NITROGEN CONTENT OF WHEAT AND CORN IN RESPONSE TO THE APPLICATION OF UREA AND THE UREASE INHIBITOR N-(N-BUTYL THIOPHOSPHORIC TRIAMIDE)

by

Chalone S. Hefley

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APPROVED:

Chairman, Thesis Committee	Date
Member, Thesis Committee	Date
Member, Thesis Committee	Date
Head, Major Department	Date
Dean, Academic College	Date
Dean, Graduate School	Date

ABSTRACT

Increasing nitrogen (N) uptake by crops is a primary goal of many crop producers due to the direct relationship between crop N content and higher yields. In order to increase N uptake by crops, the application of N fertilizer, specifically urea, is often used. However, N in the soil can be extremely volatile and is easily lost to the atmosphere through ammonia (NH_3) volatilization before it is able to be used by the intended crops. Urease, an enzyme found in the soil, is a major facilitator of the NH_3 volatilization process. Urease inhibitors were developed in order to delay the volatilization of N from N fertilizers, allowing more of the N to infiltrate the topsoil, thereby giving crops the opportunity to absorb the plant available N. This study was performed in an attempt to evaluate the effects of the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) on the harvested N content of wheat (*Triticum aestivum L.*) and corn (*Zea mays L.*) in the field. Six treatments, replicated four times each, were observed in completely randomized field plots each measuring 3.048 X 6.096 meters. The plots were treated with compost alone, compost treated with the NBPT-based inhibitor, N-Yield™, urea alone, urea treated with N-Yield™, urea treated with another NBPT-based inhibitor, Agrotain® (Ultra or Advanced, depending on the year), or were designated as a control group, wherein no fertilizer or urease inhibitor was applied. Once the crops reached maturity, they were harvested, and lab analyses were run on the dry matter harvested from each plot to determine nutrient values. In this study, N concentrations in wheat straw ranged from

0.64% in the control to 1.36% in the treatment containing urea treated with the NBPT-based inhibitor N-Yield™, while N concentrations in wheat grain ranged from 2.09% in the control to 3.52% in the treatment containing urea treated with the NBPT-based inhibitor N-Yield™. Similarly, N concentrations in the corn stover ranged from 0.81% in the compost treatment to 1.80% in the treatment containing urea treated with the NBPT-based inhibitor Agrotain®. However, the data analyzed in this study suggest that, in field conditions, while the application of urea fertilizer greatly increases N concentrations in wheat and corn, the addition of NBPT (whether Agrotain® or N-Yield™) to urea before field application does not significantly increase N concentrations over that of urea alone.

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CHAPTER ONE

LITERATURE REVIEW

Nitrogen Uptake and Plant Growth

It has long been known that in order to maximize crop yields, nitrogen (N), whether obtained from the topsoil profile, or from the application of N rich fertilizers, is one of, if not the most important essential nutrient (Dai, X. et al, 2013; Delogu et al., 1998). Without N, plant growth, productivity (yields) and grain quality are adversely affected. A study conducted by Delogu, et al. (1998) suggests that consistent yields and grain quality (protein content) are directly related to the speed and measure of N uptake by crops, and the ability to partition that N effectively.

Nitrogen is frequently acknowledged as the most limiting nutrient in crop production. Therefore, N fertilizer is one of the most commonly used inputs for cropping systems (Nassiri-Mahallati et al., 2010). There are many factors that need to be taken into consideration when trying to determine whether or not N fertilizer is necessary or will be economically productive. Some of these include crop species, soil type, soil moisture content, crop rotation/cropping system, previous crop residues, climate, accessible technology and potential for irrigation, as well as the current N content of the soil (Nassiri-Mahallati et al., 2010).

Nitrogen absorption by plants is affected by growth stage, the amount of plant available N present in the soil, the amount of plant available water, and the depth at which the N is located (Reginato et al., 1988). Some evidence has been shown that heavy application of N fertilizer in early growth stages of a plant may not be necessary (Lian-Peng et al., 2012). This is not to say that the application of N fertilizer is not needed at early stages in the crop's growth. It simply implies not as much may be needed as in later growth stages, and/or that application of N fertilizer should occur at multiple stages throughout a plant's growth cycle in order to produce the best yield results. Lian-Peng et al, (2012), further concluded that increasing the amounts of N fertilizer applied at mid- and late-growth stages (after the reproductive stages have begun) fortifies and increases N absorption and uptake, increasing grain yields. Lian-Peng et al, (2012) found that reforming N management practices by decreasing early N application rates and then applying N fertilizer soon after wheat jointing increased ear-bearing tillers to 60%, where this amount was reduced by approximately 25% in wheat where N fertilizer application was increased in the early stage of the crop's growth cycle.

How well a plant is able to take up nutrients from the soil is highly dependent on how well developed the root system becomes. Reginato et al. (1988) found that placing the right amount of N fertilizer at the proper depth, and being able to provide adequate water to the crop will markedly increase development of the crops root system by significantly increasing root density and, therefore, water uptake (Sharma and Chaudhary, 1983). Brown (1971) reported that wheat crops that received adequate N fertilization were able to remove more water from the soil and at a higher rate than those crops that did not have N fertilizer applied.

Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) can be defined in many ways, including being calculated as the ratio between the amount of N removed from the field by the crop and the initial amount of N contained in the soil plus the amount of fertilizer N applied (Johnston and Poulton, 2009). In a research study conducted by Raun and Johnson (1999) NUE is calculated as the difference of N uptake in the treated plot(s) & N uptake in the untreated plot(s), divided by the total applied N rate.

(100 [harvested N of fertilized – harvested N of control]/N applied rate)

A study conducted in the late 1990s, determined that typical NUE for various cereal crops across the world where N fertilizer is applied is only about 33% (Raun and Johnson, 1999). Raun and Johnson (1999) further determined that over-application of N fertilizer did not increase NUE, and that NUE actually decreased with increasing N fertilizer rates. Further, higher N rates can lead to an increase in N losses through volatilization, potentially leading to an increase in environmental contamination.

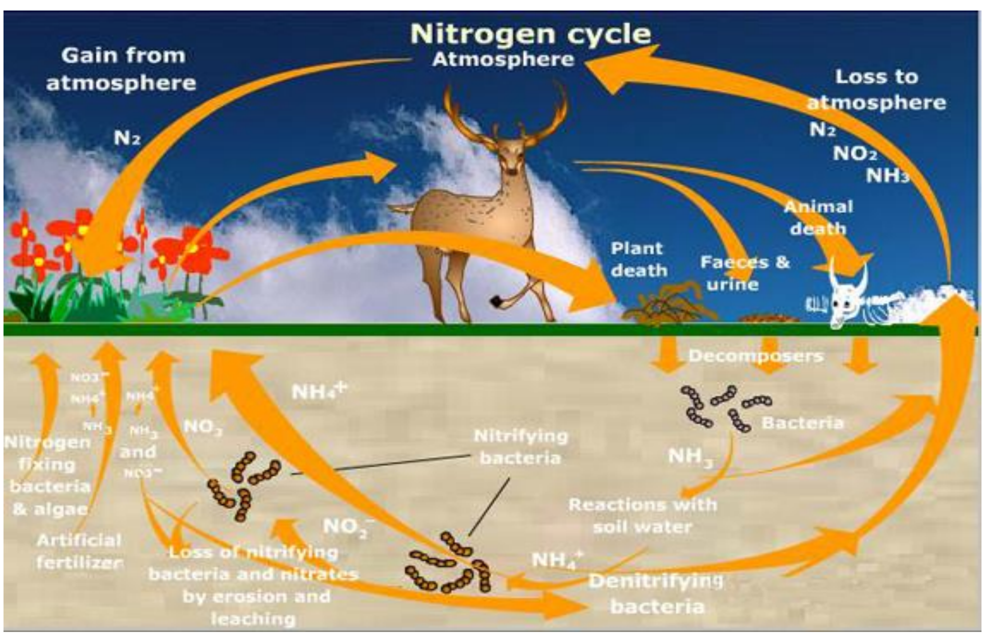
A later, but similar research report, goes further to show that NUE can be largely affected by the type, or lack thereof, of crop residue left by the preceding crop (Rahimizadh et al., 2010). Rahimizadh et al. (2010) concluded that wheat grown following a non-wheat crop, where residue was left after harvest prior to planting the wheat, had up to a 24% increase in NUE, while wheat planted following harvest of a wheat crop did not see this increase. This suggests that crop rotation can assist with increasing NUE, thereby increasing grain yields.

Soil Nitrogen

Understanding how N in the soil exists and reacts is essential to its management in crop production. The amount of N found in the soil is greatly dependent upon the quantity and quality of organic matter found in the soil (Sheaffer and Moncada, 2009). However, only a small amount of this total N is plant available. The only forms of N available for plant uptake are nitrate (NO_3) and ammonium (NH_4). Other forms of N found in the atmosphere and soil are insoluble in water and are, therefore, unavailable for plants to use. These forms of N must be converted, or "fixed" through lightening fixation, ammonification, nitrification, or biological fixation, into soluble forms in order to be available for plant consumption and usage (Figure 1.1).

There are multiple ways of attempting to increase N in the soil. One way is to increase soil organic matter. This process, while extremely beneficial on many levels, not just for the increase of N, takes time, and sometimes resources for this process are not abundantly available. Another process includes incorporating legumes into the cropping system. However, while again favorable in multiple ways, this practice may not be practical for the producer. Therefore, in consideration of time constraints, producers typically choose to apply synthetic N fertilizers instead. This method increases N content in the soil more rapidly and can be somewhat controlled.

***Figure 1.1: Development of the nitrogen cycle process*[1]**



[1]Adapted from https://rodneyjonesme.files.wordpress.com/2012/02/notorgencycle.jpg

Urea: Synthetic Nitrogen Fertilizer

Urea ($CO(NH_2)_2$) is the most universally used synthetic N fertilizer. Commercial production of urea began when the Haber-Bosch process was perfected (Gilbert et al., 2006) making the production of ammonia (NH_3) more efficient than past procedures.

$$N_{2\,(gas)} + 3H_{2\,(gas)} \leftrightarrow 2NH_{3\,(gas)}$$

Urea is formed through a process which is achievable only under high pressure (50–200 bar) and high temperatures (380–480°C) (Vojvodic et al., 2014). The production of urea can be seen in the following reactions:

$$2NH_3 + CO_2 \leftrightarrow NH_2COONH_4$$

$$NH_2COONH_4 \leftrightarrow H_2O + CO(NH_2)_2$$

Although there are atmospheric and biological means by which insoluble N forms may be converted into soluble forms, industrial fixation of N is the most prevalent in global crop production (Sheaffer and Moncada, 2009).

The use of urea as a source of N fertilizer has been progressively increasing over the past 50 years, along with its global production (Gilbert, et al 2006). According to the USDA (2012), in the United States alone, utilization of urea fertilizer has increased approximately 40 fold in the last half century. Much of this is due to the fact that urea is the most economical form of N fertilizer available today (James, 2010). Urea is high in N content (46%) (Overdahl et al., 2014), easily accessible, easily stored and transported (James, 2010), and simple in its application. Urea may be applied in a solid form of prills or granules to the soil surface or in bands, or as a solution of ammonium nitrate (UAN) (Overdahl et al., 2014). It is also easily blended with other fertilizers (Overdahl et al., 2014) which can reduce input application costs.

Once applied, urea is hydrolyzed into a soluble form of N that can be easily converted through nitrification into NO_3 for plant uptake. The hydrolyzation reaction produces NH_3 and CO_2 as seen in the following (Bremmer, 1995):

$$CO(NH_2)_2 + H_2O(l) \xleftrightarrow{urease} NH_3 + H_2NCOOH \rightarrow 2NH_{3(g)} + CO_{2(g)}$$

Urease

Urease is a naturally occurring soil born enzyme that catalyzes the reaction shown above, wherein urea is hydrolyzed for plant uptake. However, this catalyst also increases the rate at which ammonia volatilization occurs, thereby decreasing NUE in most plants and increasing the probability of N environmental contamination.

It has been found that soil urease activity can be linked to soil organic matter content and total N content (Uzun and Uyanoz, 2011). Uzun and Uyanoz, 2011, found that soils with higher organic matter content tend to have a more elevated level of microbial biomass and therefore, higher potential for urease balance and reduction of catalytic activity.

Nitrogen Losses

Urea, even with all its advantages, has a significant disadvantage in that it is extremely susceptible to N loss, especially when left exposed on or near the soil surface. Urea N loss rates vary and can be between 50% and 90% of total urea N within the first 48 hours after surface application (James, 2010). In a study conducted by Raun and Johnson in 1999, it was observed that N losses can occur through several different processes:

- Denitrification;

- Leaching;
- Runoff; and
- NH_3 volatilization.

Denitrification is the process by which nitrates (NO_3^-) or nitrites (NO_2^-) are reduced to nitric oxide (NO), nitrous oxide (N_2O), or nitrogen gas (N_2) (Gayon and Dupetit, 1882). This process is significant in that the NO and N_2O produced during the denitrification process are labeled as significant greenhouse gases, both of which contribute to the production of nitric acid, a component of acid rain.

Hilton et al., (1994) reported denitrification rates of 10 to 22% of total N from the application of nitrogen fertilizers to corn crops. While there are various models and approaches to estimating soil N loss from denitrification (Germon and Philippot, 2012), the calculated results are highly dependent upon numerous soil characteristics, including but not limited to soil texture, organic matter content, pH, and cation exchange capacity, and/or environmental conditions.

Leaching of soil N occurs when N supply exceeds N demand in a copping system and the excess N is percolated down through the soil profile (Teixeira et al., 2016). The leaching process can push soil N past the crop root zone making it unavailable to plants and potentially moving it into water tables or aquifers, causing environmental contamination of ground water supplies and/or causing eutrophication of nearby bodies of water. Excess or continuous rainfall or irrigation can escalate this action.

Runoff can occur when a strong or intense rainfall event takes place, or when excess irrigation is applied to a cropping system. Water from acute rainfall or excessive irrigation can carry unincorporated nutrients from the soil surface to other environmental areas causing nutrient loss and possible pollution.

Ammonia volatilization is the loss of NH_3 gas to the atmosphere. Since the natural state of NH_3 is gaseous, its loss can occur rather quickly (Fageria and Balinger, 2005). The process of NH_3 volatilization is a potential problem for many producers, whether natural or synthetic N fertilizers are used during crop production. The highest rates of NH_3 volatilization occur when N fertilizers are broadcast applied, unincorporated, and left without irrigation or adequate precipitation accumulations (Sanz-Cobena et al., 2011). Nitrogen loss rates, due to NH_3 volatilization, as high as 56% of total applied N fertilizer have been documented (Black et al., 1985, Gioacchini et al., 2002). This can lead to major environmental concerns and dilemmas, with estimated volatilization rates having the potential to surpass 25% of applied fertilizer sources (Lauer et al., 1976; Fillery et al., 1984). Further, in a study conducted by Watson et al. (2008), it was observed that increased temperatures elevated urea N losses even more, exceeding 30%.

While there are not only multiple ways in which N loss can occur, there are also a multitude of factors that contribute to the rate at which N loss transpires, specifically NH_3 volatilization (Bolan et al., 2012). These include, but are not limited to:

- Increasing temperature;
- Increasing soil pH;
- Unincorporated fertilizers (Rochette et al., 2009);
- Soil organic matter content (Singh et al., 2013);
- Lack of and/or excessive moisture;
- Wind velocity (Hayashi et al., 2008)

- Crop canopy;
- Tillage type (Rochette et al., 2009); and
- Types/numbers of soil organisms present.

This complexity is what makes controlling soil N loss a challenging practice that is difficult to effectively accomplish. Each of the above factors affects NH_3 volatilization rates, and while some can potentially be restricted and/or minimized, not all of them are within humanistic control.

Mitigation of N Losses

In order to reduce N loss through leaching, run-off, denitrification and NH_3 volatilization, and increase NUE potential, crop producers face a conglomerate of challenges when considering application of urea, or other N fertilizers. Some of these challenges are:

- Understanding soil types, pH, and moisture levels;
- Understanding at which point in the growth cycle N uptake is most efficient (for the crop being grown) in order for it to be most effective in producing high quality yields in the greatest quantities;
- Which method of application is the most economical and effective; and
- Knowing the proper amount to apply without over application.

Without considering each of the matters mentioned above, NUE and yields (quality and quantity) decrease, while the potential for N losses increases, thereby increasing the probability of environmental contamination.

One means by which N loss can be diminished is by the application of water immediately following the administration of N fertilizer to the soil (Sanz-Cobena et al., 2011). Since environmental weather conditions are not within the control of the producer, and if rainfall is not immediately anticipated, it is advantageous to apply irrigation promptly after application of N fertilizer to curtail the loss of N associated with NH_3 volatilization (Black et al., 1987). However, increased amounts of precipitation (rainfall or irrigation) can facilitate elevated losses of N through leaching and runoff. Careful monitoring of rainfall and irrigation amounts should be considered.

The integration of N fertilizers into the soil bed is another means by which N losses can be mitigated (Sommer and Hutchings, 1995). Nonetheless, this practice is not always a feasible option. This is especially true for those producers who utilize no-till or reduced-till systems in crop production (Bremmer, 1995).

Other techniques by which to reduce N losses from N fertilizers are proper timing of application and application of the appropriate amount of N fertilizer required. However, these actions also can pose dilemmas due to potential inconvenience and guess work (Chien et al., 2009). These methods are difficult to master in that they require soil, crop and fertilizer knowledge, field experience, and may be somewhat dependent upon unpredictable environmental conditions (wind, rain, etc.).

N-(n-butyl) Thiophosphoric Triamide (NBPT)

In addition to, or when the above described approaches to N loss mitigation are limited, or there is a desire to further reduce N loss from urea application, N fertilizer stabilizers may be used. In a research study conducted by Hendrickson (1992) it was demonstrated that one such stabilizer, N-(n-butyl) thiophosphoric triamide (NBPT), is effective at controlling urea hydrolysis and increases NUE, thereby reducing N loss when applied with urea. Another study involving NBPT conducted by Creason (1990) showed as much as a 50% inhibition when NBPT was applied. Soares et al., (2012) produced results that exhibited as much as a 78% reduction in N losses when NBPT was used with urea.

Mode of Action for NBPT: NBPTO

While NBPT is the compound marketed and used to treat urea in order to impede N loss, the conversion of NBPT to its oxon analog, NBPTO, must occur in order for the actual inhibition to take place. Once applied and added to the soil, NBPT is transformed into NBPTO, hindering the urease catalytic process (Creason et al., 1990). Since this conversion must happen in order to block the hydrolysis process, N volatilization continues until NBPTO is formed. This alteration may happen relatively quickly or may take a number of days to transpire (Byrnes and Freney, 1995).

Urea begins the action of hydrolyzing almost immediately upon application to the soil surface with the greatest part of N loss due to NH_3 volatilization occurring within the first seven days following urea application (Soares et al., 2012). In a study conducted by Gezgin and Bayrakll (1995) results showed that urea treated with NBPT had a significant reduction in NH_3 volatilization of up to 63% over that of untreated urea.

Research Objectives

There is evidence to suggest that the use of urea fertilizer treated with NBPT is beneficial for increasing yields in various crops. However, there is little published research signifying that the use of NBPT, or other urease inhibitors, in conjunction with urea fertilizer increases N uptake in winter wheat or corn, or that it potentially reduces nitrate environmental contamination. The objectives of this study were to evaluate the effect and compare the performance of urea fertilizer treated with two different NBPT urease inhibitor products, Agrotain® and N-Yield™, to that of a control (no fertilizer application), untreated urea fertilizer, and compost treatments on the nitrogen content of hard red winter wheat and field corn over a two year period.

CHAPTER TWO

WHEAT EXPERIMENT

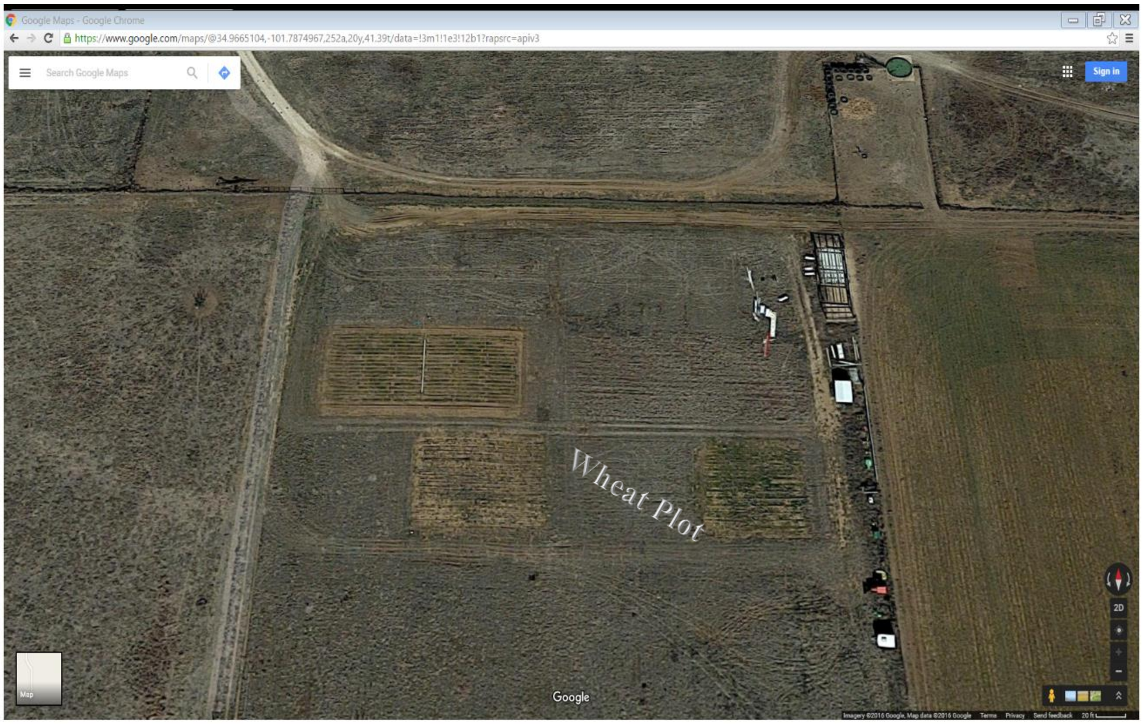
Materials and Methods

Experimental Field Site

A field experiment to determine the effects of the urease inhibitor NBPT on N uptake and volatilization was conducted for two consecutive growing seasons (2013-2014 and 2014-2015) for hard red winter wheat at the West Texas A&M University Nance Ranch, located approximately five miles East/Southeast of Canyon, Texas (Figure 2.1).

The experimental site has a climate that is semi-arid. Average annual rainfall is generally <50 centimeters, of which most is accumulated during the spring and early summer months (March - June). This climate region is prone to drought. The mean air temperatures are 11.8 °C (53.3°F) for the winter months (December – February), 22.6 °C (72.7°F) for the spring months (March – May), 32.4 °C (90.4°F) for the summer months (June – August), and 17.1 °C (62.8°F) for the fall months (September – November) (US Climate Data, 2015).

Figure 2.1 Arial view of West Texas A&M University Nance Ranch Field Research Plots. 34° 58' 05" N, 101° 47' 14" W. Adapted from http://www.gosur.com/map/?satellite=1&z=20&ll=34.968455,-101.787442&t=hybrid&lang=en



Soil

According to the USDA-NRCS website, the soil type at the experimental site is 100% Olton clay loam, 0 to 1 percent slopes (pH 6.6 - 8.4) (fine, mixed, superactive, thermic Aridic Paleustolls). The Olton series is comprised of "…very deep, well drained, moderately slowly permeable soils," (USDA-NCRS, 2015). The farmland classification for Olton Clay Loam is designated as prime farmland (USDA-NCRS, 2015). Most of the area that is comprised of Olton clay loam is irrigated cropland used for the production of cotton, sorghum and winter wheat (USDA-NCRS, 2015).

Soil Sampling

Soil samples were collected and analyzed pre-plant and post-harvest for each growing season to determine nutrient availability. Composite samples were obtained separately for each of the designated treatment plots. Three samples 15.24 centimeters – 20.32 centimeters deep were collected and composited from random locations throughout each plot. A total of 72 composite soil samples were collected and analyzed. The composite samples from each plot were delivered to Servi-Tech Laboratories (Amarillo, Texas), and individually analyzed for pH, salts, organic matter (OM), total N, phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), Sodium (Na), zinc (Zn), and cation exchange capacity (CEC).

Treatments and Application

For both the 2013-2014 and 2014-2015 growing seasons, field experiments were set up in a completely randomized design. The 2013-2014 growing season wheat crop experiment contained five treatments and a single control, with four replications each (Figure 2.2).

Figure 2.2 2013-2014 wheat plot map and designated treatment applications

NORTH↑	**A**	**B**	**C**	**D**
1	U	Cntrl	CompNY	UAG
2	UNY	Cntrl	Comp	UNY
3	Comp	Cntrl	UAG	UAG
4	CompNY	Comp	Cntrl	U
5	U	CompNY	Comp	UNY
6	U	CompNY	UNY	UNY

Control = Cntrl

Compost = Comp

Compost + N-Yield™ = CompNY

Urea = U

Urea + Agrotain® Ultra = UAG

Urea + N-Yield™ = UNY

Treatments described above were prepared and applied as follows:

- Control Treatment (Cntrl)-
    - No compost or fertilizer was applied to the designated plots
- Compost Treatment (Comp)-
    - 8.34kg (18.4lbs) of compost (Table 2.1) per plot; rate of compost application was calculated based upon 4483.40kg ha^{-1} (2 tons ac^{-1}); applying approximately 16.8kg N ha^{-1} (15lbs N ac^{-1}) according to compost analysis data (Table 2.1)

- Broadcast evenly throughout each designated plot, then tilled into the soil bed immediately prior to planting on October 4, 2013

▪ Compost + N-Yield Treatment (CompNY)-

- 8.34kg (18.4lbs) of compost treated with .003129529ml g^{-1} (3qts ton^{-1}) of the NBPT N stabilizer additive N-Yield™ per plot[1]; rate of compost application was calculated based upon 4483.40kg ha^{-1} (2 tons ac^{-1}) (Figures 2.3 and 2.4); applying approximately 16.8kg N ha^{-1} (15lbs N ac^{-1}) according to compost analysis data (Table 2.1)
- Broadcast evenly throughout each designated plot, then tilled into the soil bed immediately prior to planting on October 4, 2013

▪ Urea Treatment (U)-

- 347g of urea prills (46% N) per plot, based upon an application rate of 84.06kg ha^{-1} (75lbs ac^{-1}) for wheat; applying approximately 85.2kg N ha^{-1} (34.5lbs N ac^{-1})
- broadcast applied by hand on May 30, 2014, prior to heading
- Irrigation applied immediately following treatment application, May 30, 2014

▪ Urea + Agrotain® Ultra Treatment (UAG)-

- 347g of urea prills (46% N) per plot, based upon an application rate of 84.06kg ha^{-1} (75lbs ac^{-1}) for wheat, treated with the NBPT

[1] There is no recommended treatment rate for N-Yield® use with compost. Therefore, treatment rate was calculated using the same treatment ratio by weight as is recommended for use with urea.

N stabilizer additive Agrotain® Ultra (26.7% NBPT by weight) at the recommended application rate of 3qts ton^{-1}, or approximately 1.1ml for every 347g of urea; applying approximately 85.2kg N ha^{-1} (34.5lbs N ac^{-1})

  - Broadcast applied by hand on May 30, 2014, prior to heading
  - Irrigation applied immediately following treatment application, May 30, 2014

- Urea + N-Yield™ Treatment (UNY)-
  - 347g of urea prills (46% N) per plot, based upon an application rate of 84.06kg ha^{-1} (75lbs ac^{-1}) (34.5lbs N ac^{-1}) for wheat, treated with the NBPT N stabilizer additive N-Yield™ (20% NBPT by weight) at the recommended application rate of 3qts ton^{-1}, or approximately 1.1ml for every 347g of urea; applying approximately 85.2kg N ha^{-1} (34.5lbs N ac^{-1})
  - Broadcast applied by hand on May 30, 2014, prior to heading
  - Irrigation applied immediately following treatment application, May 30, 2014

Table 2.1 Lab analysis of compost used for both growing seasons, retrieved from West Texas A&M University feed yard compost site.

Parameters	**Analysis**	**Total Content (kg kg^{-1})**	**Estimated Available First Year (kg kg^{-1})**
Nitrogen	0.807%	0.008	0.004
Phosphorus (P_2O_5)	0.747%	0.007	0.007
Potassium (K_2O)	0.725%	0.009	0.009
Organic Matter	15.0%	0.15	N/A
C:N Ratio	10.8 ratio	N/A	N/A

Figure 2.3 Preparation of compost treated with NBPT

Figure 2.4 Preparation of NBPT treated compost

Field experiments for the 2014-2015 growing season were set up similarly to the previous year's wheat crop. However, unlike the previous year's treatments, treatments for this growing season consisted of four treatments and a single control, each consisting of four replications with the exception of the untreated compost treatment, which was replicated eight times (Figure 2.5).

Figure 2.5 2014-2015 wheat plot map and designated treatment applications

NORTH↑	A	B	C	D
1	U	Cntrl	Comp	UAG
2	UAG	Cntrl	Comp	UNY
3	Comp	Cntrl	UAG	UAG
4	Comp	Comp	Cntrl	U
5	U	Comp	Comp	UNY
6	U	Comp	UNY	UNY

Control = Cntrl

Compost = Comp

Urea = U

Urea + Agrotain® Ultra = UAG

Urea + N-Yield™ = UNY

The decision to eliminate the treatment containing compost treated with the NBPT N stabilizing product N-yield™ and using only untreated compost as a treatment was made because NBPT is a urease inhibitor and therefore should have no effect on compost N. Also, unlike the previous growing season, the compost treatments were not applied prior to planting. All treatments were topically applied on May 4, 2015, preceding heading.

One other difference in treatments for the 2014-2015 growing season was that treatment three consisted of urea prills treated with the N stabilizer additive Agrotain® Advanced, of which the formulation is 30% NBPT by weight, instead of Agrotain® Ultra. Agrotain® Advanced was used instead of Agrotain® Ultra, because Agrotain® Ultra was not obtainable at the time of treatment application. Treatment of the urea with Agrotain® Advanced was at the recommended application rate of 0.002ml g^{-1} of urea (2qts ton^{-1}), or approximately 0.724ml for every 347g of urea (Figure 2.6).

Figure 2.6 Urea treatments containing NBPT (Agrotain® Advanced and N-yield™)

Ground Site Preparation

In both growing seasons, 24 field plots of equal size, 6.096 meters X 3.048 meters (20 feet X 10 feet), were laid out in a four by six grid. Each plot contained approximately .0046 acre (200 ft^2).

Prior to cultivation in both growing seasons, the plots were treated with a pre-emergent herbicide (Roundup®) to assist in the control of weeds. Irrigation water was applied to soften the soil bed for plowing, which had become impenetrable due to prior years' drought conditions. In early October all 24 plots were plowed east to west, using conventional tillage practices, which consisted of disc plowing the seed bed approximately six inches deep prior to planting. Each plot consisted of four rows with wheat planted on 76.2cm (30in.) centers (Figure 2.7).

Figure 2.7 Disking plot area prior to planting 2014-2015 wheat crop

Wheat Crop

Hard red winter wheat (TAM 111 variety) was planted on October 4, 2013, for the 2013-2014 growing season, and on September 18, 2014, for the 2014-2015 growing season. The seeding rate was 1,111,975 seeds per hectare (450,000 seeds per acre) across all 24 field plots for both years.

Due to limited precipitation following planting in both growing seasons, irrigation was applied (Figure 2.8) at regular intervals, beginning October 30, 2013, through November 20, 2013, and beginning October 8, 2014, through October 20, 2014 to insure adequate growth prior to dormancy. Additional irrigation was applied, depending on climate conditions, beginning April 1, 2014, through June 18, 2014, for the 2013-2014 growing season, and beginning April 1, 2014, through April 27, 2014, for the 2014-2015 growing season, prior to harvest. Harvest of wheat crop was completed on July 28, 2014, and July 1, 2014, for the 2013-2014 and 2014-2015 growing seasons, respectively.

Figure 2.8 Irrigation system set up for wheat field plots

Precipitation and Irrigation

Precipitation accumulation for the 2013-2014 growing season (October 1, 2013 through July 28, 2014) was approximately 33.22cm (13.08in) (The Climate Corporation, 2015) with the mean precipitation for this period being approximately 37.78cm (14.87in) (NOAA, 2015), while the precipitation accumulation for the 2014-2015 growing season (September 18, 2014 through July 1, 2015) was approximately 53.30cm (20.98in) (The Climate Corporation, 2015) with the mean precipitation for this period being approximately 44.30cm (17.44in) (NOAA, 2015). In addition, drought conditions made it necessary to apply irrigation at regular intervals and levels during each growing season to insure survival of the wheat crop. Irrigation amounts for the 2013-2014 growing season totaled 37.05cm (14.59in) with the mean irrigation amount for this period being 0.04cm (0.02in), while the total irrigation applied during the 2014-2015 growing season was 9.76cm (3.76in) with the mean irrigation amount being 0.03cm (0.01in). Total precipitation and irrigation combined was approximately 70.28cm (27.67in) with the daily mean total combined precipitation and irrigation being 0.23cm (0.09in) for the 2013-2014 growing season, with total combined accumulations of 63.06cm (24.83in) with the daily mean total combined precipitation and irrigation being 0.21cm (0.08in) for the 2014-2015 growing season.

Harvest Samples

The 2013-2014 wheat crop was harvested on July 28, 2014. Due to the production of a limited stand and weed issues, it was resolved that approximately 75 plants would be harvested from each test plot in order to obtain adequate samples for analysis (Figure 2.9). All above ground biomass was collected and labeled for analysis. Samples were dried in an oven at 60°C for a period of seven days. Once dried, the heads were separated by hand from the straw and were threshed to separate the grain from the straw and chaff at the Texas A&M AgriLife Facility (Bushland, TX). The grain was then ground into flour at the WTAMU Greenhouse. Both the grain flour and straw samples were delivered to Servi-Tech Laboratories (Amarillo, TX), for quality analysis. The grain flour was analyzed for crude protein, Ca, P, Mg, K, S, Na, Zn, Fe, Mn, Cu, and nitrate nitrogen (NO_3-N). The straw samples were analyzed for total N, P, K, Ca, Mg, S, Zn, Fe, Mn, Cu, B, and Na content.

Figure 2.9 2014 wheat harvest

The 2014-2015 wheat crop was harvested on July 1, 2015. Unlike the 2013-2014 wheat crop, the 2014-2015 wheat crop produced a stand that was sufficient for harvest of the test plots using a meter square (Figure 2.10). A single sample from each plot was harvested. All above ground biomass located within the meter square boundaries was collected and labeled for analysis. Samples were dried in an oven at 60°C for an eight day period. Once dried, the heads were separated by hand from the straw, counted and threshed to separate the grain from the chaff at the Texas A&M AgriLife Facility (Bushland, TX). The grain and straw samples were sent to Servi-Tech Laboratories (Amarillo, TX), for equivalent quality analysis as the previous year.

Figure 2.10 2015 wheat harvest using meter square

Statistical Analysis

All statistical data analysis was conducted using SAS© (v9.4 TS Level 1M2, Copyright 2002-2012 by SAS Institute, Inc., Cary, NC, USA). Statistically significant differences were ascertained at $\alpha = 0.05$.

The nutrient content data for each year's harvested wheat grain and straw were analyzed separately, then combined and analyzed for total nutrient content for each treatment group for each year. Analysis of variances (ANOVA) were calculated for N, P, K, and S content for both the 2014 and 2015 harvested wheat straw and grain, in order to identify any significant differences among treatments for each year's harvest.

When results of the ANOVA produced significant differences, a means separation test was conducted using Tukey's HSD.

Results and Discussion

Nutrient Content

Lab analysis of the harvested wheat for the 2014 harvest year showed that the straw and grain removed from the plots treated with the urea treatments containing NBPT (Treatments UAG and UNY) contained the largest quantities of N, with the treatment means for straw UAG being 1.30% and UNY being 1.36%, and the treatment means for grain UAG being 3.30% and UNY being 3.52% (Figures 2.11 and 2.12). Similar results for phosphorus (P) (Figures 2.15 and 2.16), potassium (K) (Figures 2.17 and 2.18), and sulfur (S) (Figures 2.19 and 2.20) were also found among treatments, with treatments UAG and UNY containing the highest percentages of these nutrients. However, analysis of the harvested wheat for the 2015 harvest year showed that the largest amounts of nutrient contents varied among treatments (Figures 2.13 and 2.14, and 2.21 through 2.26).

In 2014, Treatments UNY and UAG produced the highest amounts of N content in both the wheat straw and grain, while in 2015, Treatment UNY Treatment U produced the highest amounts of N content in both the wheat straw and grain (Figures 2.11- 2.14). Further, while ANOVA test results evidenced significant differences among treatments related to straw N content for 2014 ($p \leq 0.0001$) and 2015 ($p \leq 0.0141$), and produced significant differences ($p \leq 0.0001$) among treatments related to grain N content for both 2014 and 2015, no statistical differences were found among Treatments U, UAG or UNY regarding N content for wheat straw or grain for either the 2014 or 2015 growing season. However, Tukey's HSD test results determined that differences existed between treatments relative to N, P, K, and S nutrient contents as seen in Table 2.1 and Table 2.2

for the 2014 and 2015 wheat crops, respectively. In both years, no statistical differences were found among any of the urea treatments, untreated or treated.

Figure 2.11 2014 wheat straw N content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

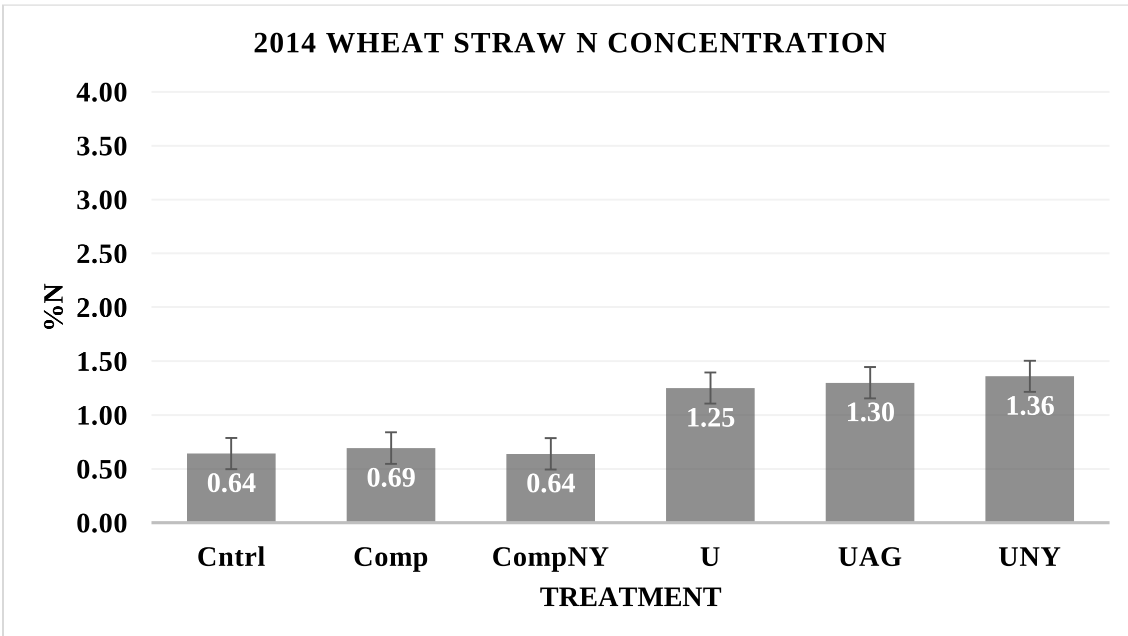


Figure 2.12 2014 wheat grain N content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

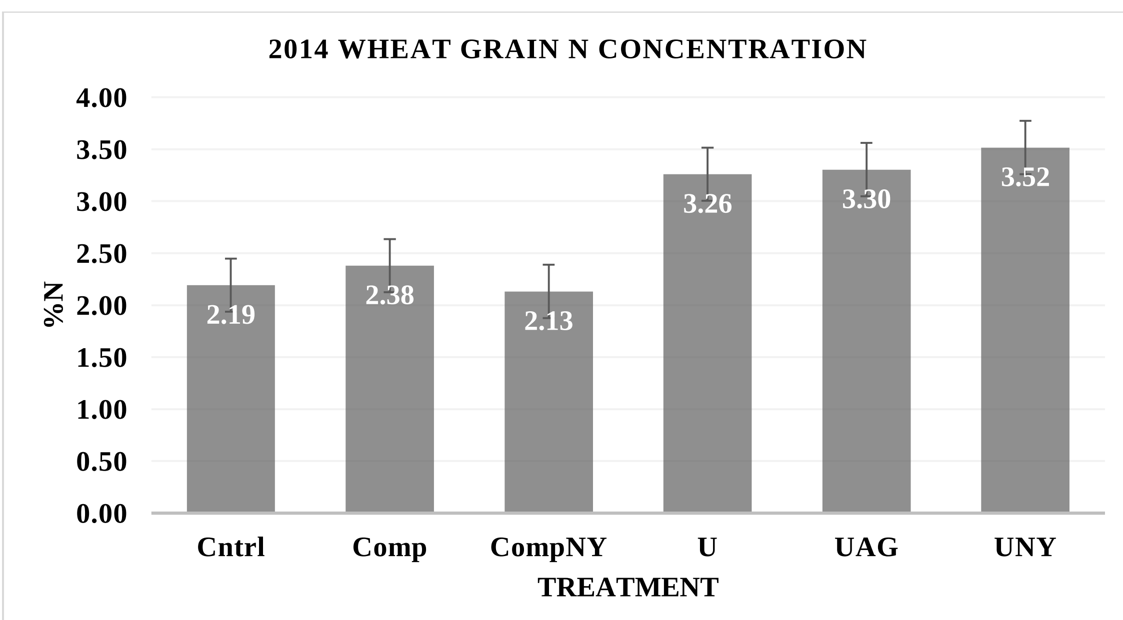


Figure 2.13 2015 wheat straw N content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

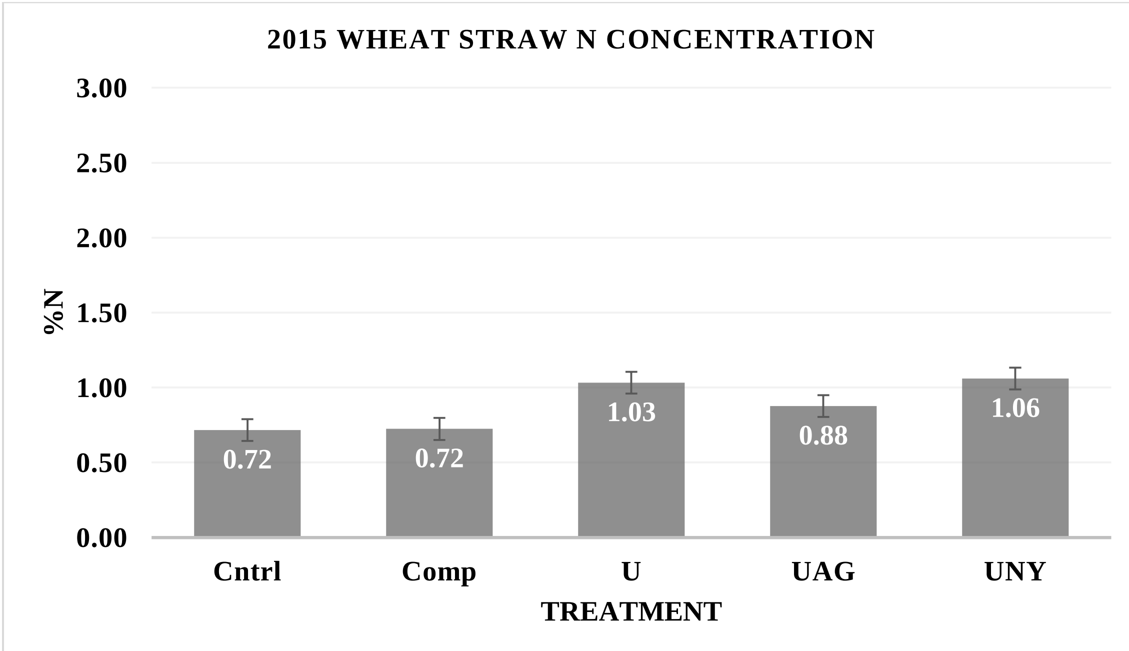
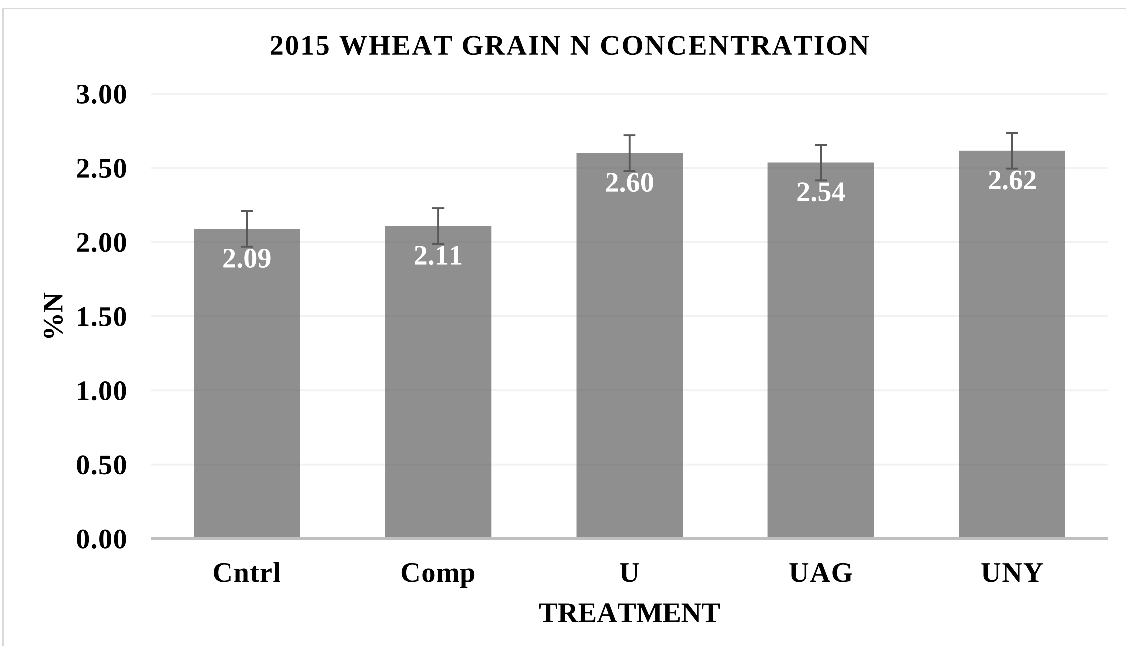


Figure 2.14 2015 wheat grain N content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.



In 2014, UNY was also consistently higher in nutrient content for P, K, and S (Figures 2.15 through 2.20), with significant differences ($p \leq 0.0001$) being found among treatments as shown in Table 2.1. However, in 2015, while UNY was still higher than the Cntrl and Comp in K, and S content (Figures 2.21 through 2.24), it was not highest in P content (Figure 2.25 and 2.26). Further, UNY only exhibited significant differences ($p \leq 0.0098$) when compared to the Cntrl and Comp, in 2015, and was not statistically different from U or UAG in N, P, K, or S concentrations for either year (Table 2.2).

Figure 2.15 2014 wheat straw P content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

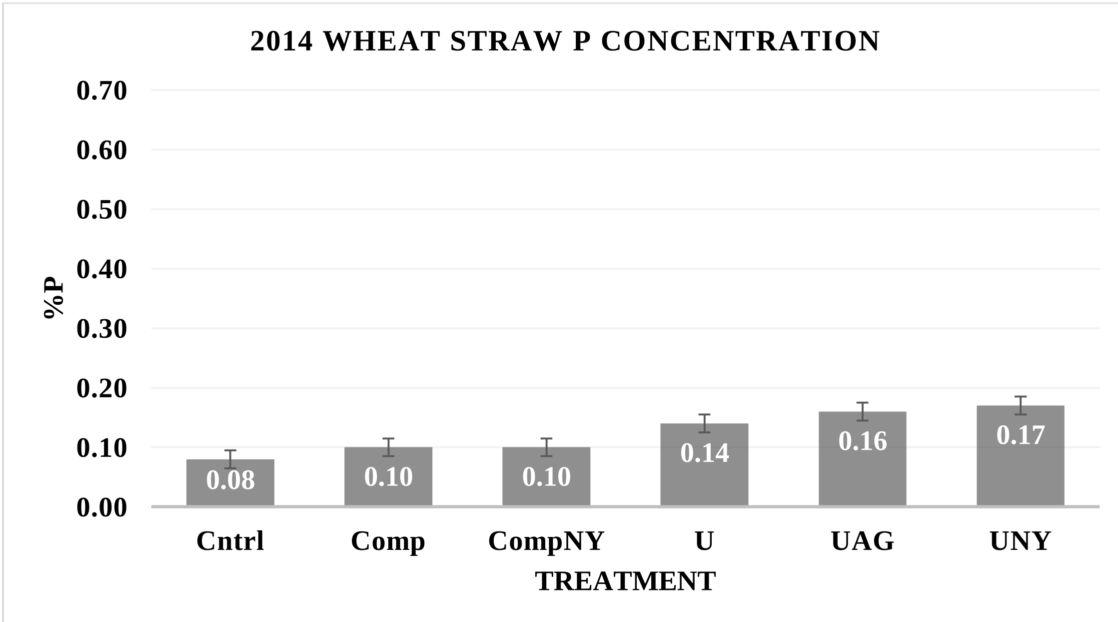


Figure 2.16 2014 wheat grain P content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

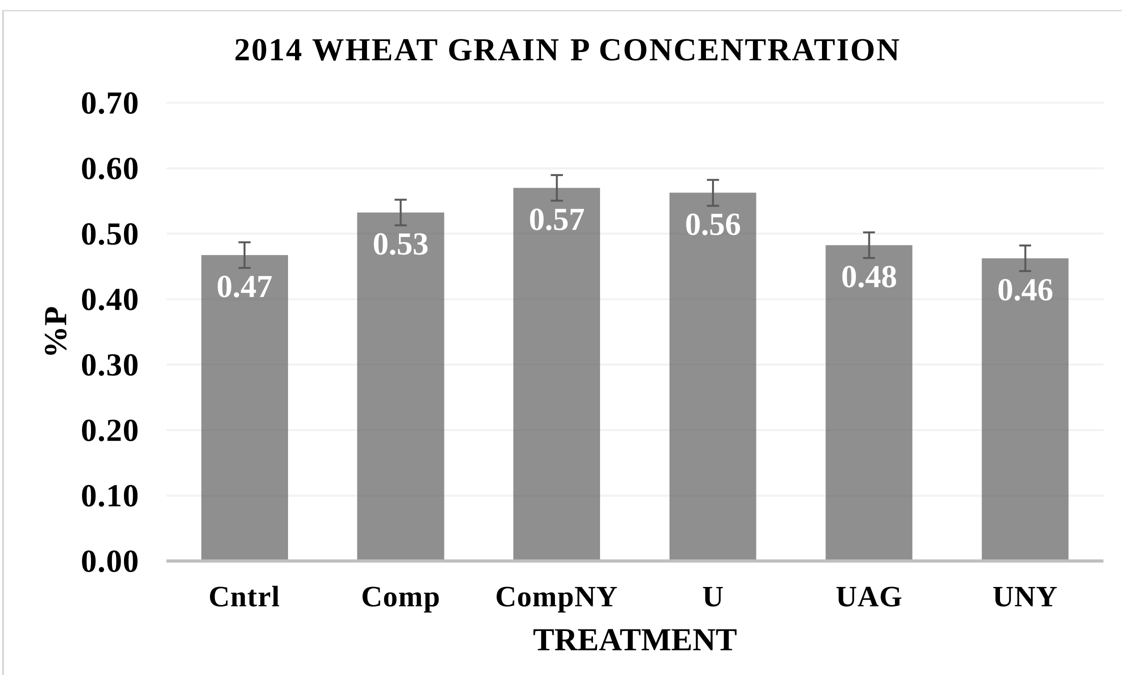


Figure 2.17 2014 wheat straw K content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

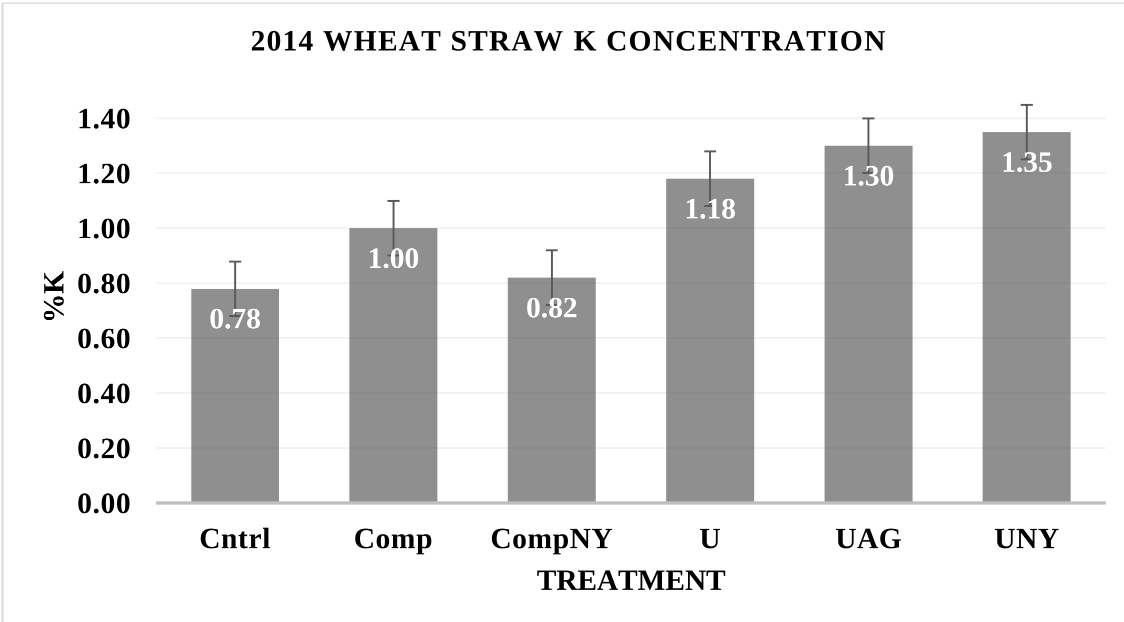


Figure 2.18 2014 wheat grain K content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

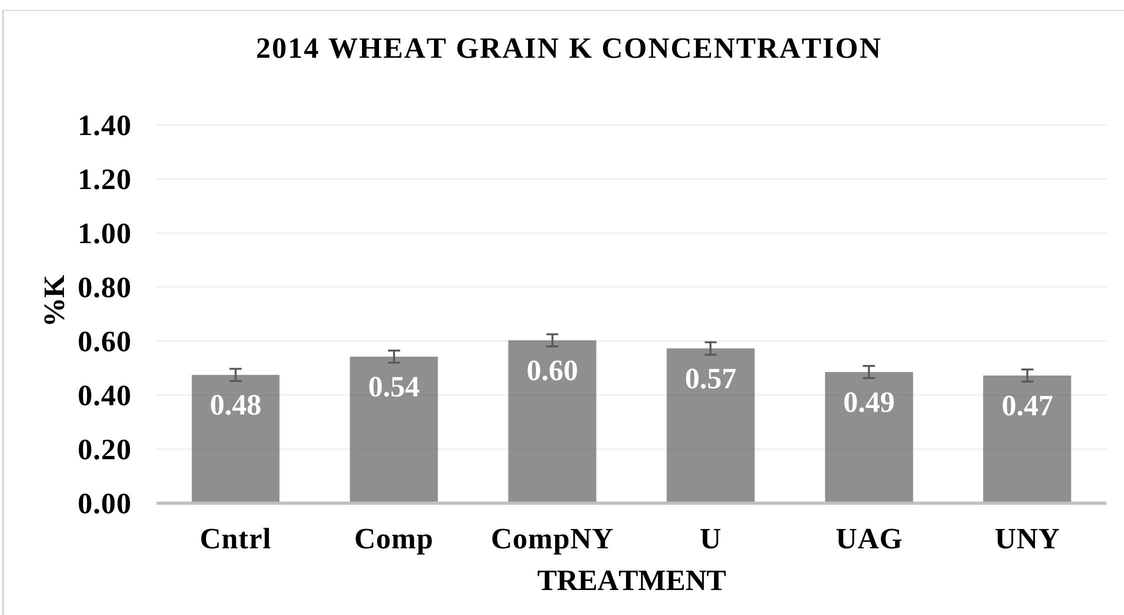


Figure 2.19 2014 wheat straw S content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

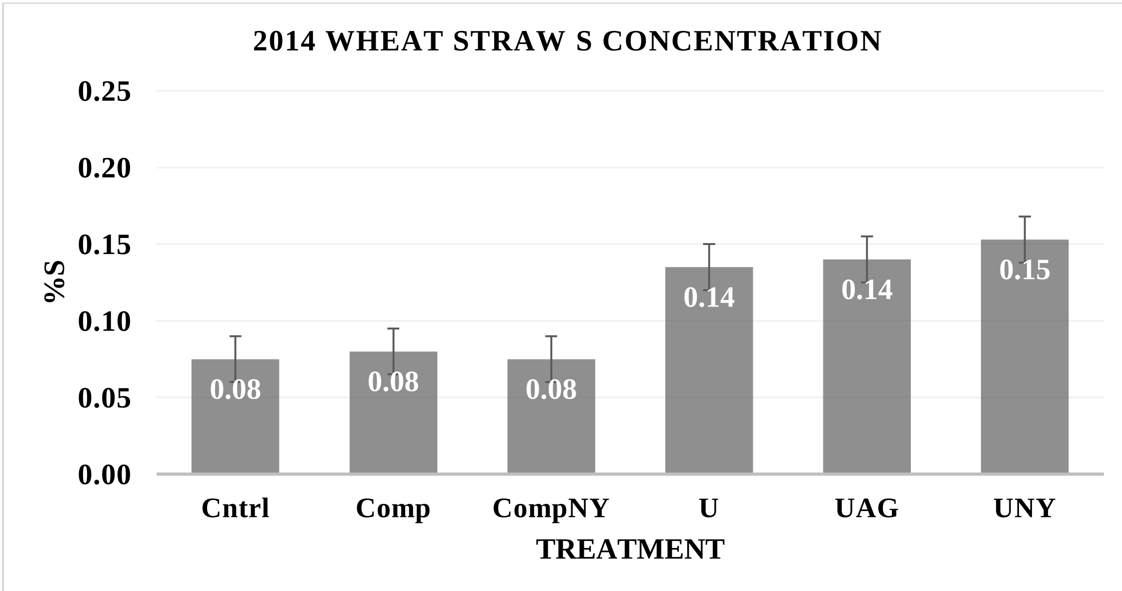


Figure 2.20 2014 wheat grain S content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

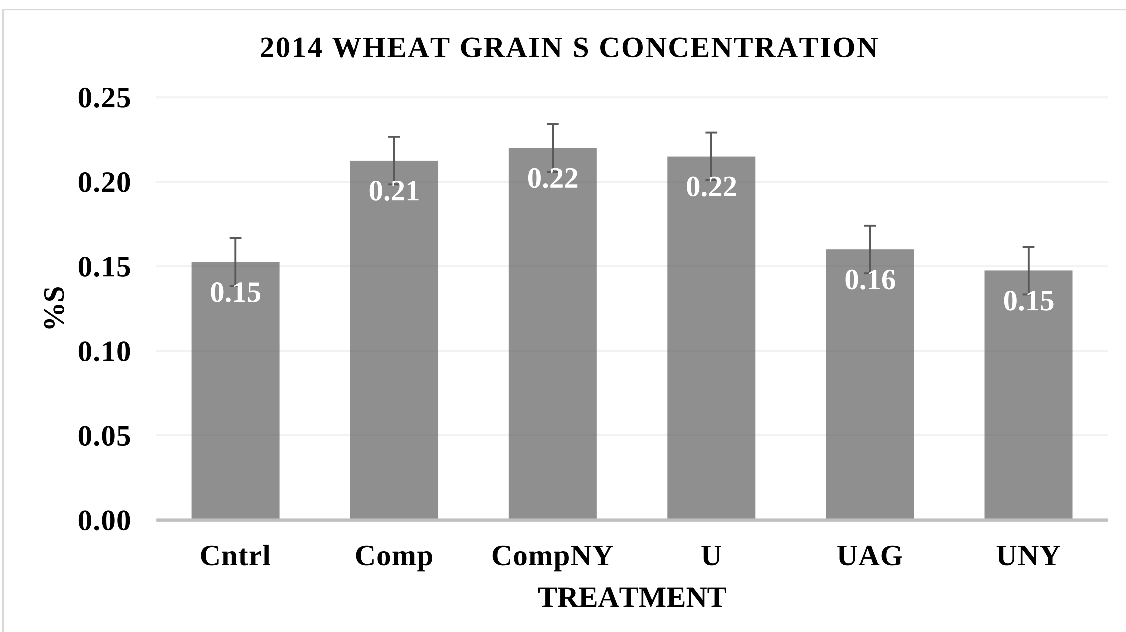


Figure 2.21 2015 wheat straw K content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

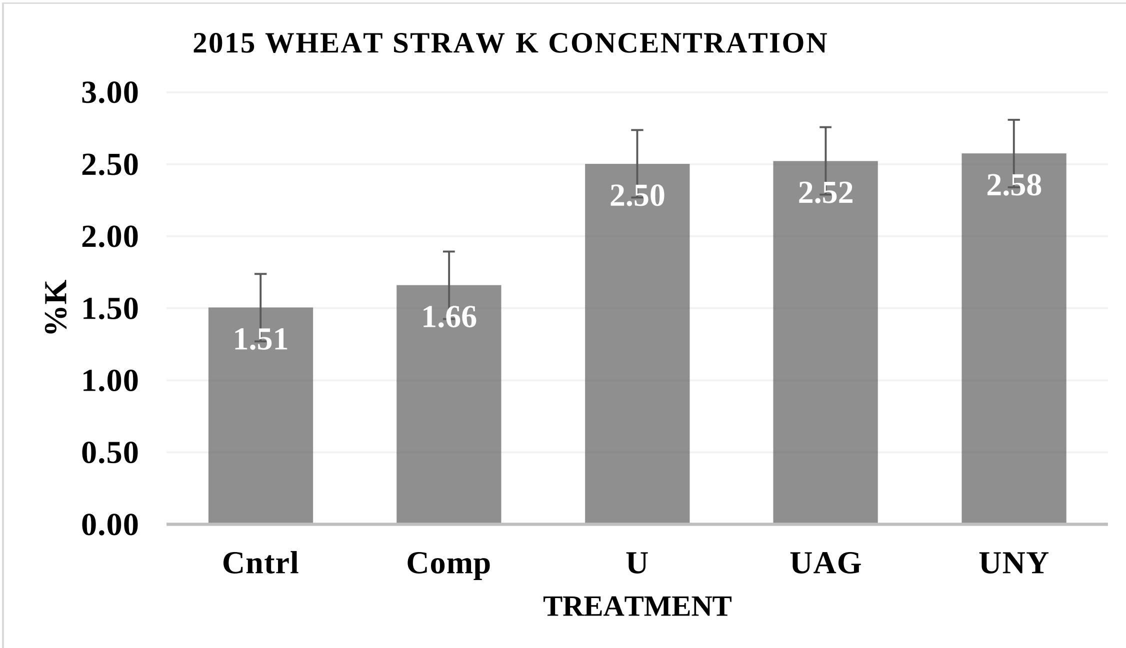


Figure 2.22 2015 wheat grain K content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

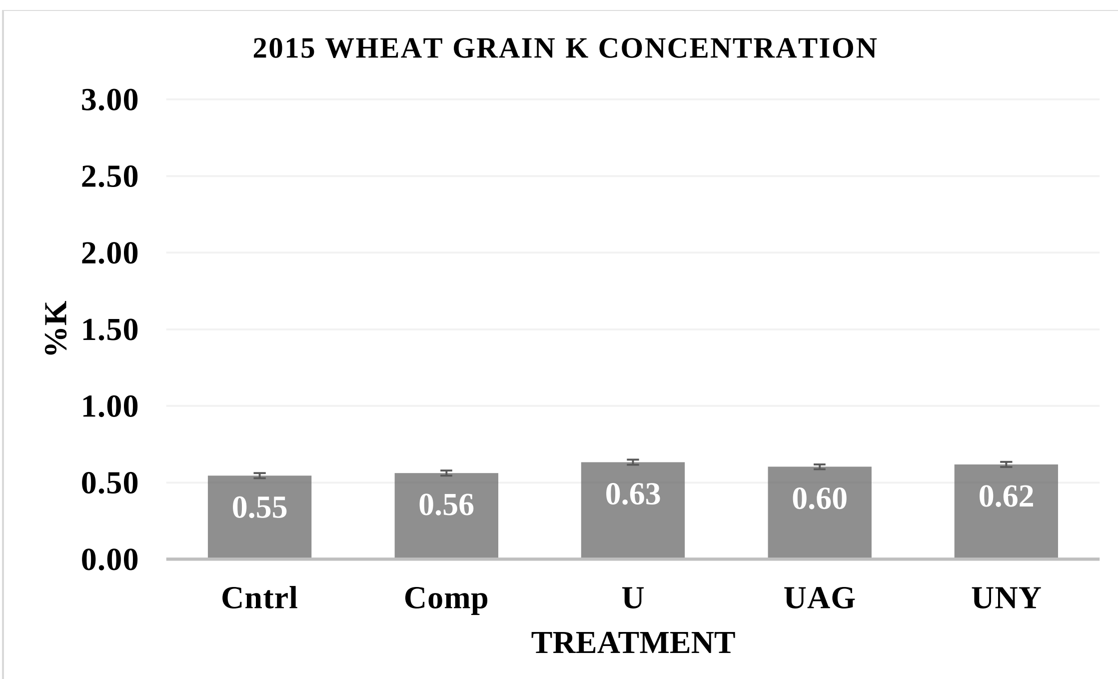


Figure 2.23 2015 wheat straw S content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

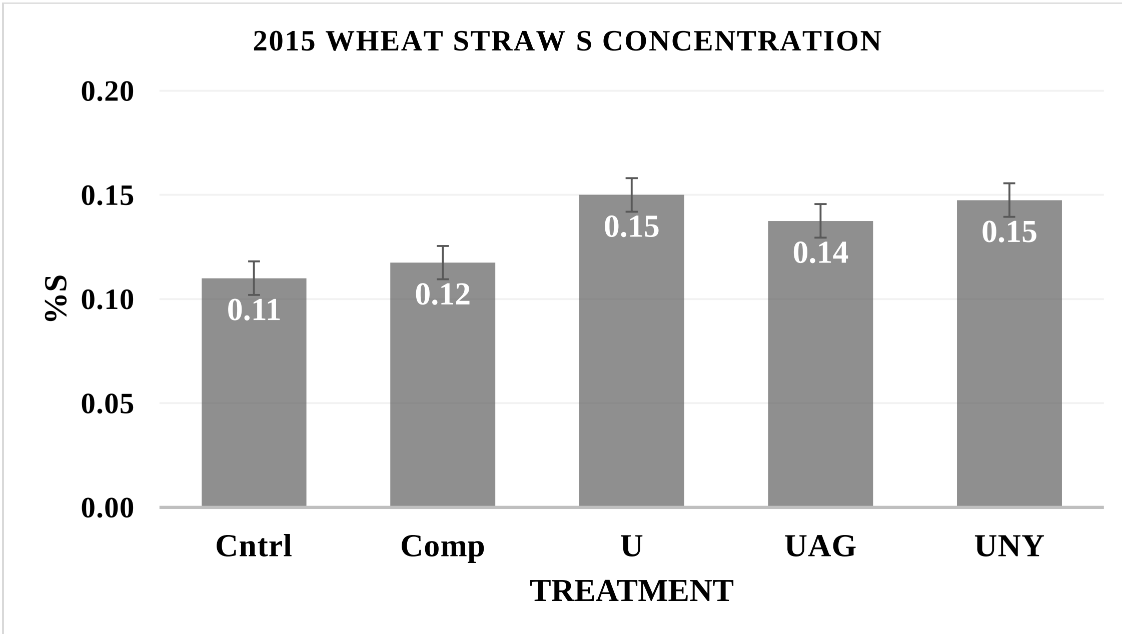


Figure 2.24 2015 wheat grain S content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

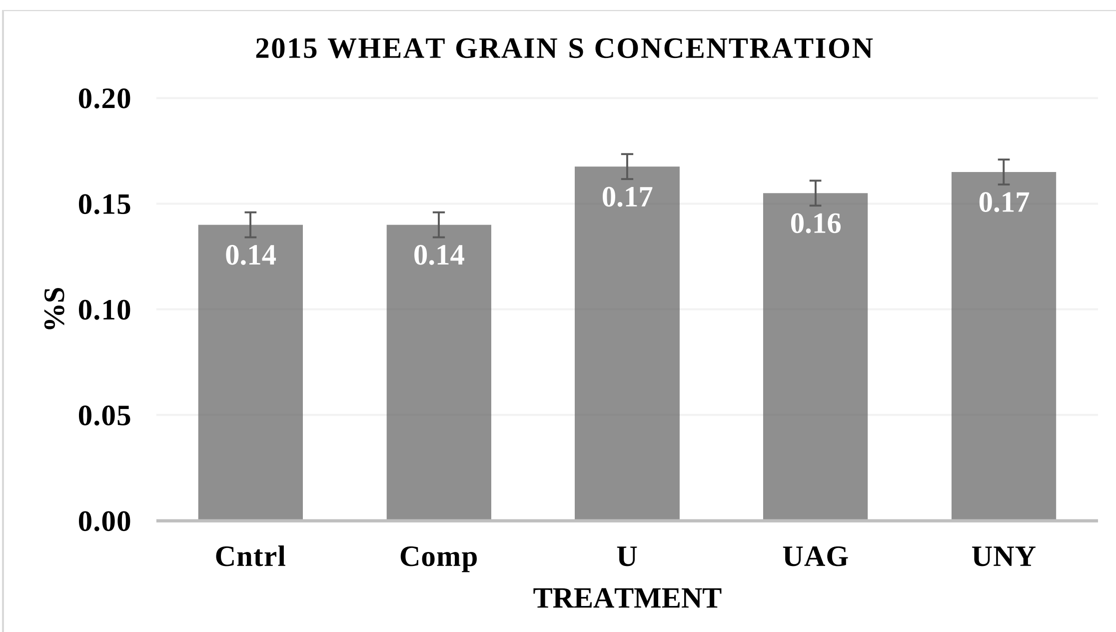


Figure 2.25 2015 wheat straw P content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

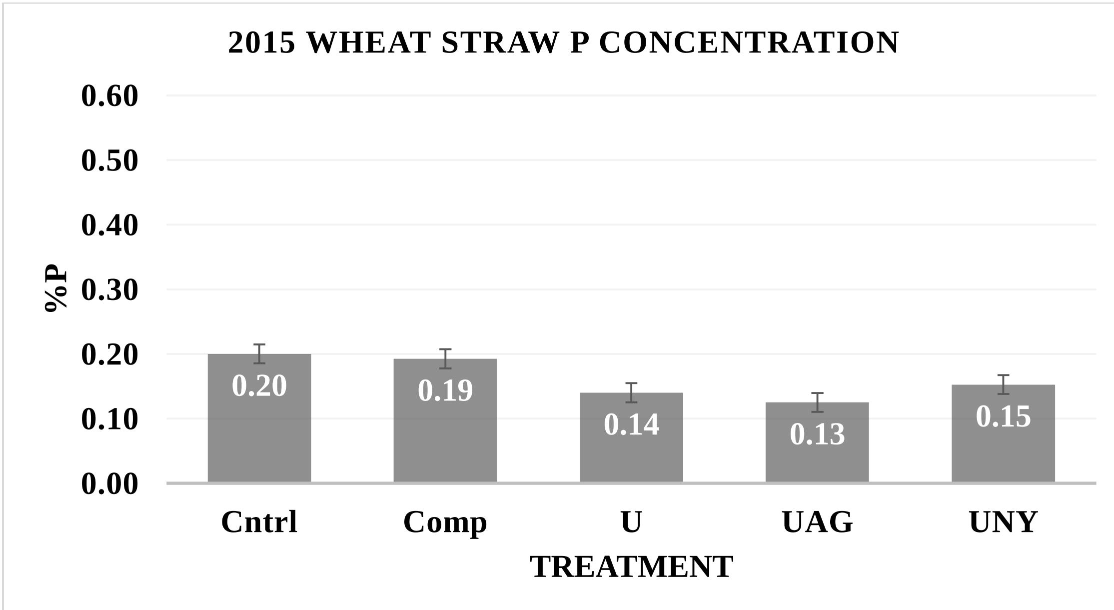


Figure 2.26 2015 wheat grain P content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

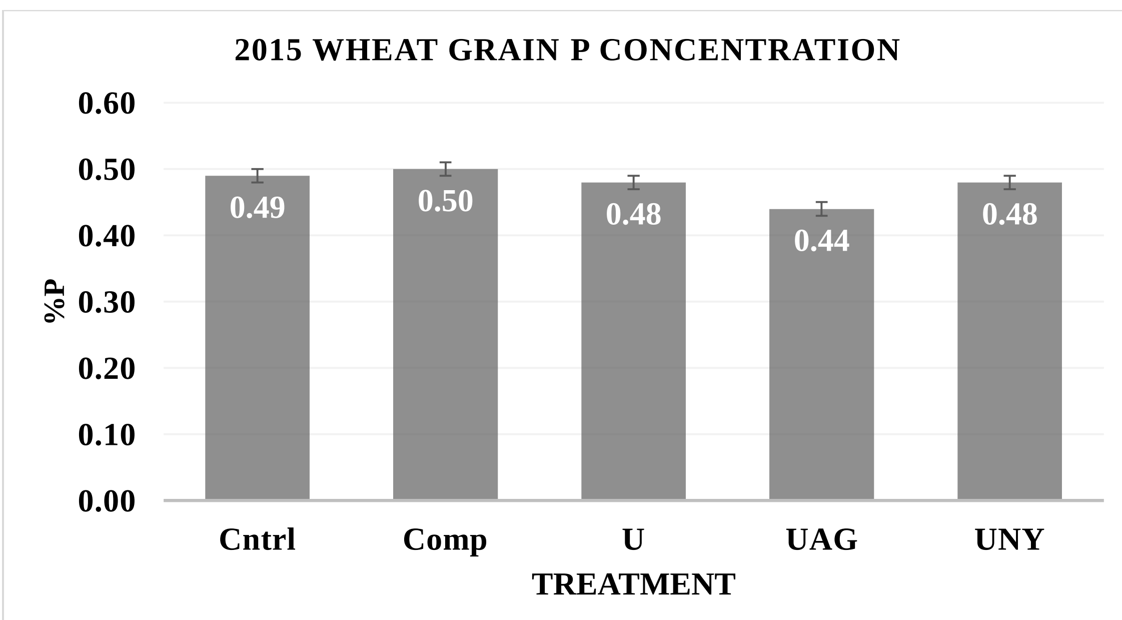


Table 2.2 Mean nutrient content percentages of 2014 wheat straw and grain (percentage on dry weight basis). Means in the same column within the same nutrient type with the same letter are not significantly different using Tukey's HSD (p<0.0001 for straw and p<0.0141 for grain).

Nutrient	Treatment	Straw	Grain
	CompNY	0.640^{a}	2.132^{a}
	Cntrl	0.642^{a}	2.192^{a}
N	Comp	0.692^{a}	2.380^{a}
	U	1.250^{b}	3.260^{b}
	UAG	1.300^{b}	3.304^{b}
	UNY	1.360^{b}	3.516^{b}
	Cntrl	0.077^{a}	0.467^{ab}
	Comp	0.095^{ab}	0.482^{ab}
P	U	0.137^{bcd}	0.532^{bc}
	UAG	0.155^{cd}	0.562^{c}
	UNY	0.170^{d}	0.570^{c}
	Cntrl	0.777^{a}	0.475^{a}
	CompNY	0.817^{a}	0.472^{a}
K	Comp	1.002^{ab}	0.485^{ab}
	U	1.185^{b}	0.542^{bc}
	UAG	1.305^{b}	0.572^{c}
	UNY	1.350^{b}	0.602^{c}
	CompNY	0.075^{a}	0.147^{a}
	Cntrl	0.075^{a}	0.152^{a}
S	Comp	0.080^{a}	0.160^{a}
	U	0.135^{b}	0.212^{b}
	UAG	0.140^{b}	0.215^{b}
	UNY	0.152^{b}	0.220^{b}

Table 2.3 Mean nutrient content percentages of 2015 wheat straw and grain (percentage on dry weight basis). Means in the same column within the same nutrient type with the same letter are not significantly different using Tukey's HSD (p≤0.0001 for both straw and grain).

Nutrient	Treatment	Straw	Grain
N	Cntrl	0.716[a]	2.088[a]
	Comp	0.724[ab]	2.108[a]
	UAG	0.876[ab]	2.536[b]
	U	1.032[ab]	2.600[b]
	UNY	1.060[b]	2.616[b]
P	UAG	0.125[a]	0.442[a]
	U	0.140[a]	0.480[a]
	UNY	0.152[ab]	0.477[a]
	Comp	0.192[bc]	0.495[a]
	Cntrl	0.200[bc]	0.485[a]
K	Cntrl	1.505[a]	0.545[a]
	Comp	1.660[a]	0.562[a]
	U	2.502[b]	0.632[a]
	UAG	2.522[b]	0.602[a]
	UNY	2.575[b]	0.617[a]
S	Cntrl	0.110[a]	0.140[a]
	Comp	0.117[ab]	0.140[a]
	UAG	0.137[ab]	0.155[ab]
	UNY	0.147[b]	0.165[ab]
	U	0.150[b]	0.167[b]

Observations of P, K, and S concentrations indicate that while application of urea fertilizer improves the overall content of these nutrients over that of the control and compost treatments, treatment of urea with NBPT does not notably raise P, K or S content over that of untreated urea. Further, specific analysis of the wheat N content data suggests application of untreated urea or urea treated with NBPT significantly improves N concentrations by approximately 50% in wheat as compared to the control and compost treatments. This is an expected reaction, by simple reason that the application of urea fertilizer substantially increases the amount of nitrogen available in the soil. However, it is notable to acknowledge that in wheat, urea treated with NBPT does not produce results that are statistically different from those of untreated urea.

Summary

It can be concluded from the data collected and statistically analyzed, that urea fertilizer, untreated and that treated with the urease inhibitor, NBPT, increases N content of wheat at harvest when compared to wheat grown with compost, or without N fertilizer. The harvested wheat grown using the treatment containing the NBPT product, N-Yield™, ranked highest in N concentration for both harvest years (Tables 2.1 and 2.2). It was anticipated that the use of NBPT in conjunction with urea would notably raise N concentrations within the plant. However, based upon statistical analysis, results showed that although wheat grown using urea treated with the NBPT product, N-Yield™ had the highest N concentrations in both the wheat straw and grain, it did not significantly increase the N content over that of the wheat grown using untreated urea or the NBPT product Agrotain®.

These results are consistent with the conclusions made by McClallen (2014), wherein it was observed that wheat fertilized with urea treated with NBPT showed a significant difference in protein content over that of unfertilized wheat, but did not produce yields that were statistically different than those produced by wheat grown with untreated urea applied.

CHAPTER THREE

CORN EXPERIMENT

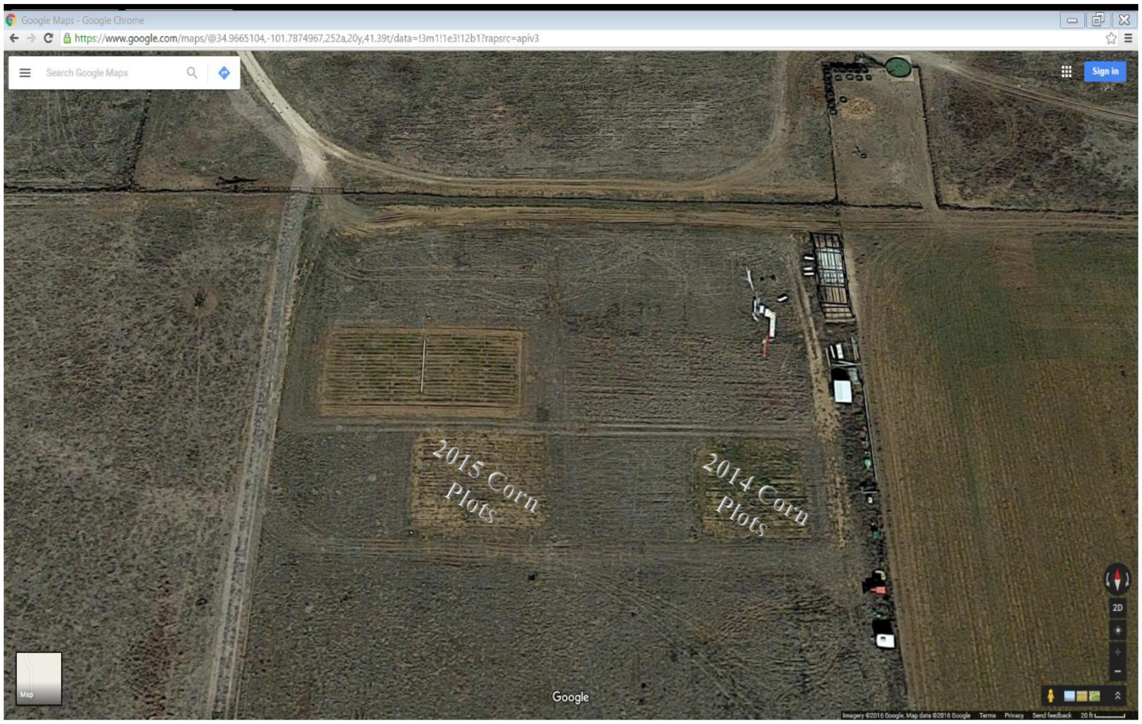
Materials and Methods

Experimental Field Site

A field experiment to determine the effects of the urease inhibitor NBPT on N uptake and N content in field corn was conducted for two consecutive growing seasons (2014 and 2015) at the West Texas A&M University Nance Ranch, located approximately five miles East/Southeast of Canyon, Texas. The corn field research plots were located immediately adjacent to the previously described wheat plots (Figure 3.1).

The experimental site has a climate that is semi-arid. Average annual rainfall is generally <50cm, of which most is accumulated during the spring and early summer months (March - June). This climate region is prone to drought. The mean air temperatures are 11.8 °C (53.3°F) for the winter months (December – February), 22.6 °C (72.7°F) for the spring months (March – May), 32.4 °C (90.4°F) for the summer months (June – August), and 17.1 °C (62.8°F) for the fall months (September – November) (US Climate Data, 2015).

Figure 3.1 Arial view of West Texas A&M University Nance Ranch Field Research Plots. 34° 58’ 05” N, 101° 47’ 14” W. Adapted from http://www.gosur.com/map/?satellite=1&z=20&ll=34.968455,-101.787442&t=hybrid&lang=en



Soil

According to the USDA-NRCS website, the soil type at the experimental site is 100% Olton clay loam, 0 to 1 percent slopes (pH 6.6 - 8.4) (fine, mixed, superactive, thermic Aridic Paleustolls). The Olton series is comprised of “…very deep, well drained, moderately slowly permeable soils,” (USDA-NCRS, 2015). The farmland classification for Olton Clay Loam is designated as prime farmland (USDA-NCRS, 2015). Most of the area that is comprised of Olton clay loam is irrigated cropland used for the production of cotton, sorghum and winter wheat (USDA-NCRS, 2015).

Soil Sampling

Soil samples were collected and analyzed pre-plant and post-harvest for each growing season to determine nutrient availability. Composite samples were obtained separately for each of the designated treatment plots. Three samples, 15.24cm– 20.32cm deep, were collected and composited from random locations throughout each plot. A total of 84 composite soil samples were collected and analyzed for nutrient content. There were a total of 48 samples (24 plots X 2) for the 2014 harvest season and 36 samples (18 plots X 2) for the 2015 harvest season. All composite samples from each plot were delivered to Servi-Tech Laboratories (Amarillo, Texas), and individually analyzed for pH, salts, OM, total N, P, K, S, Ca, Mg, Na, Zn, and CEC.

2014 Treatments and Application

Treatments and their application were comparable to those used for the 2014-2015 wheat crop experiment, which contained four treatments and a single control, with four replications each, with the exception of the compost treatment, of which none was treated with any NBPT additive and contained eight replications. Further, the compost treatments were applied identically to those used in the 2013-2014 wheat crop experiment, with the compost being disc plowed into the seed bed prior to planting. Randomization of the plots was conducted in the same manner as the wheat plots (Figure 3.2).

Figure 3.2 2014 corn plot map and designated treatment applications

NORTH↑	**A**	**B**	**C**	**D**
1	Comp	UAG	UNY	UNY
2	Comp	Cntrl	Cntrl	Comp
3	U	Comp	U	Cntrl
4	UNY	UAG	Comp	UAG
5	UAG	U	Comp	Comp
6	Cntrl	U	Comp	UNY

Control = Cntrl   Urea + Agrotain® Ultra = UAG   Urea = U

Compost = Comp   Urea + N-Yield™ = UNY

Treatments were prepared and applied as follows:

- Control (Cntrl)-
  - No compost or fertilizer was applied to the designated plots
- Compost (Comp)-
  - 8.34kg (18.4lbs) of compost per plot; rate of compost application was calculated based upon 4483.40kg ha^{-1} (2 tons ac^{-1}); applying approximately 16.8kg N ha^{-1} (15lbs N ac^{-1}) according to compost analysis data (Table 2.1)

- Applied evenly throughout each of four designated plots, then tilled into the soil bed immediately prior to planting on May 30, 2014

▪ Urea (U)-

- 694g of urea prills (46% N) per plot, based upon an application rate of 168.13kg ha^{-1} (150lbs ac^{-1}) for corn (Figure 3.3); applying approximately 170.4kg N ha^{-1} (69lbs N ac^{-1})
- broadcast applied by hand August 15, 2014, approximately 75 days following planting
- Irrigation applied immediately following treatment application, on August 15, 2014

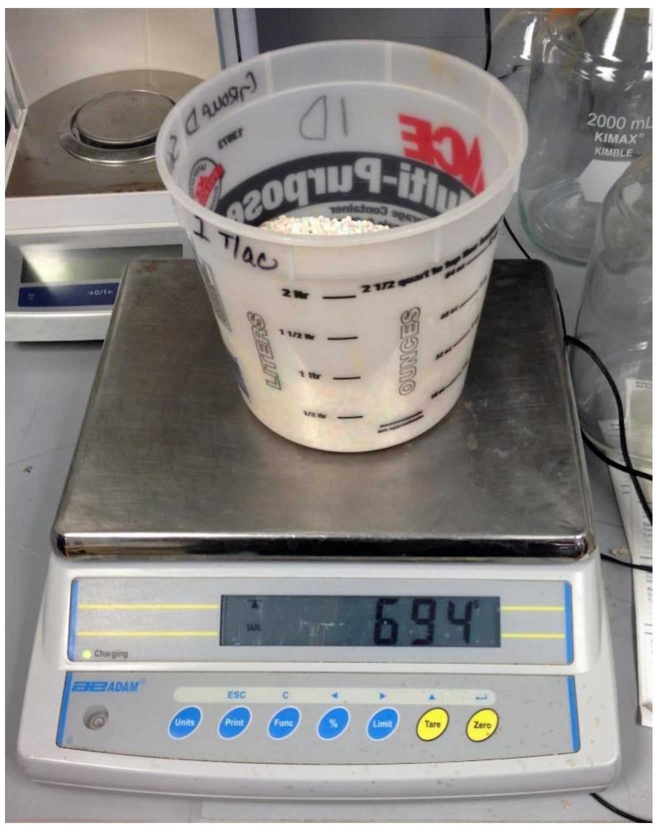
▪ Urea + Agrotain® Ultra (UAG)-

- 694g of urea prills (46% N) treated with the NBPT N stabilizer additive Agrotain® Ultra (26.7% NBPT by weight) at the recommended application rate of three quarts per ton (2.2ml for every 694g urea); applying approximately 170.4kg N ha^{-1} (69lbs N ac^{-1})
- broadcast applied by hand August 15, 2014, approximately 75 days following planting
- Irrigation applied immediately following treatment application, on August 15, 2014

▪ Urea + N-yield™ (UNY)-

- 694g of urea prills (46% N) treated with the NBPT N stabilizer additive N-yield™ (20% NBPT by weight) at the recommended application rate of 3qts ton^{-1} (2.2ml for every 694g urea); applying approximately 170.4kg N ha^{-1} (69lbs N ac^{-1})
- broadcast applied by hand August 15, 2014, approximately 75 days following planting
- Irrigation applied immediately following treatment application, on August 15, 2014

Figure 3.3 Urea measured for 2014 and 2015 corn treatments 3, 4 and 5



Irrigation was applied immediately following application of all treatments and was continued at regular intervals and levels until September 18, 2014, just prior to harvest.

2014 Ground Site Preparation

For the 2014 growing season, 24 field plots of equal size, 6.096 meters X 3.048 meters (20 feet X 10 feet), were laid out in a six by four grid, immediately adjacent to the wheat plots described above. Each individual plot contained approximately 18.581m^2 (200ft^2) or 0.002 hectare (.005 acre), with the total plot area measuring 18.288 meters X 24.384 meters (60 feet X 80 feet), containing approximately 445.93m^2 or 0.045 hectare (0.111 acre).

Prior to cultivation, it was necessary to apply irrigation water to soften the soil bed for plowing, again as a result of drought conditions creating an impervious seed bed. The plots were also treated with a pre-emergent herbicide (Ortho® Weed B Gon®) to assist in the control of weeds. However, mid-season it became evident that weed control throughout the plots was to be a continuous problem (Figure 3.4). It became necessary to enact other physical forms of weed control, such as hoeing and operation of a weed eater, in order to effectively reduce the rapidly invading weed population.

Figure 3.4 2014 corn plots showing intense weed problem

As with the wheat crop, all corn plots were plowed east to west, using conventional tillage practices on May 30, 2014. Each plot consisted of four rows with corn planted on 76.2cm (30in) centers.

2015 Treatments and Application

Field experiments for the 2015 growing season were set up similarly to the 2014 corn crop. However, germination of the most easterly plots (column D) was not successful enough to produce a proper stand for adequate data collection in this study. Therefore, although treatments and their application were equivalent to those used for the 2014 corn crop, the treatments for the 2015 growing season consisted of only three replications each for the control and urea treatments (untreated and treated), and six replications for the compost treatments.

Treatments were prepared and applied as follows:

- Control (Cntrl)-
    - No compost or fertilizer was applied to the designated plots
- Compost (Comp)-
    - 8.34kg (18.4lbs) of compost per plot; rate of compost application was calculated based upon 4483.40kg ha^{-1} (2 tons ac^{-1}); applying approximately 16.8kg N ha^{-1} (15lbs N ac^{-1}) according to compost analysis data (Table 2.1)
    - Applied by hand August 31, 2015, approximately 58 days following planting; not incorporated into the soil bed
- Urea (U)-
    - 694g of urea prills (46% N) per plot, based upon an application rate of 168.13kg ha^{-1} (150lbs ac^{-1}) for corn (Figure 3.3); applying approximately 170.4kg N ha^{-1} (69lbs N ac^{-1})
    - Applied by hand August 31, 2015, approximately 58 days following planting
- Urea + Agrotain® Advanced (UAG)-
    - 694g of urea prills (46% N) treated with the NBPT N stabilizer additive Agrotain® Advanced (30% NBPT by weight) at the recommended application rate of 2qts ton^{-1} (1.45ml for every 694g urea); applying approximately 170.4kg N ha^{-1} (69lbs N ac^{-1})
    - Broadcast applied by hand August 31, 2015, approximately 58 days following planting

- Urea + N-yield™ (UNY)-
    - 694g of urea prills (46% N) treated with the NBPT N stabilizer additive N-yield™ (20% NBPT by weight) at the recommended application rate of 3qts ton^{-1} (2.2ml for every 694g urea); applying approximately 170.4kg N ha^{-1} (69lbs N ac^{-1})
    - broadcast applied by hand August 31, 2015, approximately 58 days following planting

Randomization of the plots resulted in a completely randomized plot design (Figure 3.5).

Figure 3.5 2015 corn plot map and designated treatment applications

NORTH↑	**A**	**B**	**C**	**D**
1	UAG	U	Cntl	Not viable
2	U	UNY	Comp	Not viable
3	Comp	Cntl	UNY	Not viable
4	Comp	UAG	Comp	Not viable
5	UNY	Comp	UAG	Not viable
6	Cntl	U	Comp	Not viable

Control = Cntrl Urea + Agrotain® Ultra = UAG Urea = U

Compost = Comp Urea + N-Yield™ = UNY

No precipitation occurred immediately following application of treatments and irrigation was withheld for a total of 10 days, then applied at regular intervals and levels until harvest on October 5, 2015.

2015 Ground Site Preparation

Originally, for the 2015 growing season, 24 field plots identical to those used for the 2014 growing season were established and cultivated on June 10, 2015. However, due to the midseason weed problems that occurred during the 2014 growing season, a more effective pre-emergent herbicide, QuinStar®, was chosen to be applied to the experimental plots pre-cultivation, on June 3, 2015. Two weeks post planting it became evident the seed germination rate had been significantly reduced by the application of QuinStar® herbicide, and a sufficient stand would not be produced from the initial planting.

A new experimental plot site for the corn, located directly west of the wheat plots was prepared and planted on July 3, 2015. Ground preparation was identical to that of the 2014 growing season site. However, pre-emergent herbicides were not used prior to the cultivation or planting in the preparation of this site. Once the seed germinated and a population was reasonably established, Roundup® herbicide was applied to assist with weed control.

Once again, all 24 corn plots were plowed east to west, using conventional tillage practices with each plot consisting of four rows with seeds planted on 76.2cm (30in) centers.

Corn Crop

Channel 216-49VT3P variety field corn (*Zea mays L.*) was planted on May 30, 2014, for the 2014 growing season with a replant of all the plots due to poor germination rates (<70%) on June 18, 2014 (Figure 3.6). Due to the germination problem with the 2014 corn crop, Northrup King N75H-GTA variety field corn (*Zea mays L.*) was chosen to replace the Channel 216-49VT3P variety for the 2015 field experiment. The crop for the 2015 growing season was originally planted on June 10, 2015, then fully replanted on July 3, 2015, due to further germination issues that occurred during the 2015 growing season caused by erroneous herbicide application. The seeding rate for both growing seasons was 64,248 seeds ha^{-1} (26,000 seeds ac^{-1}) across all field plots for both years.

Figure 3.6 2014 corn seed in planter at planting

Precipitation and Irrigation

Total precipitation for the 2014 growing season (May 30, 2014 through October 3, 2014) was approximately 34.67cm (13.65in) (The Climate Corporation, 2015), with the mean precipitation for this period calculated to be around 32.94cm (12.97in) (NOAA, 2015). During the 2015 growing season (July 3, 2015 through October 5, 2015) the total precipitation was approximately 23.06cm (9.08in) (The Climate Corporation, 2015), with the mean precipitation during this period calculated to be approximately 25.53cm (10.05in) (NOAA, 2015).

Due to limited precipitation and the standard demands of corn crops in general, irrigation was applied (Figure 3.7) at regular intervals and levels to insure crop survival beginning May 30, 2014, through September 18, 2014, for the 2014 growing season, and beginning July 3, 2015, through September 30, 2015, for the 2015 growing season. Irrigation amounts for the 2014 growing season totaled 29.44cm (11.59in), with 45.41cm (17.87in) being the total irrigation applied during the 2015 growing season.

Total precipitation and irrigation combined was approximately 64.11cm (25.24in) for the 2014 growing season and 68.47cm (26.96in) for the 2015 growing season.

Figure 3.7 2015 corn irrigation system set up

Harvest Samples

The 2014 corn crop was harvested on October 3, 2014 and the 2015 corn crop was harvested on October 5, 2015. Five plants from two rows located in the center of each plot were removed from the plots at ground level. The area from where the plants were harvested was measured in order for total dry matter per area to be calculated. The whole plant samples were placed in a drying oven at 60°C for a total of 14 days. Once dry, all plot samples were weighed (Figure 3.8) and total biomass per plot per acre was calculated. After collecting biomass data, all samples (24 for 2014; 18 for 2015) were sent to Servi-Tech Laboratories, Amarillo, Texas, for quality analysis. Analysis data included total N, P, K, Ca, Mg, S, Zn, Fe, Mn, Cu, B, and Na content.

Lab analysis of the corn for both the 2014 and 2015 harvest years was done solely on the corn stover due to limited availability of grain as a result of deer and rodent infestation of the field plots.

Figure 3.8 Weighing of corn for biomass calculations

Statistical Analysis

All statistical data analysis was conducted using SAS© (v9.4 TS Level 1M2, Copyright 2002-2012 by SAS Institute, Inc., Cary, NC, USA). Statistically significant differences were ascertained at $\alpha = 0.05$.

Nutrient content data for each year's harvested corn crop (corn stover) was analyzed for total nutrient content for each treatment group for each year. ANOVA was calculated for N, P, K, and S content for both the 2014 and 2015 harvest years, in order to identify any significant differences among treatments for each year's harvested corn stover.

When results of the ANOVA produced significant differences, a means separation test was conducted using Tukey's HSD.

Results and Discussion

Biomass

The UNY treatment had the highest average biomass weight for both harvest years, 5858 kg ha^{-1} and 4893.5 kg ha^{-1} for 2014 and 2015 respectively (Figures 3.9 and 3.10). Data showed the lowest average biomass weights varied among the remaining treatments in both years with no consistency among those treatments.

While the data suggests that applying urea treated with N-Yield increases plant biomass marginally, it does not affirm that the application of urea treated with NBPT significantly augments plant biomass. Further, results of the ANOVA tests for both 2014 and 2015 harvested corn stover (Figures 3.11 and 3.12) showed no statistical differences among treatments with regard to biomass weights. However, since corn plant biomass weight is greatly dependent upon the size and number of grain kernels per ear per plant, these results may not be truly representative of treatment effects due to the loss of grain and the data that would be associated with it.

Figure 3.9 2014 corn biomass averages (kg ha^{-1}) by treatment. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

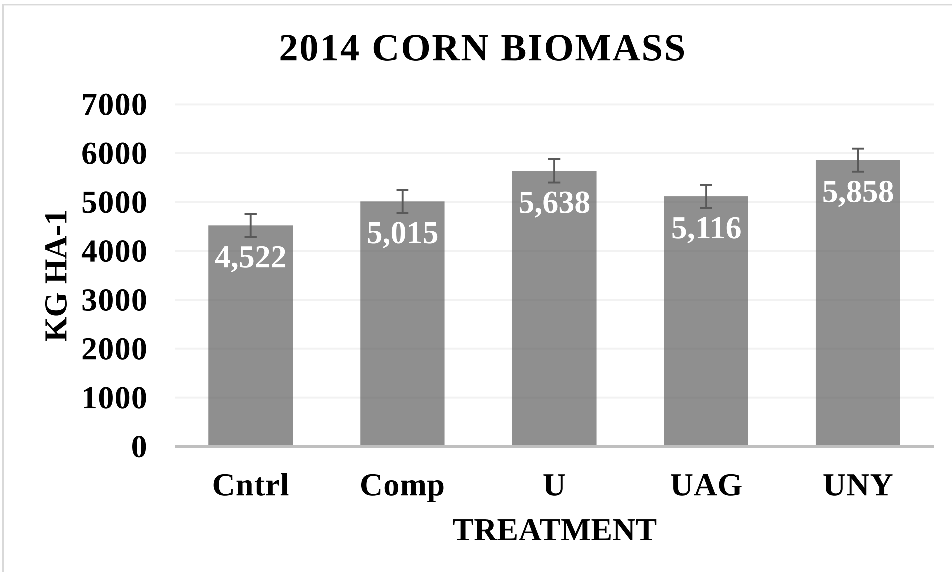


Figure 3.10 2015 corn biomass averages (kg ha^{-1}) by treatment. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

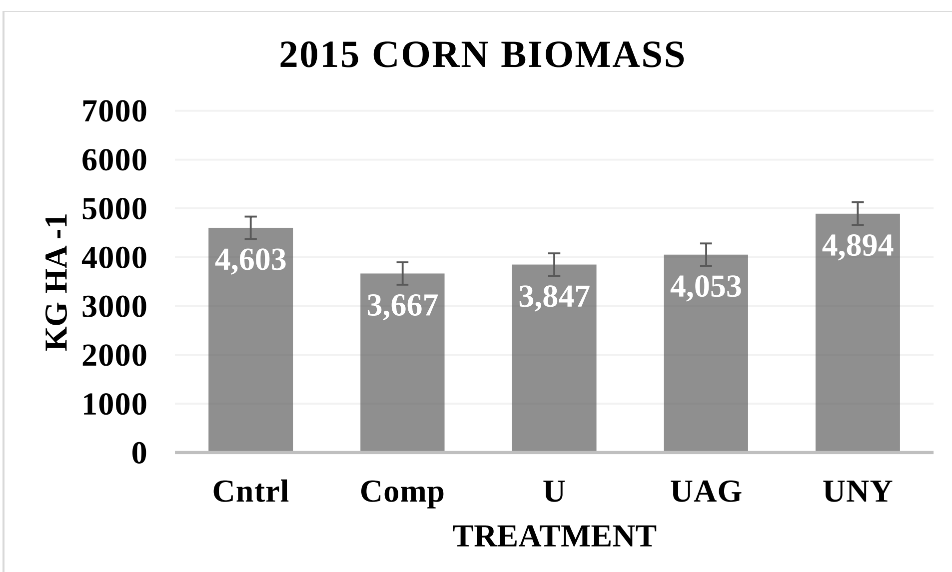


Figure 3.11 2014 corn biomass boxplot in kg ha^{-1} for each treatment. Each box represents 50% of the values with the line contained within the box representing the median and the diamond marker representing the mean value.

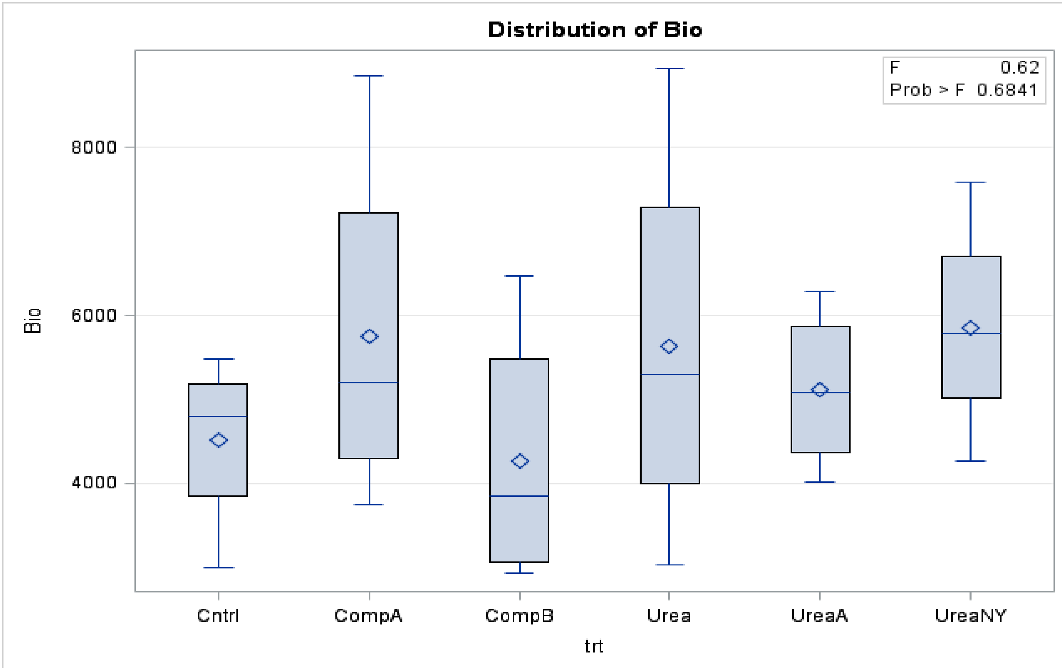
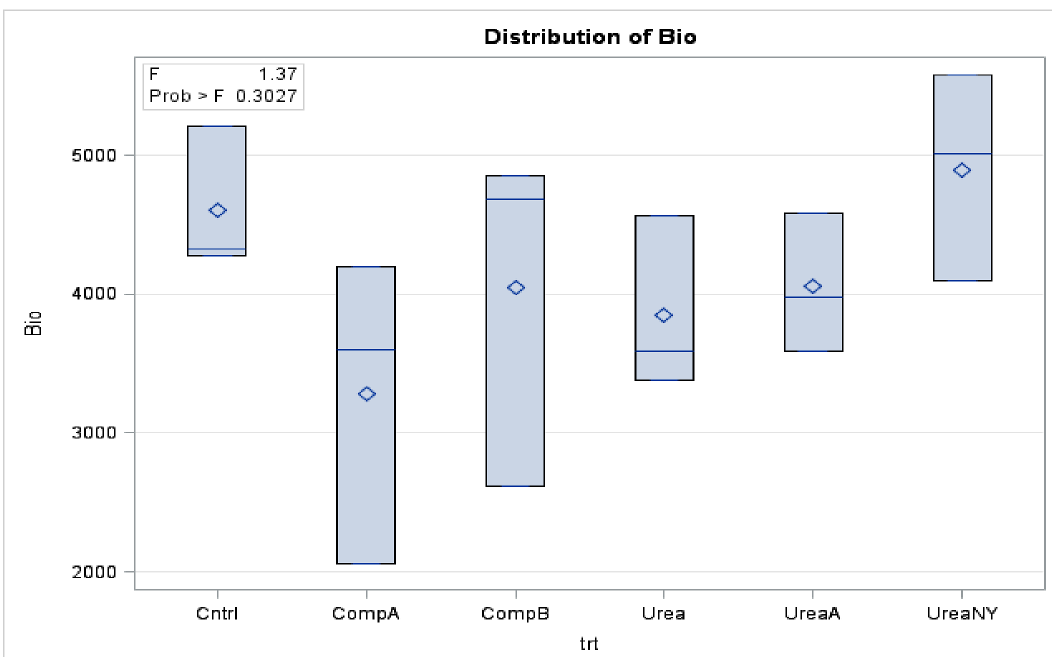


Figure 3.12 2015 corn biomass boxplot in kg ha^{-1} for each treatment. Each box represents 50% of the values with the line contained within the box representing the median and the diamond marker representing the overall mean value.



Nutrient Content

Lab analysis of the corn stover dry matter showed that Treatment U and Treatment UAG contained the largest quantities of N on average for both the 2014 and 2015 harvest years, with the means for Treatment U being 1.53% for 2014 and 1.25% for 2015, and the means for Treatment UAG being 1.80% for 2014 and 1.27% for 2015 (Figure 3.13 and 3.14). Significant differences ($p<0.0367$) were found between Treatment UAG and each of the other treatments in 2014, while in 2015, the test results reflected that both Treatment U and Treatment UAG were significantly higher ($p<0.0030$) in N content than all other treatments, with no difference being found between Treatment U and Treatment UAG (Table 3.1 and 3.2). While this outcome is in favor of NBPT being instrumental in increasing N uptake, it is not wholly conclusive for the reason that only one of the treatments containing NBPT was found to improve N uptake over that of the other treatments.

Table 3.1 Mean nutrient content of 2014 corn stover (percentage on dry weight basis). Means in the same column within the same nutrient type with the same letter were not significantly different using Tukey's HSD

Nutrient	Treatment	Mean
N	Cntrl	0.95[a]
	Comp	1.04[ab]
	UNY	1.34[ab]
	U	1.25[b]
	UAG	1.80[b]
P	UNY	0.19[a]
	U	0.25[ab]
	Comp	0.25[ab]
	UAG	0.28[ab]
	Cntrl	0.36[b]
K	U	1.52[a]
	Comp	1.56[a]
	UAG	1.63[a]
	Cntrl	1.66[a]
	UNY	1.91[a]
S	Cntrl	0.09[a]
	UAG	0.10[a]
	UNY	0.10[a]
	Comp	0.12[a]
	U	0.14[a]

Table 3.2 Mean nutrient content of 2015 corn stover (percentage based on dry weight basis). Means in the same column within the same nutrient type with the same letter are not significantly different using Tukey's HSD

Nutrient	Treatment	Mean (%)
N	Comp	0.66^{a}
	UNY	0.96^{ab}
	Cntrl	1.04^{ab}
	U	1.25^{b}
	UAG	1.27^{b}
P	Comp	0.28^{a}
	UNY	0.29^{a}
	UAG	0.30^{a}
	Cntrl	0.33^{a}
	U	0.34^{a}
K	Comp	1.14^{a}
	UAG	1.23^{a}
	U	1.31^{a}
	UNY	1.46^{a}
	Cntrl	1.46^{a}
S	Comp	0.06^{a}
	UNY	0.08^{ab}
	UAG	0.09^{bc}
	Cntrl	0.10^{bc}
	U	0.11^{c}

Figure 3.13 2014 corn stover N content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

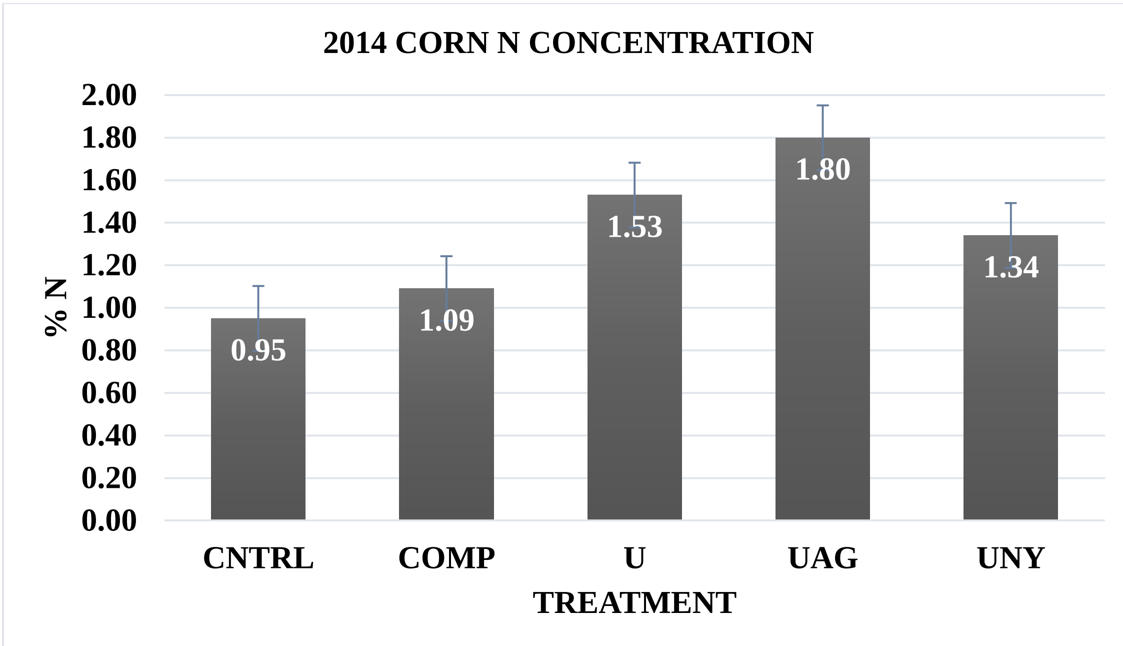
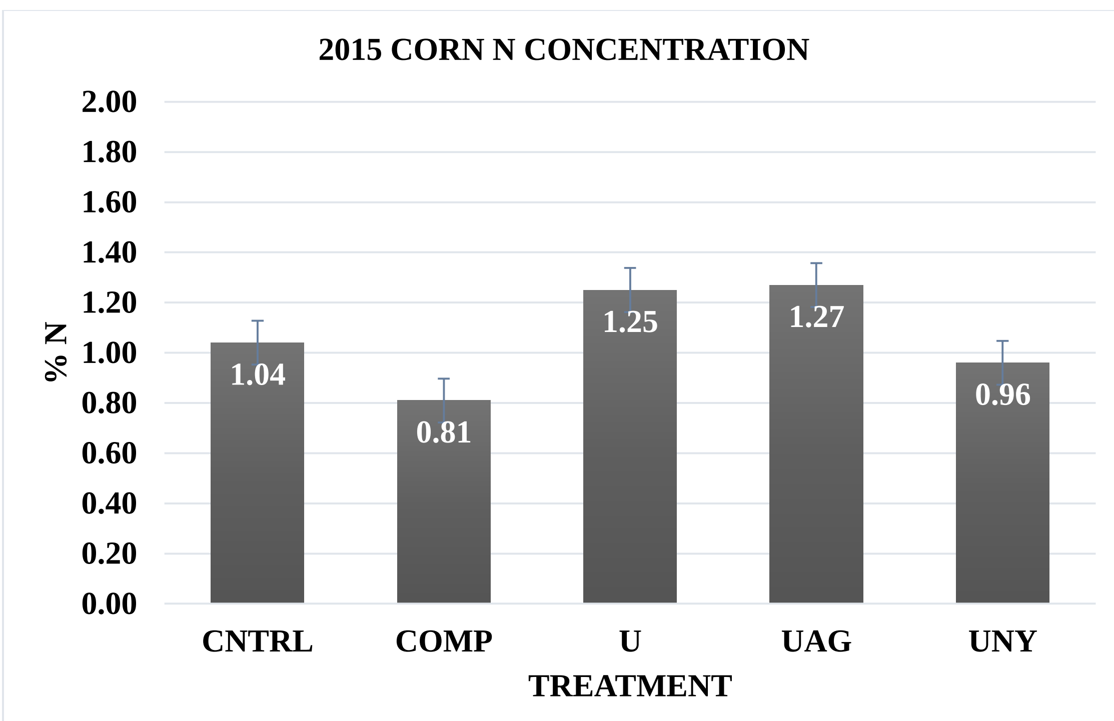


Figure 3.14 2015 corn stover N content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.



While the results related to N content in corn contrast somewhat with those documented by McClallen, 2014, it is important to note that the McClallen research focused on grain protein only, not whole plant content, while this study lacks grain content data and is based solely upon corn stover data. Since corn grain generally contains approximately 59% of the total N contained within the corn plant (International Plant Nutrition Institute, 2011), it is difficult to accurately access total N concentrations in this study without adequate grain analysis data, also making it challenging to calculate total N uptake.

In 2014, the only other nutrient that exhibited a statistical difference ($\alpha=0.05$) among treatments was found in the comparison of the means related to corn P content. Treatment Cntrl contained the highest concentration of P for the 2014 harvest (Figure 3.15), while Treatment U contained the highest concentration for the 2015 harvest (Figure 3.16). Results of Tukey's HSD test for 2014 P concentration showed differences ($p<0.006$) between Treatment Cntrl and Treatment UAG, with all other treatments showing no difference between each other or Treatment Cntrl or Treatment UAG (Table 3.1). The P content of the corn harvested in 2015 showed no statistical differences ($p<0.08$) within treatments (Table 3.2).

Figure 3.15 2014 corn stover P content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

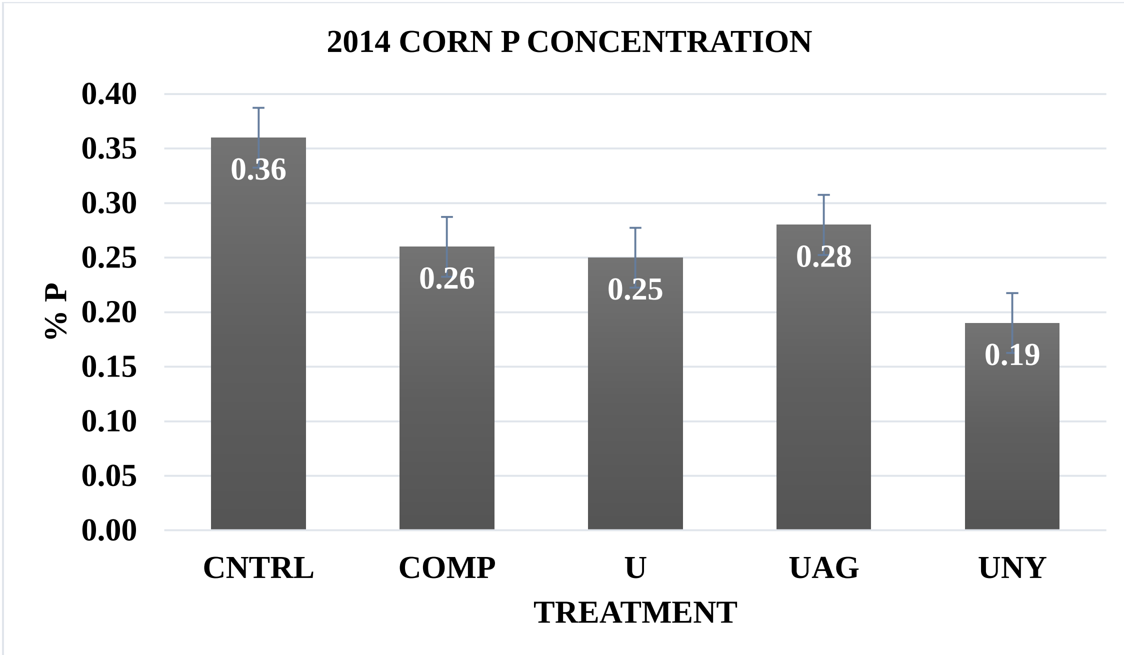
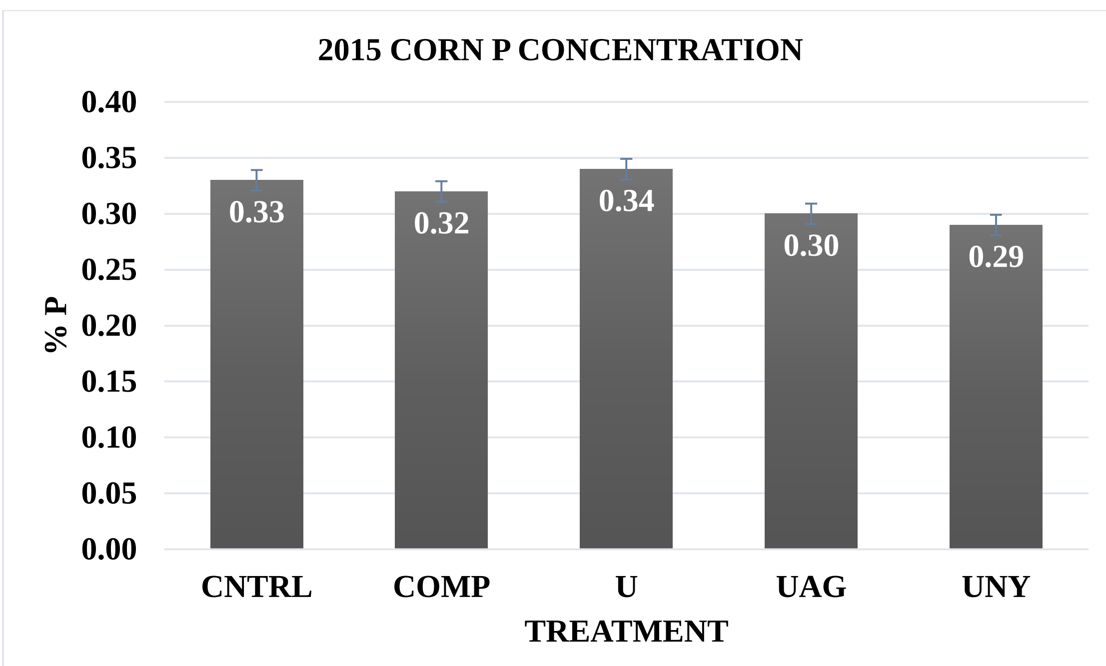


Figure 3.16 2015 corn stover P content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.



Although K content of the corn stover for both the 2014 and 2015 harvest seasons (Figure 3.17 and 3.18) showed slight mean variation among treatments, with the highest concentrations being 1.91% in Treatment UNY for the 2014 harvest year, and 1.46% in Treatment Cntrl for the 2015 harvest year, the results of the ANOVA tests did not conclude that any significant differences (2014 $p<0.80$ and 2015 $p<0.20$) existed for either year (Table 3.1 and 3.2).

The corn stover S content for the 2014 harvest year was highest in Treatment UAG (Figure 3.19), but statistical analysis exhibited no significant differences ($p<0.16$) within treatments (Table 3.1). However, the corn stover data for the 2015 harvest year for S content was highest in Treatment U (Figure 3.20) with significant differences ($p<0.0008$) being found between Treatment Comp and Treatments Cntrl, U and UAG, and between Treatment U and Treatment UNY (Table 3.2).

Figure 3.17 2014 corn stover K content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

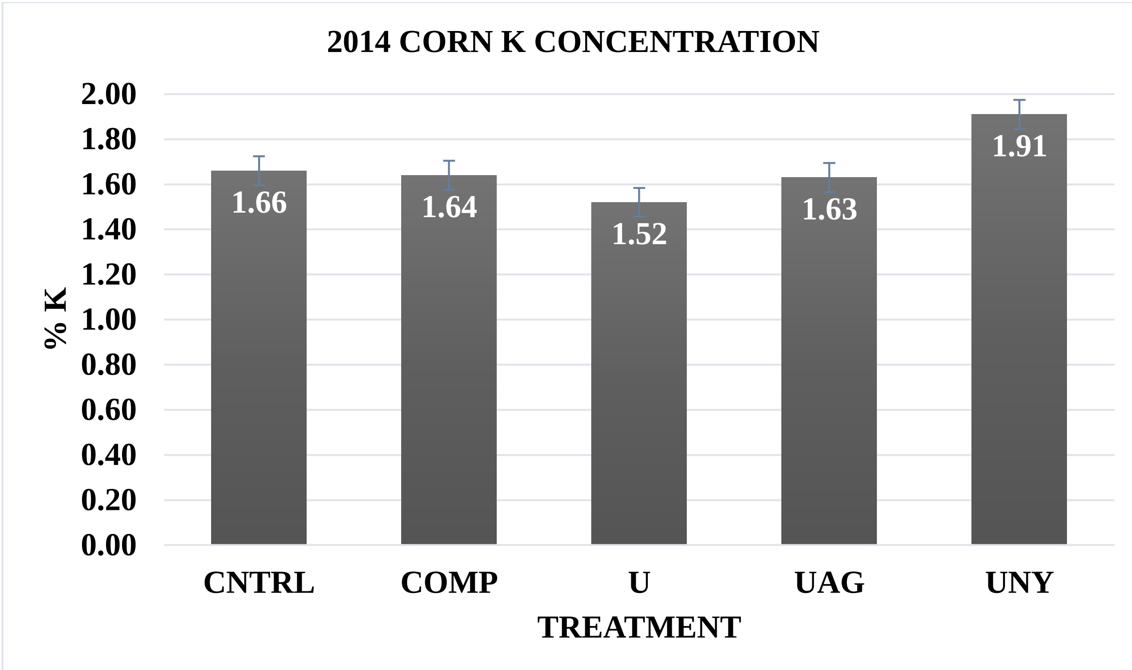


Figure 3.18 2015 corn stover K content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

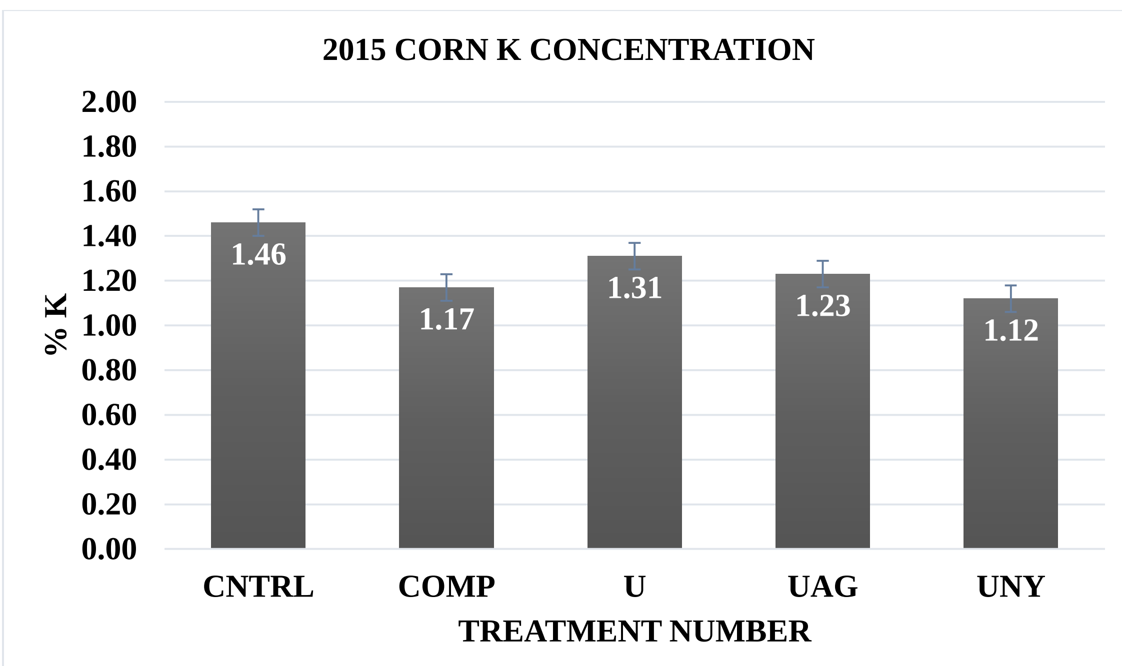


Figure 3.19 2014 corn stover S content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.

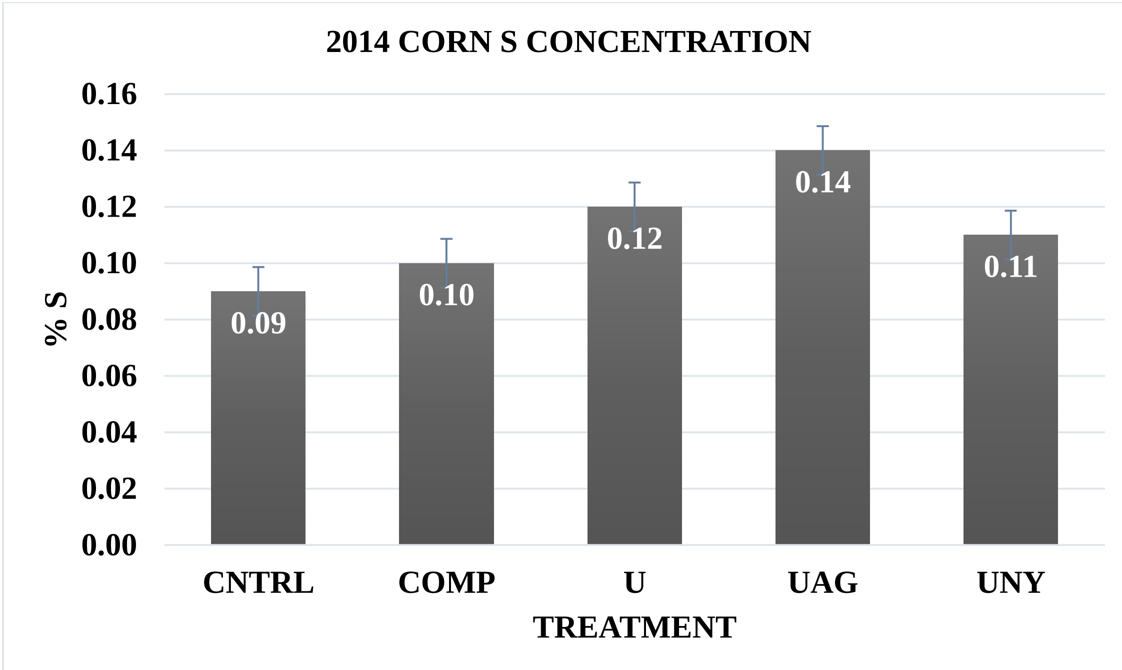
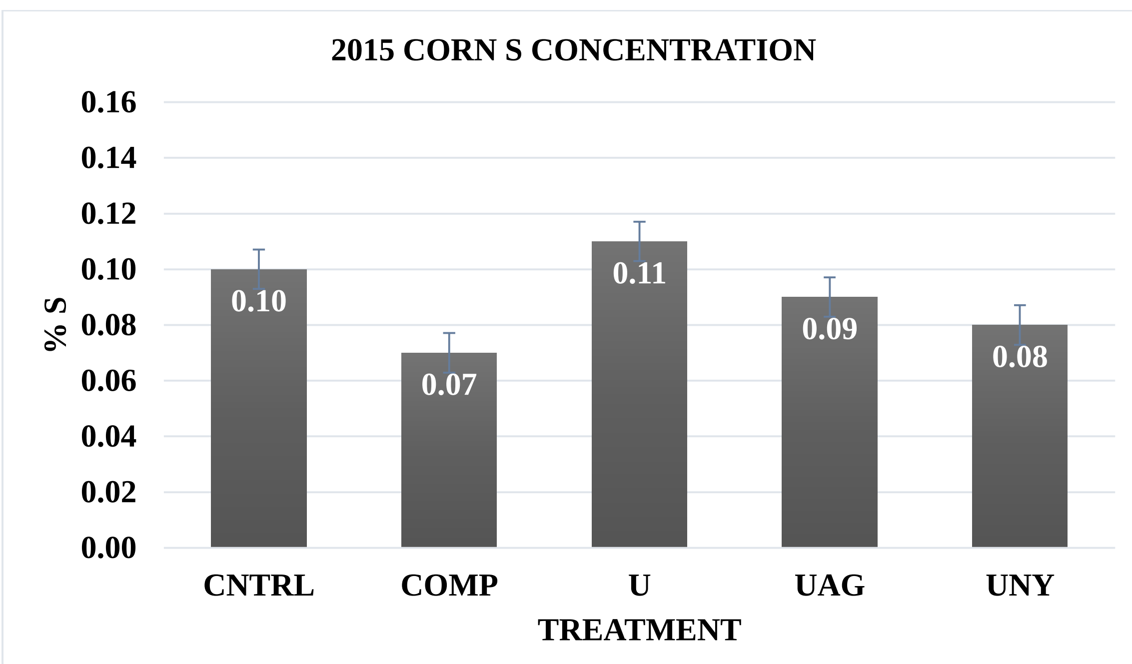


Figure 3.20 2015 corn stover S content. Each bar represents the overall mean for each treatment group with error bars indicating the standard error, estimating the variability between samples throughout each treatment.



Soil Nitrogen

Nitrogen Mass Balance

A total mass balance was calculated for N (Table 3.3). Loss of N is designated by positive balances, while N gain is designated by negative balances. Nitrogen losses may be explained by leaching, runoff, volatilization, or experimental/sampling error, while N gains may be accounted for by bacterial N fixation, unaccounted for rainfall N, or experimental/sampling error.

Table 3.3 Soil nitrogen mass balance for corn based upon N concentration averages per treatment. All calculations are in kg/ha.

Year	Treatment	Initial	Ending	Added	Removed	Balance
	Cntrl	17.37	20.74	0	44.19	-47.56
	Comp	24.10	21.58	7.40	65.58	-55.66
2014	U	21.58	20 .18	77.34	91.39	-12.65
	UAG	24.10	17.09	77.34	93.91	-9.56
	UNY	39.51	19.33	77.34	82.52	15
	Cntrl	21.66	22.04	0	48.64	-49.02
	Comp	17.93	14.94	7.40	22.47	-12.08
2015	U	19.42	20.55	77.34	48.97	27.24
	UAG	14.20	21.67	77.34	51.65	18.22
	UNY	19.05	22.79	77.34	47.66	25.94

In both 2014 and 2015, N removal rates were highest in Treatments UNY, UAG, and U, all of which contained urea or urea treated with NBPT solution. While this is a notable observation, it is also an expected result in that urea contributes an additional 68.93 kg ha^{-1} of N to the soil as compared to the compost treatments, and an additional 77.34 kg ha^{-1} of N to the soil as compared to the control.

Treatment UNY exhibited the highest N removal rate for both years. This suggests that the NBPT concentration rate, which is greater in Treatment UAG than in

Treatment UNY, may have some effect on N uptake. However, statistical analysis conducted on the N removal rates illustrated no significant differences within treatments.

Summary

From the data collected, it can be concluded that the addition of NBPT, as Agrotain®, to urea prior to application increases N concentrations in harvested corn as compared all other treatments. In both 2014 and 2015, the corn harvested that received the treatment containing urea + Agrotain® contained the greatest amount of N concentration. Statistical analysis found that the treatment containing urea + Agrotain® was significantly different from the control in 2014, and the compost treatment in 2015. No other statistical differences were ascertained between any other treatments.

Nitrogen removal rates observed in the mass balance calculations for both years show that the urea treatments containing Agrotain® have higher removal rates than all other treatments. Even though the mass balance N removal rates are not significantly different, the results support the N concentration results from the main effect data.

The results of this field study show that urea + Agrotain® performed better than any other treatment, including urea + N-Yield™, to increase N content in corn. Contrastingly, the McClallen (2014) field study reported that N-Yield™ performed better than Agrotain®, contradicting the results of this study. These conflicting results may be explained by the possible decomposition of the N-Yield™ sample used in this field study. In both harvest years, the treatment containing urea + N-Yield™ did not perform as well as in the wheat portion of this study, or as well as in any portion of the McClallen (2014) study. There were concerns at the time of treatment application about the shelf life of the product on hand, as it was already over 3+ years old. There is a possibility that the product used was in a state of decay and was not as effective as it would have been if a new sample of N-Yield^{TM} had been obtainable at the time of this study. Observations made by Watson et al. (2008), concluded that NBPT is sensitive to decomposition, and provides some support for this theory.

CHAPTER FOUR

CONCLUSION

The objectives of this research study were to evaluate the effect and compare the performance of urea fertilizer treated with the urease inhibitor, NBPT, with that of untreated urea fertilizer, and compost on the N content of hard red winter wheat and corn upon harvest. Although it is evident that urea treated with NBPT does increase N uptake and N removal rates in wheat and corn, no pattern was found upon statistical analysis of the data collected in either the wheat or corn studies to suggest that the use of NBPT with urea will produce results that are significantly different than those that would be attained by the use of urea alone.

Future Research

It is still unclear if NBPT treated urea significantly improves N removal rates in wheat, due to missing biomass calculations in this study. Without this information it is difficult to ascertain if volatilization and leaching are being reduced. Further research focusing specifically on N removal rates in wheat would be advantageous to evaluate the effectiveness of NBPT.

Although it was determined that no statistical differences were found among urea treatments in this study, the urea treatments containing NBPT, whether it was Agrotain or N-Yield, exhibited the highest N concentrations of any of the treatments. Further, studies should be conducted to evaluate the possible economic value, if any, of using NBPT.

Future research, on a longer timeline and larger scale, is needed in order to resolve the result conflicts between harvest years within this study, and the McClallen (2014) corn field study. It would also be prudent to focus on the concentration percentage of NBPT being used in order to determine whether or not higher concentrations boost the potential for increasing N uptake, thereby increasing the probability of reducing N loss.

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APPENDIX A

SOIL NUTRIENT CONTENT DATA

WHEAT PLOTS SOIL NUTRIENT DATA

0-6 inch soil nutrient concentrations for wheat plots. Samples taken September 27, 2013.

TRT	**pH**	**Salts**	**OM**	N	**P**	**K**	**S**	**Ca**	**Mg**	**Na**	**Zn**	**CEC**
1	6.3	0.13	1.1	2	58	389	6	1236	284	9	0.9	10
1	6.3	0.08	1	2	56	397	7	1209	287	11	1.1	10
1	6.3	0.11	1	2	62	437	5	1134	274	5	0.8	9
1	5.9	0.11	1.1	4	76	415	7	1087	259	9	1	9
2	6	0.12	1	1	64	423	7	1194	286	10	0.9	11
2	6	0.11	1	2	78	399	6	1084	246	6	0.9	10
2	6	0.14	1.1	4	73	415	6	1147	256	9	0.8	9
2	5.9	0.18	1.1	14	54	449	10	1344	321	12	1	12
3	6.2	0.06	1.1	1	40	359	5	1394	317	8	0.6	11
3	6	0.1	1	1	68	478	6	1193	290	7	0.9	11
3	6	0.06	1	1	63	403	7	1420	294	8	1.2	11
3	6.1	0.09	1	3	65	357	7	1155	248	9	1.1	9
4	6.1	0.06	1.1	2	51	396	6	1299	306	6	0.7	10
4	6.1	0.09	1	2	59	411	5	1178	288	5	0.7	11
4	6.6	0.21	1	4	61	410	14	1725	344	34	1.1	13
4	6	0.12	1	6	80	457	8	1153	253	9	0.9	10
5	6.3	0.1	1.1	2	57	327	6	1251	273	11	0.7	9
5	6	0.12	1	4	96	439	8	1044	233	6	0.9	10
5	5.9	0.09	1	6	79	384	7	974	216	8	0.8	9
5	6.3	0.14	1.1	7	41	365	10	1426	317	15	1.7	11
6	6	0.08	1	2	74	389	9	1127	291	13	0.9	10
6	6.2	0.13	1.2	3	70	462	5	1144	257	11	0.8	9
6	5.9	0.15	1	5	89	468	9	1150	259	8	0.8	10
6	5.8	0.14	1	10	89	389	8	1036	222	7	0.8	8

0-6 inch soil nutrient concentrations for wheat plots. Samples taken September 18, 2014

TRT	**pH**	**Salts**	**OM**	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Mn**	**Cu**	**CEC**
1	6.7	0.14	0.9	4	37	370	9	1322	301	29	0.7	30	19	1.2	10
1	6.7	0.14	1	4	40	405	7	1325	312	25	0.7	28	18	1.2	10
1	6.6	0.16	0.9	4	37	365	12	1320	318	27	0.6	26	18	1.1	10
1	6.6	0.2	0.9	4	50	367	18	1386	322	33	0.7	28	19	1.2	11
2	7	0.15	0.9	4	50	379	7	1341	342	40	0.9	24	15	1.2	11
2	6.7	0.14	0.9	4	59	412	6	1331	300	30	1.1	29	18	1.3	10
2	6.6	0.16	0.9	5	60	376	11	1321	295	33	0.8	27	17	1.2	10
2	7.4	0.17	1.1	7	58	472	8	1769	365	42	1.2	25	15	1.2	13
3	7.3	0.15	0.9	3	45	447	8	1615	351	42	0.9	25	15	1.2	12
3	7.1	0.13	0.9	3	53	382	7	1333	342	38	0.9	23	14	1.1	11
3	7	0.13	0.9	3	45	371	9	1401	333	42	0.7	23	16	1.1	11
3	6.8	0.15	0.9	4	55	392	6	1313	303	34	0.9	25	17	1.2	10
4	6.9	0.16	0.7	4	28	322	8	1439	350	45	0.7	23	15	1.1	11
4	6.8	0.14	0.9	5	32	351	7	1374	328	33	0.7	26	18	1.2	11
4	6.9	0.17	1	6	38	327	9	1566	363	27	0.9	24	15	1.2	12
4	6.6	0.19	0.9	9	61	357	10	1249	275	27	0.7	28	19	1.2	10
5	6.9	0.16	0.9	5	33	362	10	1451	328	25	0.9	27	19	1.3	11
5	6.8	0.17	0.9	6	50	360	9	1404	310	38	0.6	27	18	1.2	11
5	6.5	0.21	0.7	9	61	322	15	1277	274	42	0.6	29	19	1.2	10
5	6.9	0.21	0.8	11	60	330	9	1230	275	34	0.7	27	16	1.2	9
6	7	0.15	0.9	4	58	372	7	1452	317	33	0.7	29	19	1.2	11
6	7	0.17	0.9	7	67	385	9	1261	277	27	0.7	32	21	1.3	10
6	6.8	0.14	0.9	8	65	338	10	1229	280	28	0.7	28	16	1.2	9
6	6.2	0.2	0.9	9	67	375	11	1271	287	21	1.1	30	19	1.3	10

0-6 inch soil nutrient concentrations for wheat plots. Samples taken August 4, 2015

TRT	**pH**	**Salts**	**OM**	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Mn**	**Cu**	**CEC**
1	6.7	0.16	1.2	3	33	319	7	1220	295	30	0.8	35	15	1.1	10
1	7	0.19	1.2	3	36	335	3	1251	319	31	0.9	29	14	1.1	10
1	6.8	0.18	1.5	4	33	353	5	1216	318	22	0.8	29	15	1	10
1	7.1	0.12	1.5	<1	65	403	3	1105	320	19	1.1	36	15	1.1	9
2	6.9	0.09	1.2	1	55	364	3	1206	294	23	1	35	15	1.2	10
2	6.7	0.1	1.2	2	31	297	3	1245	290	20	0.8	27	17	1.2	9
2	7.1	0.13	1.3	2	35	363	3	1326	333	34	0.8	27	14	1.1	10
2	6.9	0.13	1.2	3	46	363	5	1260	309	28	0.9	33	17	1.2	10
3	6.9	0.12	1.2	2	35	381	4	1203	294	31	0.8	27	13	1.1	10
3	7.1	0.14	1.3	2	31	321	2	1343	335	30	0.7	26	15	1	10
3	7	0.13	1.2	2	34	309	6	1295	326	34	0.7	25	14	1	10
3	7	0.13	1.4	3	60	400	3	1276	298	26	1.2	36	14	1.1	10
4	6.8	0.1	1.2	1	29	294	3	1157	278	21	0.8	27	16	1.1	9
4	6.9	0.14	1.1	2	29	297	3	1145	288	27	0.9	27	15	1.1	9
4	6.7	0.1	1.2	2	32	318	3	1159	290	23	0.7	29	16	1.1	9
4	6.9	0.19	1.4	5	46	390	4	1499	331	37	1	31	15	1.2	11
5	6.8	0.14	1.3	2	36	313	1	1222	289	23	0.9	29	17	1.2	9
5	6.8	0.14	1.1	2	35	319	5	1220	307	30	0.8	28	16	1.1	10
5	6.9	0.16	1.3	4	31	357	4	1273	323	31	0.8	30	15	1.1	10
5	6.4	0.16	1.5	5	54	385	2	1077	266	16	0.9	43	19	1.2	9
6	6.8	0.17	1.2	2	31	356	6	1218	302	29	0.8	30	16	1.1	10
6	6.9	0.12	1.2	2	33	315	5	1205	301	29	0.8	29	16	1.2	9
6	6.6	0.1	1.3	3	30	319	4	1236	295	23	0.7	28	16	1.1	10
6	6.4	0.14	1.2	7	54	347	5	1069	259	18	0.8	42	18	1.1	8

CORN PLOTS SOIL NUTRIENT DATA

0-6 inch soil nutrient concentrations for corn east plots. Samples taken May 30, 2014.

TRT	pH	Salts	OM	N (ppm)	N (lbs/ac)	P	K	S	Ca	Mg	Na	Zn	CEC
1	6.3	0.14	0.9	8	14	54	316	10	1100	256	46	0.6	9
1	6	0.17	0.9	8	14	64	292	8	876	222	23	0.7	7
1	6	0.12	0.9	9	16	70	381	7	1231	261	8	0.7	9
1	6.6	0.19	0.9	10	18	60	333	11	1222	282	56	0.6	10
2	6.4	0.18	0.9	9	16	61	325	6	1126	264	36	0.8	9
2	6.4	0.15	0.9	10	18	60	360	16	1125	260	62	1.1	9
2	5.7	0.17	0.9	14	25	81	410	8	1035	228	10	0.6	9
2	5.7	0.17	0.9	15	27	80	402	7	1036	226	6	0.6	9
3	6.3	0.21	0.9	11	20	68	353	14	1054	225	36	0.9	8
3	5.7	0.17	0.9	12	22	68	366	7	1057	222	7	0.7	9
3	5.5	0.15	0.9	14	25	86	394	11	1029	226	11	0.6	9
3	6.3	0.22	0.9	19	34	63	308	10	1111	275	53	0.7	9
4	5.9	0.11	0.9	8	14	71	375	8	1109	236	9	0.6	9
4	5.9	0.11	0.9	9	16	72	384	6	1092	242	9	0.6	9
4	6	0.22	0.9	12	22	62	329	10	1052	235	51	0.7	9
4	6.7	0.13	0.9	14	25	68	327	11	1087	258	61	0.9	9
5	5.7	0.12	0.9	9	16	71	350	10	1042	225	11	0.6	9
5	6.2	0.13	0.8	12	22	67	304	10	1133	249	33	0.7	9
5	5.7	0.14	1	13	23	78	388	8	1000	217	7	0.7	9
5	5.9	0.12	0.9	14	25	68	401	8	1234	256	6	0.7	9
6	5.8	0.12	0.9	6	11	70	353	6	972	213	5	0.7	9
6	5.9	0.12	0.9	11	20	73	331	9	1069	227	12	0.6	8
6	5.9	0.23	0.9	27	49	53	342	13	1054	232	32	0.5	9
6	5.5	0.31	0.9	34	61	74	373	15	995	241	37	0.7	9

0-6 inch soil nutrient concentrations for corn east plots. Samples taken June 2015.

TRT	pH	Salts	OM	N (ppm)	N (lbs/ac)	P	K	S	Ca	Mg	Na	Zn	Fe	Mn	Cu	CEC
1	6.4	0.16	0.9	6	14	25	306	5	1137	244	15	0.7	24	17	1.1	9
1	6.4	0.14	0.9	7	17	27	319	7	1114	260	23	0.6	30	18	1.1	9
1	6.4	0.15	1	8	19	12	303	6	1376	293	25	0.4	19	17	1.1	10
1	6.7	0.25	1.4	10	24	36	335	5	1242	323	28	0.8	28	15	1.2	10
2	6.8	0.13	1.3	3	7	30	363	4	1320	330	27	0.7	31	17	1.1	10
2	6.7	0.14	1.3	4	10	38	401	6	1311	317	27	0.8	35	17	1.1	10
2	6.8	0.16	1.1	5	12	24	319	4	1358	316	29	0.6	23	16	1	10
2	6.7	0.17	1.4	20	48	43	347	4	1214	343	26	0.8	25	15	1.1	10
3	6.6	0.14	1	4	10	28	317	6	139	263	24	0.7	35	19	1.2	9
3	6.4	0.17	1.2	5	12	35	338	5	1165	283	24	0.7	31	17	1.1	9
3	6.7	0.17	1.2	11	26	40	336	3	1191	318	27	0.8	25	15	1.1	10
3	6.8	0.18	1.3	13	31	46	350	3	1180	321	35	0.9	25	13	1	10
4	6.4	0.15	0.9	5	12	20	262	6	1110	245	19	0.6	26	19	1.1	8
4	6.5	0.16	1	7	17	24	343	6	1252	281	26	0.5	21	16	1	10
4	6.5	0.19	1.1	8	19	34	371	5	1081	248	19	0.8	22	15	1	9
4	6.3	0.19	1.1	10	24	38	354	6	1113	265	23	0.8	31	18	1.1	9
5	6.5	0.14	1.3	3	7	28	311	4	1273	303	23	0.7	26	16	1.1	10
5	6.4	0.12	0.9	6	14	24	285	5	1132	256	19	0.6	27	18	1.1	9
5	6.4	0.15	1.2	6	14	35	333	6	1268	272	26	0.7	28	16	1.1	10
5	6.4	0.18	1.2	11	26	41	391	6	1078	265	22	0.8	36	15	1.1	9
6	6.8	0.15	1.3	5	12	41	364	4	1268	309	23	0.7	33	17	1.1	10
6	6.5	0.15	0.9	6	14	31	364	4	1160	264	19	0.7	23	16	1.1	9
6	6.5	0.16	1.1	8	19	36	367	4	1209	288	26	0.8	29	17	1.1	9
6	6.3	0.18	1.1	10	24	42	398	6	1132	269	28	0.7	25	16	1.1	9

0-6 inch soil nutrient concentrations for corn west plots. Samples taken July 6, 2015.

TRT	**pH**	**Salts**	**OM**	**N (ppm)**	**N (lbs/ac)**	**P**	**K**	**S**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Mn**	**Cu**	**CEC**
1	6.6	0.17	0.9	11	26	38	454	8	1265	290	29	0.8	26	15	1.1	10
1	7.3	0.27	0.9	6	14	36	415	6	1877	375	30	0.9	20	11	1	14
1	6.5	0.21	1.1	8	19	31	366	6	1285	358	29	0.9	27	18	1.2	10
2	6.5	0.14	1.2	6	14	42	400	8	1170	273	21	0.9	33	16	1.2	9
2	6.4	0.12	0.9	5	12	35	318	6	1170	261	28	0.7	27	18	1.2	9
2	6.4	0.16	0.9	6	14	28	337	6	1283	279	19	0.7	26	18	1.1	10
3	7	0.22	1.4	13	31	48	332	8	1210	294	34	1	27	13	1.2	9
3	6.6	0.21	1.1	6	14	31	361	6	1170	260	19	0.7	27	16	1.1	9
3	6.5	0.2	1.1	9	22	41	731	8	2107	430	74	0.8	38	17	1.2	16
4	6.4	0.14	1.1	6	14	37	366	7	1291	303	30	0.8	28	16	1.2	10
4	7	0.2	1.2	12	29	44	364	5	1311	345	35	1	22	11	1	11
4	6.7	0.17	0.9	5	12	26	354	6	1360	310	28	0.7	22	15	1.1	10
5	7.2	0.19	1	9	22	45	317	7	1185	406	39	0.9	18	8	1	10
5	6.6	0.17	1	8	19	39	393	6	1209	281	24	1	23	13	1	9
5	6.5	0.2	1.1	7	17	41	383	8	1091	260	18	0.7	29	18	1.2	9
6	6.6	0.15	1	9	22	48	466	5	1147	269	20	0.9	26	13	1.2	9
6	6.7	0.15	1	7	17	30	357	5	1320	311	25	0.7	25	16	1.1	10
6	6.7	0.21	1.2	9	22	35	336	7	1201	266	23	0.8	27	14	1.1	9

0-6 inch soil nutrient concentrations for corn west plots. Samples taken October 19, 2015.

TRT	**pH**	**Salts**	**OM**	**N (ppm)**	**N (lbs/ac)**	**P**	**K**	**S**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Mn**	**Cu**	**CEC**
1	6.4	0.17	1.1	7	17	37	425	6	1474	339	20	0.9	30	19	1.3	11
1	6.8	0.16	0.9	7	17	35	344	6	1150	274	33	0.8	22	13	1	9
1	6.5	0.21	0.9	10	24	38	401	6	1165	261	33	0.9	22	14	1	9
2	6.4	0.14	0.9	5	12	38	326	5	1090	249	27	0.7	24	14	1	8
2	6.8	0.14	1.1	5	12	26	383	6	1558	340	29	0.8	24	15	1.2	12
2	6.7	0.18	0.9	6	14	28	377	5	1330	301	27	0.6	22	15	1.2	10
3	6.7	0.12	0.8	7	17	40	399	5	1149	285	27	0.9	27	13	1.1	9
3	6.4	0.13	0.9	7	17	31	351	4	1255	282	21	0.7	25	16	1.1	10
3	6.8	0.15	1	7	17	33	389	6	1367	310	29	0.7	22	12	1	11
4	6.4	0.12	0.9	3	7	25	274	6	1263	272	28	0.7	23	16	1.1	9
4	6.3	0.14	0.9	5	12	31	334	6	1288	283	23	0.7	27	20	1.1	10
4	6.7	0.19	1.3	12	29	40	406	6	1252	331	31	1	24	14	1.1	10
5	6.3	0.14	0.9	6	14	22	293	5	1253	267	15	0.6	25	18	1.1	9
5	6.6	0.14	1.1	6	14	31	388	5	1344	320	29	0.7	24	15	1.1	11
5	6.7	0.18	1.2	10	24	48	378	6	1254	296	25	1	26	12	1	10
6	6.8	0.15	1	6	14	33	431	7	1583	338	33	0.8	26	15	1.1	12
6	6.5	0.15	1	8	19	40	369	4	1126	249	25	0.8	21	12	1	9
6	6.5	0.18	1.1	8	19	39	437	7	1412	348	25	0.9	27	17	1.2	11

APPENDIX B

WHEAT RESPONSE DATA

2014 Wheat Straw Nitrogen Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.54	0.52	0.57	1.15	1.05	1.16
Rep 2	0.63	0.63	0.59	1.16	1.11	1.26
Rep 3	0.69	0.71	0.70	1.33	1.45	1.48
Rep 4	0.71	0.91	0.70	1.36	1.59	1.54

2014 Wheat Straw Phosphorus Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.09	0.07	0.11	0.11	0.11	0.14
Rep 2	0.07	0.11	0.07	0.13	0.14	0.15
Rep 3	0.09	0.09	0.12	0.15	0.19	0.17
Rep 4	0.06	0.11	0.11	0.16	0.18	0.22

2014 Wheat Straw Potassium Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.804	0.735	0.832	1.17	1.095	1.192
Rep 2	0.786	1.209	0.932	1.17	1.454	1.296
Rep 3	0.732	1.076	0.817	1.298	1.333	1.161
Rep 4	0.791	0.98	0.694	1.097	1.337	1.749

2014 Wheat Straw Sulfur Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.07	0.07	0.07	0.14	0.12	0.14
Rep 2	0.07	0.80	0.80	0.12	0.12	0.13
Rep 3	0.09	0.08	0.80	0.15	0.15	0.16
Rep 4	0.07	0.09	0.07	0.13	0.17	0.18

2014 Wheat Grain Nitrogen Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	13.2	19.1	20	17.9	13.4	11.8
Rep 2	13.2	19.2	21.3	19.3	15.2	13.4
Rep 3	13.7	19.8	22.9	21.7	15.3	13.9
Rep 4	14.7	23.4	23.7	23.7	15.6	14.2

2014 Wheat Grain Phosphorus Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.47	0.53	0.5	0.52	0.47	0.47
Rep 2	0.48	0.5	0.56	0.57	0.5	0.47
Rep 3	0.47	0.53	0.58	0.57	0.47	0.47
Rep 4	0.45	0.57	0.64	0.59	0.49	0.44

2014 Wheat Grain Potassium Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.48	0.53	0.56	0.55	0.47	0.48
Rep 2	0.48	0.5	0.6	0.55	0.5	0.48
Rep 3	0.49	0.55	0.59	0.58	0.47	0.47
Rep 4	0.45	0.59	0.66	0.61	0.5	0.46

2014 Wheat Grain Sulfur Analysis Data

	Cntrl	Comp	CompNY	U	UAG	UNY
Rep 1	0.15	0.21	0.21	0.19	0.15	0.14
Rep 2	0.15	0.2	0.22	0.22	0.16	0.15
Rep 3	0.15	0.21	0.22	0.22	0.17	0.14
Rep 4	0.16	0.23	0.23	0.23	0.16	0.16

2015 Wheat Straw Nitrogen Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	0.624	0.544	0.784	0.784	0.944
Rep 2	0.640	0.640	0.976	0.800	1.008
Rep 3	0.800	0.832	1.008	0.880	1.072
Rep 4	0.800	0.880	1.360	1.040	1.216

2015 Wheat Straw Phosphorus Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	0.20	0.18	0.15	0.11	0.15
Rep 2	0.18	0.18	0.12	0.14	0.19
Rep 3	0.20	0.18	0.13	0.11	0.14
Rep 4	0.22	0.23	0.16	0.14	0.13

2015 Wheat Straw Potassium Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	1.44	1.54	2.21	2.33	2.63
Rep 2	1.55	1.79	2.67	2.46	2.29
Rep 3	1.82	1.67	2.14	2.49	2.74
Rep 4	1.21	1.64	2.99	2.81	2.64

2015 Wheat Straw Sulfur Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	0.12	0.10	0.14	0.12	0.13
Rep 2	0.10	0.11	0.14	0.14	0.16
Rep 3	0.12	0.13	0.14	0.13	0.15
Rep 4	0.10	0.13	0.18	0.16	0.15

2015 Wheat Grain Nitrogen Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	2.080	2.048	2.416	2.432	2.368
Rep 2	2.080	2.112	2.480	2.448	2.528
Rep 3	2.096	2.128	2.736	2.624	2.784
Rep 4	2.096	2.144	2.768	2.640	2.784

2015 Wheat Grain Phosphorus Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	0.500	0.490	0.450	0.480	0.470
Rep 2	0.500	0.480	0.440	0.480	0.490
Rep 3	0.460	0.490	0.510	0.340	0.480
Rep 4	0.480	0.520	0.520	0.470	0.470

2015 Wheat Grain Potassium Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	0.580	0.590	0.550	0.630	0.590
Rep 2	0.550	0.520	0.540	0.680	0.600
Rep 3	0.510	0.560	0.710	0.460	0.680
Rep 4	0.540	0.580	0.730	0.640	0.600

2015 Wheat Grain Sulfur Analysis Data

	Cntrl	Comp	U	UAG	UNY
Rep 1	0.140	0.130	0.150	0.160	0.150
Rep 2	0.140	0.140	0.170	0.160	0.160
Rep 3	0.140	0.140	0.170	0.130	0.180
Rep 4	0.140	0.150	0.180	0.170	0.170

APPENDIX C

CORN RESPONSE DATA

2014 Corn Stover Biomass Analysis Data (lbs/acre)

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	2681.95	3352.13	2614.05	2698.91	3586.60	3804.70
Rep 2	4197.53	4316.93	2857.22	4432.60	4205.18	5137.79
Rep 3	4370.59	4971.79	4016.94	5016.09	4862.88	5194.34
Rep 4	4887.12	7903.94	5763.94	7974.62	5603.72	6768.36

2014 Corn Stover Biomass Analysis Data (kg/ha)

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	3006.06	3757.23	2929.96	3025.06	4020.03	4264.49
Rep 2	4704.80	4838.63	3202.51	4968.27	4713.37	5758.68
Rep 3	4898.77	5572.62	4502.38	5622.28	5450.55	5822.07
Rep 4	5477.72	8859.12	6460.51	8938.34	6280.93	7586.31

2014 Corn Stover Nitrogen Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	0.73	0.63	0.63	1.03	1.48	0.92
Rep 2	0.98	0.67	0.67	1.58	1.79	1.04
Rep 3	1.00	1.38	1.38	1.69	1.89	1.53
Rep 4	1.09	1.46	1.46	1.80	2.05	1.87

2014 Corn Stover Phosphorus Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	0.34	0.16	0.26	0.18	0.22	0.16
Rep 2	0.42	0.21	0.27	0.31	0.29	0.17
Rep 3	0.33	0.33	0.22	0.29	0.29	0.20
Rep 4	0.34	0.29	0.31	0.23	0.30	0.23

2014 Corn Stover Potassium Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	1.58	1.70	1.51	1.62	1.93	2.09
Rep 2	1.73	1.67	2.32	1.40	1.53	1.57
Rep 3	1.57	1.50	1.52	1.56	1.66	2.23
Rep 4	1.75	1.36	1.48	1.49	1.41	1.75

2014 Corn Stover Sulfur Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	0.07	0.09	0.10	0.14	0.07	0.08
Rep 2	0.08	0.13	0.08	0.11	0.08	0.09
Rep 3	0.08	0.13	0.13	0.15	0.13	0.09
Rep 4	0.13	0.14	0.13	0.14	0.10	0.15

2015 Corn Stover Biomass Analysis Data (lbs/acre)

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	3811.16	1842.68	2331.08	3021.01	3207.26	3652.41
Rep 2	3857.71	3207.87	4182.17	3207.25	3549.40	4469.42
Rep 3	4650.78	3741.77	4324.31	4069.52	4092.48	4975.86

2015 Corn Stover Biomass Analysis Data (kg/ha)

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	4271.73	2065.36	2612.78	3386.10	3594.85	4093.79
Rep 2	4323.91	3595.53	4687.58	3594.84	3978.34	5009.55
Rep 3	5212.82	4193.96	4846.89	4561.32	4587.05	5577.18

2015 Corn Stover Nitrogen Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	0.86	0.58	0.94	1.05	1.16	0.84
Rep 2	0.97	0.62	0.95	1.22	1.29	1.01
Rep 3	1.29	0.79	0.96	1.48	1.35	1.04

2015 Corn Stover Phosphorus Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	0.31	0.23	0.36	0.36	0.28	0.23
Rep 2	0.33	0.26	0.37	0.33	0.33	0.32
Rep 3	0.35	0.34	0.35	0.34	0.29	0.32

2015 Corn Stover Potassium Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	1.15	1.21	1.20	1.24	1.33	1.21
Rep 2	1.88	1.15	1.24	1.34	1.18	1.04
Rep 3	1.36	1.05	1.16	1.35	1.17	1.12

2015 Corn Stover Sulfur Analysis Data

	Cntrl	CompA	CompB	U	UAG	UNY
Rep 1	0.08	0.06	0.08	0.10	0.08	0.07
Rep 2	0.10	0.06	0.08	0.11	0.10	0.08
Rep 3	0.11	0.07	0.08	0.12	0.10	0.08

APPENDIX D

SAS DATA

SAS code for 2014 harvested wheat straw; analysis for N, P, K, and S.

```
title1 '2014 Wheat Straw';
DATA wheat;
INPUT trt$ N P K S;
CARDS;
Cntrl   0.540  0.090  0.804  0.070
Cntrl   0.630  0.070  0.786  0.070
Cntrl   0.690  0.090  0.732  0.090
Cntrl   0.710  0.060  0.791  0.070
Comp  0.520  0.070  0.735  0.070
Comp  0.630  0.110  1.209  0.080
Comp  0.710  0.090  1.076  0.080
Comp  0.910  0.110  0.980  0.090
CompNY        0.570  0.110  0.832  0.070
CompNY        0.590  0.070  0.932  0.080
CompNY        0.700  0.110  0.694  0.070
CompNY        0.700  0.120  0.817  0.080
Urea    1.150  0.110  1.170  0.140
Urea    1.160  0.130  1.170  0.120
Urea    1.330  0.150  1.298  0.150
Urea    1.360  0.160  1.097  0.130
UreaA  1.050  0.110  1.095  0.120
UreaA  1.110  0.140  1.454  0.120
UreaA  1.450  0.190  1.333  0.150
UreaA  1.590  0.180  1.337  0.170
UreaNY        1.160  0.140  1.192  0.140
UreaNY        1.260  0.150  1.296  0.130
UreaNY        1.480  0.170  1.161  0.160
UreaNY        1.540  0.220  1.749  0.180
;
PROC GLM data=wheat;
CLASS trt;
MODEL N = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL P = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL K = trt;
MEANS trt / tukey;
RUN;
```

```
PROC GLM data=wheat;
CLASS trt;
MODEL S = trt;
MEANS trt / tukey;
RUN;
```

SAS code for 2014 harvested wheat grain; analysis for N, P, K, and S.

```
title1 '2014 Wheat Grain';
DATA wheat;
INPUT trt$ N P K S;
CARDS;
Cntrl   2.112  0.470  0.480  0.150
Cntrl   2.112  0.480  0.480  0.150
Cntrl   2.192  0.470  0.490  0.150
Cntrl   2.352  0.450  0.450  0.160
Comp  2.144  0.470  0.470  0.150
Comp  2.432  0.500  0.500  0.160
Comp  2.448  0.470  0.470  0.170
Comp  2.496  0.490  0.500  0.160
CompNY       1.888  0.470  0.480  0.140
CompNY       2.144  0.470  0.480  0.150
CompNY       2.224  0.470  0.470  0.140
CompNY       2.272  0.440  0.460  0.160
Urea    3.056  0.530  0.530  0.210
Urea    3.072  0.500  0.500  0.200
Urea    3.168  0.530  0.550  0.210
Urea    3.744  0.570  0.590  0.230
UreaA  2.864  0.520  0.550  0.190
UreaA  3.088  0.570  0.550  0.220
UreaA  3.472  0.570  0.580  0.220
UreaA  3.792  0.590  0.610  0.230
UreaNY        3.200  0.500  0.560  0.210
UreaNY        3.408  0.560  0.600  0.220
UreaNY        3.664  0.580  0.590  0.220
UreaNY        3.792  0.640  0.660  0.230
;
PROC GLM data=wheat;
CLASS trt;
MODEL N = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL P = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL K = trt;
MEANS trt / tukey;
RUN;
```

```
PROC GLM data=wheat;
CLASS trt;
MODEL S = trt;
MEANS trt / tukey;
RUN;
```

SAS code for 2015 harvested wheat straw; analysis for N, P, K, and S.

```
title1 '2015 Wheat Straw';
DATA wheat;
INPUT trt$ N P K S;
CARDS;
Cntrl  0.624  0.200  1.440  0.120
Cntrl  0.640  0.180  1.550  0.100
Cntrl  0.800  0.200  1.820  0.120
Cntrl  0.800  0.220  1.210  0.100
Comp  0.544  0.180  1.540  0.100
Comp  0.640  0.180  1.790  0.110
Comp  0.832  0.180  1.670  0.130
Comp  0.880  0.230  1.640  0.130
Urea  0.784  0.150  2.210  0.140
Urea  0.976  0.120  2.670  0.140
Urea  1.008  0.130  2.140  0.140
Urea  1.360  0.160  2.990  0.180
UreaA 0.784  0.110  2.330  0.120
UreaA 0.800  0.140  2.460  0.140
UreaA 0.880  0.110  2.490  0.130
UreaA 1.040  0.140  2.810  0.160
UreaNY     0.944  0.150  2.630  0.130
UreaNY     1.008  0.190  2.290  0.160
UreaNY     1.072  0.140  2.740  0.150
UreaNY     1.216  0.130  2.640  0.150
;
PROC GLM data=wheat;
CLASS trt;
MODEL N = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL P = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL K = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL S = trt;
MEANS trt / tukey;
RUN;
```

SAS code for 2015 harvested wheat grain; analysis for N, P, K, and S.

```
title1 '2015 Wheat Grain';
DATA wheat;
INPUT trt$ N P K S;
CARDS;
Cntrl   2.080  0.500  0.580  0.140
Cntrl   2.080  0.500  0.550  0.140
Cntrl   2.096  0.460  0.510  0.140
Cntrl   2.096  0.480  0.540  0.140
Comp    2.048  0.490  0.590  0.130
Comp    2.112  0.480  0.520  0.140
Comp    2.128  0.490  0.560  0.140
Comp    2.144  0.520  0.580  0.150
Urea    2.416  0.450  0.550  0.150
Urea    2.480  0.440  0.540  0.170
Urea    2.736  0.510  0.710  0.170
Urea    2.768  0.520  0.730  0.180
UreaA   2.432  0.480  0.630  0.160
UreaA   2.448  0.480  0.680  0.160
UreaA   2.624  0.340  0.460  0.130
UreaA   2.640  0.470  0.640  0.170
UreaNY         2.368  0.470  0.590  0.150
UreaNY         2.528  0.490  0.600  0.160
UreaNY         2.784  0.480  0.680  0.180
UreaNY         2.784  0.470  0.600  0.170
;
PROC GLM data=wheat;
CLASS trt;
MODEL N = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL P = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL K = trt;
MEANS trt / tukey;
RUN;
PROC GLM data=wheat;
CLASS trt;
MODEL S = trt;
MEANS trt / tukey;
RUN;
```

SAS code for 2014 corn harvested analysis for biomass, N, P, K and S.

```
title1 '2014 Corn';
DATA corn;
INPUT trt$ Bio N P K S;
CARDS;
Cntrl	3006.06		0.73	0.34	1.58	0.07
Cntrl	4704.8	0.98	0.42	1.73	0.08
Cntrl	4898.77		1.00	0.33	1.57	0.08
Cntrl	5477.72		1.09	0.34	1.75	0.13
CompA		3757.23		0.63	0.16	1.70	0.09
CompA		4838.63		0.67	0.21	1.67	0.13
CompA		5572.62		1.38	0.33	1.50	0.13
CompA		8859.12		1.46	0.29	1.36	0.14
CompB		2929.96		0.73	0.26	1.51	0.10
CompB		3202.51		0.95	0.27	2.32	0.08
CompB		4502.38		1.02	0.22	1.52	0.13
CompB		6460.51		1.84	0.31	1.48	0.13
Urea	3025.06		1.03	0.18	1.62	0.14
Urea	4968.27		1.58	0.31	1.40	0.11
Urea	5622.28		1.69	0.29	1.56	0.15
Urea	8938.34		1.80	0.23	1.49	0.14
UreaA	4020.03		1.48	0.22	1.93	0.07
UreaA	4713.37		1.79	0.29	1.53	0.08
UreaA	5450.55		1.89	0.29	1.66	0.13
UreaA	6280.93		2.05	0.30	1.41	0.10
UreaNY		4264.49		0.92	0.16	2.09	0.08
UreaNY		5758.68		1.04	0.17	1.57	0.09
UreaNY		5822.07		1.53	0.20	2.23	0.09
UreaNY		7586.31		1.87	0.23	1.75	0.15
;
PROC anova data=corn;
CLASS trt;
MODEL Bio = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
CLASS trt;
MODEL N = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
CLASS trt;
MODEL P = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
```

```
CLASS trt;
MODEL K = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
CLASS trt;
MODEL S = trt;
MEANS trt / tukey;
RUN;
```

SAS code for 2015 corn harvested analysis for biomass, N, P, K and S.

```
title1 '2015 Corn';
DATA corn;
INPUT trt$ Bio N P K S;
CARDS;
Cntrl	4271.73		0.86	0.31	1.15	0.08
Cntrl	4323.91		0.97	0.33	1.88	0.10
Cntrl	5212.82		1.29	0.35	1.36	0.11
CompA		2065.36		0.58	0.23	1.21	0.06
CompA		3595.53		0.62	0.26	1.15	0.06
CompA		4193.96		0.79	0.34	1.05	0.07
CompB		2612.78		0.94	0.36	1.20	0.08
CompB		4687.58		0.95	0.37	1.24	0.08
CompB		4846.89		0.96	0.35	1.16	0.08
Urea	3386.1 1.05	0.36	1.24	0.10
Urea	3594.84		1.22	0.33	1.34	0.11
Urea	4561.32		1.48	0.34	1.35	0.12
UreaA	3594.85		1.16	0.28	1.33	0.08
UreaA	3978.34		1.29	0.33	1.18	0.10
UreaA	4587.05		1.35	0.29	1.17	0.10
UreaNY		4093.79		0.84	0.23	1.21	0.07
UreaNY		5009.55		1.01	0.32	1.04	0.08
UreaNY		5577.18		1.04	0.32	1.12	0.08
;
PROC anova data=corn;
CLASS trt;
MODEL Bio = trt;
MEANS trt / tukey;
RUN;PROC anova data=corn;
CLASS trt;
MODEL N = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
CLASS trt;
MODEL P = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
CLASS trt;
MODEL K = trt;
MEANS trt / tukey;
RUN;
PROC anova data=corn;
CLASS trt;
MODEL S = trt;
```

```
MEANS trt / tukey;
RUN;
```