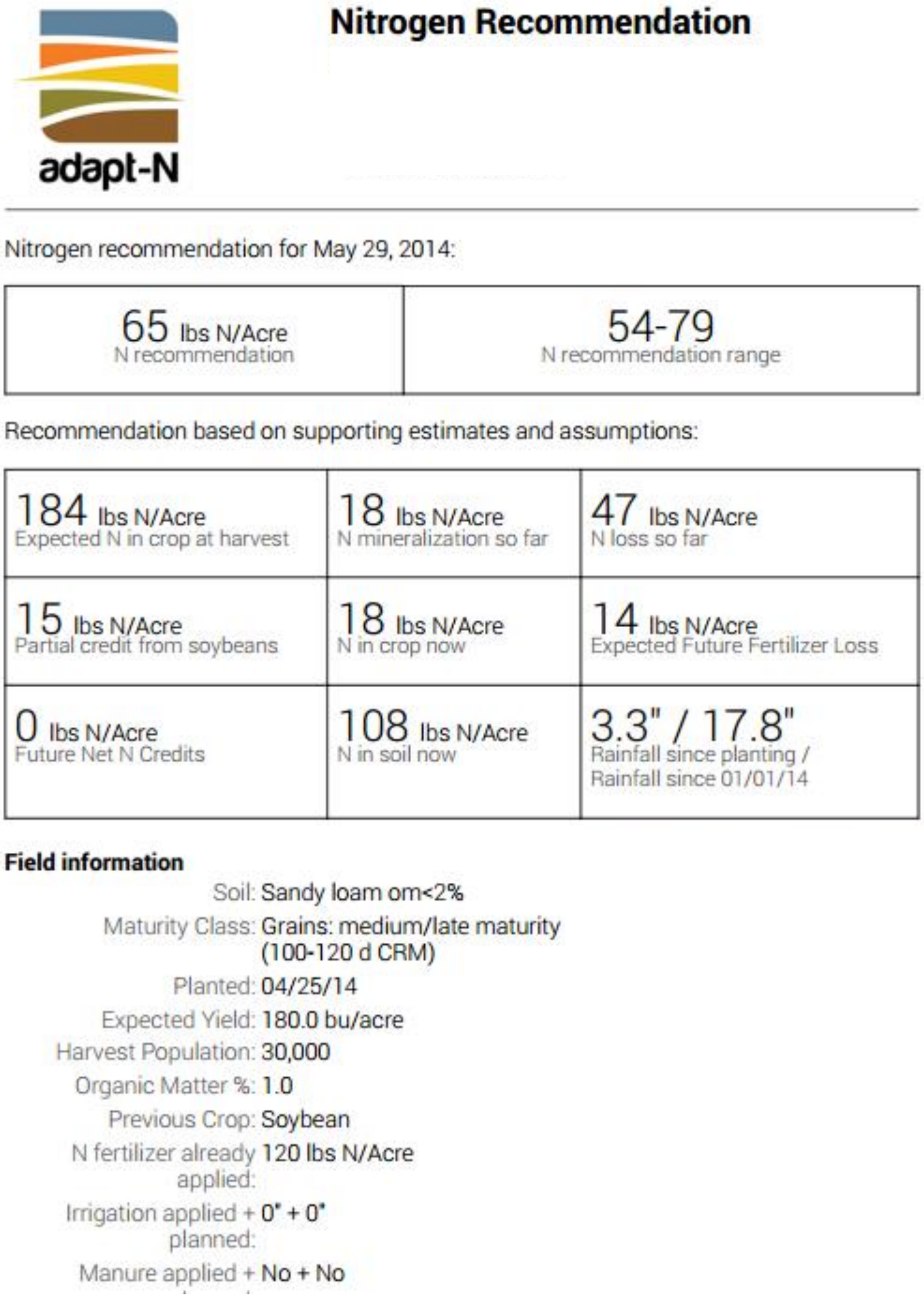
75 lbs N/Acre N recommendation	63-85 N recommendation range

Recommendation based on supporting estimates and assumptions:

164 lbs N/Acre Expected N in crop at harvest	36 lbs N/Acre N mineralization so far	71 lbs N/Acre N loss so far
0 lbs N/Acre Partial credit from soybeans	18 lbs N/Acre N in crop now	16 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	78 lbs N/Acre N in soil now	3.6" / 20.4" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil: Sandy loam om>2%
Maturity Class: Grains: 116 day corn
Planted: 05/08/14
Expected Yield: 160.0 bu/acre
Harvest Population: 27,500
Organic Matter %: 1.68
Previous Crop: Silage Corn
N fertilizer already applied: 85 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + planned: No + No



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Nitrogen Recommendation

Nitrogen recommendation for May 29, 2014:

65 lbs N/Acre N recommendation	54-79 N recommendation range

Recommendation based on supporting estimates and assumptions:

184 lbs N/Acre Expected N in crop at harvest	18 lbs N/Acre N mineralization so far	47 lbs N/Acre N loss so far
15 lbs N/Acre Partial credit from soybeans	18 lbs N/Acre N in crop now	14 lbs N/Acre Expected Future Fertilizer Loss
0 lbs N/Acre Future Net N Credits	108 lbs N/Acre N in soil now	3.3" / 17.8" Rainfall since planting / Rainfall since 01/01/14

Field information

Soil: Sandy loam om<2%
Maturity Class: Grains: medium/late maturity (100-120 d CRM)
Planted: 04/25/14
Expected Yield: 180.0 bu/acre
Harvest Population: 30,000
Organic Matter %: 1.0
Previous Crop: Soybean
N fertilizer already applied: 120 lbs N/Acre
Irrigation applied + planned: 0" + 0"
Manure applied + No + No