THE EFFECT OF ESN NITROGEN FERTILIZER ON BERMUDAGRASS FORAGE PRODUCTION

by

KATHRYN MARIE PAYNE

(Under the Direction of Dennis W. Hancock)

ABSTRACT

Due to regulation of ammonium nitrate (AN), forage producers have become more reliant on urea-based fertilizers. Environmentally Smart Nitrogen (ESN) is a polymer-coated urea that physically regulates N release. ESN has been shown to reduce volatilization losses caused by urea, but it releases N too slowly to be effective on early harvest yields. This study was designed to determine the response of ESN:urea blends (0, 50, 75, and 100% ESN) applied twice per season on 'Russell' bermudagrass [*Cynodon dactylon* (L.) Pers.] forage production compared to conventional treatments (AN and urea) split in four applications per season. All treatments received 336 kg N ha⁻¹ season⁻¹. The 50% and 75% ESN blends increased total DM yield, N removal, CP, and TDN when compared to conventional urea, while still being comparable to AN. The 50% and 75% ESN blends were also shown to be cost-effective alternatives to conventional AN and urea systems.

INDEX WORDS: Bermudagrass, Fertilizer, Enhanced efficiency, Slowrelease, Polymer-coated urea, Nitrogen recovery, Yield, Ammonia volatilization, Nitrate, ESN[®], Urea, Ammonium nitrate, Partial budget, Economic analysis

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DEDICATION

I would like to dedicate this thesis to my family, friends, and professors who have played an important role in my life and education.

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TABLE OF CONTENTS

ACKNOV	WLEDGEMENTS	V
LIST OF	TABLESv	iii
LIST OF	FIGURES	X
LIST OF	COMMON ABBREVIATIONS	xi
СНАРТЕ	R	
1	INTRODUCTION	1
	REFERENCES	5
2	LITERATURE REVIEW	7
	REFERENCES	16
3	THE EFFECT OF ESN:UREA BLENDS ON THE YIELD, N UPTAKE, N	
	RECOVERY, AMMONIA VOLATILIZATION LOSS, FORAGE	
	QUALITY, AND NITRATE ACCUMULATION OF BERMUDAGRASS	
	HAY	22
	ABSTRACT	23
	INTRODUCTION	24
	MATERIALS AND METHODS	25
	RESULTS AND DISCUSSION	31
	CONCLUSION	37
	REFERENCES	39

4	BASIC COST ANALYSIS OF ESN:UREA BLENDS COMPARED TO	
	CONVENTIONAL SYSTEMS OF AN AND UREA ON BERMUDAGRA	ASS
	HAY PRODUCTION	53
	ABSTRACT	54
	INTRODUCTION	55
	MATERIALS AND METHODS	56
	RESULTS AND DISCUSSION	58
	CONCLUSION	60
	REFERENCES	61
5	SUMMARY AND CONCLUSION	63
NDI	IX	65
A	SELECT TABLES AND FIGURES	65
	4 5 NDI A	 4 BASIC COST ANALYSIS OF ESN: UREA BLENDS COMPARED TO CONVENTIONAL SYSTEMS OF AN AND UREA ON BERMUDAGRA HAY PRODUCTION ABSTRACT INTRODUCTION MATERIALS AND METHODS RESULTS AND DISCUSSION CONCLUSION REFERENCES 5 SUMMARY AND CONCLUSION NDIX A SELECT TABLES AND FIGURES

LIST OF TABLES

Page
Table 3.1: Soil chemical attributes in the 0- to 10-cm depth prior to treatment
application
Table 3.2: Treatments, number of applications, and application rates at green-up and after
each harvest (H1, H2, H3, H4)
Table 3.3: Harvest dates for Rome and Eatonton sites in 2010, 2011, and 2012 41
Table 3.4: Monthly rainfall (mm), 30-yr mean monthly rainfall (mm), and mean
maximum and minimum air temperature (°C) for the Rome and Eatonton sites in
2010, 2011, and 2012
Table 3.5: Analysis of variance for the effects and interactions of treatment, site, and year
on bermudagrass forage DM yield and N uptake during a 3-yr period 43
Table 3.6: Mean total seasonal forage yield averages across two sites and the 2010, 2011,
and 2012 seasons
Table 3.7: Mean seasonal N uptake averaged across two sites for the 2010, 2011, and
2012 seasons
Table 3.8: Analysis of variance for the effects and interactions of treatment, site, and year
on the amount of N recovered in bermudagrass forage during a 3-yr period 44
Table 3.9: Mean percentage of N applied that is recovered in the harvested forage during
the whole season as a mean across two sites and 2010, 2011, and 2012 seasons 45

able 3.10: Analysis of variance for the effects and interactions of treatment, site, and	
year on the amount of ammonium trapped in acid traps following the H2 fertilizer	
application during a 2-yr period 45	
Table 3.11: The amount of ammonium in the ammonia volatilization acid traps following	
the H2 application of treatments averaged over the 2011 and 2012 seasons and	
both sites	
Table 3.12: Analysis of variance for the effects and interactions of treatment, site, and	
year on bermudagrass forage crude protein (CP), total digestible nutrients (TDN),	
and relative forage quality (RFQ) during a 3-yr period 46	
Table 3.13: Mean crude protein (CP), total digestible nutrients (TDN), and relative forage	
quality (RFQ) in harvested forage samples averaged across two sites and three	
years	
Table 3.14: Analysis of variance for the effects and interactions of treatment, site, and	
year on the accumulation of nitrate in bermudagrass forage across two sites and	
three years	
Table 3.15: Mean nitrate (NO ₃ -N) accumulation in harvested forage averaged across two	
sites and three years	
Table 4.1: Profits or losses (\$/ha) associated with implementing ESN:Urea blend systems	
when compared to conventional AN and Urea	

LIST OF FIGURES

ly after H2 (A) and enclosed	Figure 3.1: Ammonia volatilization traps installed immed
	by the PVC pipe chambers (B) for 7 days in the f

- Figure 3.4: Volumetric water content (cm³ water cm⁻³ soil) fluctuation throughout the growing season of Rome in 2010 (a), 2011 (b), 2012 (c) and of Eatonton in 2010 (d), 2011 (e), and 2012 (f). Arrows denote the timing of the first (H1), second (H2), third (H3), and fourth (H4) harvests during the 2010, 2011, and 2012 growing seasons.

LIST OF COMMON ABBREVIATIONS

0 ESN:100 Urea- 100% urea treatment; 50 ESN:50 Urea- 50% ESN blended with 50% urea treatment; 75 ESN:25 Urea- 75% ESN blended with 25% urea treatment; 100 ESN:0 Urea- 100% ESN; AN- Ammonium nitrate; CON- Control treatment; CP- Crude protein; EE- enhanced-efficiency nitrogen; ESN- Environmentally Smart Nitrogen[®]; H1- Harvest one; H2- Harvest two; H3- Harvest three; H4- Harvest four; N- Nitrogen; RFQ- Relative forage quality; TDN- Total digestible nutrients

CHAPTER 1

INTRODUCTION

Nitrogen (N) fertilization is a critical component of bermudagrass ([*Cynodon dactylon* (L.) Pers.] hay and forage production. In the past, ammonium nitrate (AN) was the primary source of N fertilizer. As a consequence of a significant regulatory burden on agribusinesses that sell and distribute AN, most forage producers have been unable to procure AN fertilizer in recent years and have shifted to the use of urea-based fertilizers as a replacement. With the increased use of surface-applied urea fertilizers on pastures and hayfields, the risk of ammonia volatilization loss is substantially greater (Hargrove and Kissel, 1979; Rawluk, 2001; Silveira et al., 2007; Massey et al., 2011).

Research has focused on improving urea-based fertilizers and minimizing economic and environmental risks. Several enhanced efficiency (EE) fertilizers have been produced to reduce this risk of N loss. Theoretically, these fertilizers are able to inhibit the rapid conversion of urea to ammonia by chemically inhibiting the urease enzyme activity in the soil or physically slowing the release of the fertilizer.

Environmentally Smart Nitrogen (ESN[®], Agrium Advanced Technologies, Brantford, Ontario, Canada) is a polymer-coated, controlled-release N fertilizer. The polymer coating acts as a physical barrier to the wetting and release of urea into the soil (Connell, 2011). Water slowly diffuses through the polymer coating, dissolves the urea granule into solution, and the urea solution slowly diffuses across the polymer coating by osmosis, with diffusion rates dependent upon soil moisture and temperature (Haderlein et al., 2001; McKenzie et al., 2007; Connell et al., 2011; Golden et al., 2011). Because the polymer coating can be made thinner or thicker, this technology allows a customizable product that can control the release of N to make it consistent with the needs of the crop.

Although ESN has primarily been used in row-crop agronomic systems, previous research in Georgia has shown that the use of ESN for bermudagrass forage production substantially reduces the amount of ammonia lost through volatilization (Connell et al., 2011). While ESN was very effective in reducing volatilization loss, yields from ESN-treated bermudagrass were lower than alternative N sources. This led the authors to conclude that the N was released too slowly from the polymer coating to be an effective N source (as formulated in that study) during growth periods early in the season.

To relieve this delay in N release, a potential solution is to blend the polymercoated ESN with untreated urea. Blending ESN and urea may reduce the risk of ammonia volatilization while providing the immediate release of nitrogen needed for early bermudagrass harvest yields. If forage yields and quality were to increase, ESN/urea blends could be a justifiable substitution for AN as a N source in forage systems.

Using ESN/urea blends could also lead to reducing the number of N fertilizer applications per season. The current recommendation is to split the seasonal N requirement into four equal applications. If this number could be reduced to two because of a slow release form of N, then the producer would save the cost of the extra expense and effort of the two additional applications. Theoretically, this reduction could be possible as long as it resulted in consistent bermudagrass forage yields throughout the growing season. Splitting these ESN blend fertilizer applications only twice per growing season could also help to be more cost-effective than applying conventional fertilizer recommendations split into four applications.

Therefore, the goal of this research project was to evaluate the potential of blending ESN and untreated urea (0, 50, 75, and 100% ESN) into two equally split applications relative to the conventional recommendation of applying AN or splitting among four applications during the growing season. The objectives of this study were to compare these ESN blends and conventional systems in terms of:

- total seasonal forage production and yield distribution throughout the growing season. Evaluating the total seasonal forage produced can determine if these ESN/urea blends will be an effective substitute for AN. Forage yield distribution could show that the slower release of N by these blends provides more consistent harvest yields.
- forage nutritive quality by measuring CP, TDN, and RFQ. Although forage quality is not critically impacted by N fertilization, it will be important to determine that these ESN/urea blends will provide forage quality comparable to currently recommended fertilizer strategies.
- 3. amount of ammonia lost through volatilization. The potential for these ESN blends to reduce volatilization loss is a key reason they are considered for comparison against currently recommended practices. Increasing the proportion of ESN in the blend should lead to a reduction in N lost through volatilization.
- 4. recovery of the total N applied by the plant. Increased N content in the harvested forage of ESN/urea blends will be a resourceful indicator that the

forage is recovering the N applied. It is also important to determine the amount of NO₃-N found in the harvested forage, acknowledge that levels are not high enough to risk livestock to nitrate toxicosis.

5. cost-effectiveness through a basic cost analysis. ESN/urea blends have the potential to reduce input costs and thus increase net revenue by reducing the number of fertilizer applications per growing season.

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CHAPTER 2

LITERATURE REVIEW

Response of Bermudagrass to Nitrogen Application

Research has shown that bermudagrass is very responsive to N application and can produce 20 to 55 kg DM for every kg N ha⁻¹ added (Burton and DeVane, 1952; Burton and Jackson, 1962; Mathias et al., 1978; Osborne et al., 1999; Silveira et al., 2007; Stone et al., 2012). Along with the increase in yields, higher rates of N consistently increase the protein concentration in bermudagrass (Burton et al., 1969; Prine and Burton, 1956; Adeli et al., 2005). Osborne et al. (1999) found that while N rates > 672 kg N ha⁻¹ resulted in a doubling of forage yield, the percent of N recovered decreased with rates higher than 224 kg N ha⁻¹. Silveira et al. (2007) also found that as application rates increased, N recovery decreased on bermudagrass production systems. Agyin-Birikorang et al. (2012) suggest that application rates higher than 70 kg N ha⁻¹ as AN on sandy soils will result in NO₃-N concentrations in the leachate that exceed the maximum contaminant limit in the groundwater. Distributing the N fertilizer application throughout the growing season into split applications has been shown to increase yield by 0.67 to 1.6 kg ha⁻¹ in late summer cuttings (Burton and Jackson, 1962). Split applications have also shown to increase protein and N content, as well as the amount of N recovered (Burton and DeVane, 1952; Burton et al., 1969; Connell et al., 2011).

Transition to Urea-Based N Fertilizers

Due to the heavy regulation of ammonium nitrate (AN), this ideal N source has become less available. Producers have become more reliant on urea, a lower cost alternative that has become the most widely used N source around the world. Multiple research studies have found that the use of urea leads to lower yields than ammoniumbased fertilizers. Osborne et al. (1999) found that AN increased Midland bermudagrass yield by up to 29% when compared to urea. Over a three year study on two soil types, Silveira et al. (2007) found that urea produced 92% of the bermudagrass forage yielded by the AN treatment. Other studies have found that AN produces higher bermudagrass yields (Burton and DeVane, 1952; Westerman et al., 1983; Connell et al., 2011; Massey et al., 2011). It has been commonly acknowledged that ammonia volatilization has reduced the effectiveness of N fertilizers on forage yield and N recovery (Oberle and Bundy, 1987; Liantie et al., 1993; Blennerhassett et al., 2006; Connell et al., 2011; Massey et al., 2011). Reports of ammonia loss from the application of urea in forage systems have exhibited a wide range, with estimated losses on the low end being 10% of the total N applied (Lightner et al., 1990) and Vaio et al. (2008) reporting losses of up to 46% of the total N applied.

Ammonia Volatilization from Urea

The amount of ammonia volatilization is affected by several soil and environmental factors, including soil pH; soil and air temperature; humidity; amount of thatch, residual forage, and detritus on the soil surface; and fertilizer source, rate, timing, and application method, as well as the method used to assess volatilization loss. Urea (CO(NH₂)₂), an organic N source, must be hydrolyzed to ammonium (NH₄⁺) and bicarbonate (HCO₃⁻) (Eq. 2.1) to provide plant available nitrogen (ammonium and nitrate). This hydrolysis is catalyzed by urease, an enzyme that is ubiquitous and abundant in the soil, especially in the organic matter and thatch at the soil surface.

Eq. 2.1.
$$CO(NH_2)_2 + H^+ + 2H_2O ----(Urease) ---> 2NH_4^+ + HCO_3^-$$

The hydrolysis of urea to ammonium and bicarbonate occurs rapidly, ammonium levels build up, and the soil pH significantly increases around the urea pellet. The ammonium produced can go through the process nitrification to generate nitrate, the N form that is more quickly taken up by plants. If the ammonium is not taken up by the plant or nitrified quickly enough, there is a risk that the ammonium will be converted to ammonia (NH₃) gas and H⁺, described in Eq. (2.2). Consequently, ammonia loss is increased at higher soil pH and urea concentrations (Cabrera et al., 1991).

Eq. 2.2.
$$NH_4^+ ---> NH_3 + H^+$$

Factors that increase the rate of hydrolysis include high urease activity, high soil pH, increased soil temperature, water availability, and high humidity (Bremmer and Douglas, 1971; Bouwmeester et al., 1985; Black et al., 1987; Reynolds and Wolf, 1987). Because of the abundance of organic matter, detritus, and thatch in permanent pasture and hay fields, urease is in greater abundance in forage crops and crops produced with conservation tillage than in conventionally tilled fields.

High soil pH and temperature drives the conversion of NH₄ produced during hydrolysis into NH₃. The ammonia may be lost to the atmosphere through volatilization if it has not been properly incorporated into the soil. Although incorporating the urea fertilizer directly into the soil is a more effective method of reducing this NH₃ loss

(Bouwman et al., 2002), it is not a realistic option in a forage system. Surface applied urea must be incorporated in the soil matrix through diffusion with water.

Ammonia volatilization has been shown to increase with several environmental conditions, such as high temperatures, humidity, wind, soil pH > 7, and soils with low cation exchange capacities. Volatilization also increases when urea is applied to a moist soil followed by dry weather and when application is followed by rain events producing less than 2 cm of water (Bouwmeester et al., 1985; Black et al., 1987; Bowman et al., 1987). Bowman et al. (1987) also showed that a maximum volatilization loss was reached when 0.2 cm water was added to Kentucky bluegrass turf, just enough to dissolve the urea but not enough to incorporate the urea into the soil. Volatilization losses from urea are most likely to occur within ten days of urea application (Stevens et al., 1989; Blennerhassett et al., 2006; Huckaby et al., 2012).

Several enhanced efficiency N fertilizers have been introduced to reduce N lost to volatilization by slowing the rapid conversion of urea to ammonia by chemically inhibiting the activity of the urease enzyme in the soil or by physically slowing the release of the fertilizer.

ESN as an Enhanced Efficiency Nitrogen Fertilizer

Environmentally Smart Nitrogen (ESN) (ESN[®], Agrium Advanced Technologies, Brantford, Ontario, Canada) is a polymer-coated, controlled-release nitrogen fertilizer. The polymer coating acts as a physical barrier to the wetting and release of urea into the soil (Connell, 2011). Water slowly diffuses through the polymer coating, dissolves the urea pellet into solution, and the urea solution slowly diffuses by osmosis across the polymer coating, with diffusion rates dependent upon soil moisture and temperature (Fig. 2.1; Haderlein et al., 2001; McKenzie et al., 2007; Connell et al., 2011; Golden et al., 2011). Because the polymer coating can be made thinner or thicker, this technology allows a customizable product that could theoretically control the release of N to make it consistent with the nitrogen needs of the crop. Studies evaluating the release of N from the polymer coating on different soils indicate that N release typically begins between 7-14 d after application and reaches 70-80% release between 42-56 d after application (Cahill et al., 2010; Golden et al., 2011). Golden et al. (2011) reported that increased soil temperature positively improves N release and that soil temperature had a greater effect than soil series and moisture.

Most of the research with ESN to date has been on its use in agronomic field crops. However, the research has demonstrated mixed results. In Minnesota, ESN was able to increase N recovery by 10%, decrease nitrate leaching by 26%, and produce similar grade A potato yields when compared to soluble N (Wilson et al., 2009; Wilson et al., 2010). However, a study comparing ESN and untreated urea in a no-till canola cropping system showed that canola yield and seed oil were similar in 14 and 19 of 20 site years, respectively (Blackshaw et al., 2011). In Missouri, the polymer-coated urea was observed to reduce NO₃-N concentration in the groundwater by 51 to 63% in the early season, suggesting ESN may reduce NO₃-N leaching (Nelson et al., 2009). In Arkansas, ESN increased nitrogen recovery efficiency by 19% on continuous corn production (Halvorson and Bartolo, 2013).

Although the use of enhanced efficiency N fertilizers did not affect corn grain yield in Kentucky (Sistani et al., 2014), the most limiting trait associated with the application of polymer-coated urea is reduced crop yields. ESN did not increase corn

grain yield or N uptake when compared to urea in Missouri (Nelson et al., 2009). In North Carolina, ESN reduced corn and winter wheat grain yields when compared to urea ammonium nitrate (Cahill et al., 2010).

While it was seen that polymer-coated urea decreased wheat yields compared to untreated urea, the higher N and protein concentrations was attributed to the slow release nature of ESN (Farmaha and Sims, 2013b). Grain yield and protein concentration in winter wheat production were reduced when ESN was surface applied and compared to urea and ammonium nitrate in Canada (McKenzie et al., 2010).

The use of ESN polymer-coated urea on forage systems has not been extensively established as for row crops. A previous study in Georgia reported that the use of ESN reduced the amount of NH₃ volatilization by 81% when compared to untreated urea (Connell et al., 2011). This study also showed that N was released too slowly, resulting in a reduction of bermudagrass forage yield in early harvests. Field studies in Utah of polymer coated urea on Kentucky bluegrass and perennial ryegrass reduced NH₃ volatilization by 41-50% compared to untreated urea (Story et al., 2011).

Despite the mixed results with using ESN, one can conclude that ESN significantly reduces the loss of N through NH₃ volatilization, reduces NO₃-N leaching, improves N recovery/N use efficiency, and may improve crop quality. A possible solution for the reduced yields associated with polymer-coated urea may be applying it in blends with untreated urea. This may provide the immediate need of N by the crop from urea while reducing the amount of N loss with ESN.

A Case for Blending ESN and Urea

In Michigan, a 75% ESN: 25% urea blend on corn resulted in higher yields than untreated urea when applied at pre-plant; sidedress applications yielded higher with blends higher in urea (Steinke, 2012). A study in Minnesota evaluated the effectiveness of blending ESN and urea on hard red spring wheat and found that as the proportion increased, protein concentrations increased (Farmaha and Sims, 2013a). This study also showed that the grain yield was significantly affected in one location, reducing yields as the proportion of ESN increased. These preliminary examinations of blends of ESN and untreated urea appear promising, but work is needed in all agronomic crops, under a variety of conditions, and at different proportions of ESN:urea. Although blends have yet to be evaluated in forage systems, there appears to be the potential to improve yields and nutritive value by blending ESN and urea while mitigating environmental loss in forage production systems.

Nitrate Accumulation in Bermudagrass

Although bermudagrass forage yield production is benefitted by the application of N, there is a potential risk of forage nitrate accumulation that can reach toxic levels for livestock consumption. Forage concentrations starting from 2,500 ppm NO₃-N have been considered to lead to subclinical toxicosis, and concentrations above 4,500 ppm NO₃-N pose a higher risk of acute toxicosis (Wright and Davison, 1964) that may lead to death shortly after consumption. Forage systems typically accumulate dangerous levels of nitrates when under environmental stress. Environmental conditions like abnormally high or low temperatures, humidity, reduced sunlight and light intensity, shorter day length, and reduced rainfall have been reported to contribute to nitrate accumulation (Davidson et al., 1941; Gomm, 1979; Veen and Kleinendorst, 1985; Bergareche and Simon, 1989).

Of these environmental conditions, drought stress has been most associated with nitrate accumulation (Davidson et al., 1941).

Accumulation of nitrates in forage crops has been attributed to excessive N applications. Unlike environmental conditions, this can be remedied by using sound forage management practices. Splitting N applications throughout the season and waiting to harvest or graze a few days after a rain following drought have been suggested to reduce the risk of exceeding toxic levels of nitrate accumulation (Wright and Davison, 1964; Connell et al., 2011).

Although choosing a drought-tolerant forage species, like bermudagrass, can also be helpful in reducing the risk of nitrate accumulation, there have still been reports of high levels of nitrate accumulation (Lovelace et al., 1968; Hojjati et al., 1972; Connell et al., 2011). Connell et al. (2011) showed that ammonium nitrate was more likely to accumulate nitrates, but enhanced efficiency N sources split twice throughout the growing season did not increase or decrease the risk of toxic nitrate concentrations compared to urea.

Economic Analysis

Another major concern about using polymer-coated urea has been the high cost associated with this fertilizer technology. Though the polymer-coated urea would clearly be more expensive than untreated urea, ESN could prove cost-effective if yield and nutritive value is improved in response to the inclusion of at least substantial amounts of ESN. The implementation of ESN/urea blends could reduce the cost of physical application by reducing the number of applications and trips across the field made over the season. The price of hay may also play a role in the cost-effectiveness of these fertilizer blends, as hay price is generally a reflection of its supply and demand resulting from the moisture and fertilizer competency effect on yield.

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CHAPTER 3

THE EFFECT OF ESN: UREA BLENDS ON THE YIELD, N UPTAKE, N RECOVERY, AMMONIA VOLATILIZATION LOSS, FORAGE QUALITY, AND NITRATE ACCUMULATION OF BERMUDAGRASS HAY¹

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Abstract

As a result of the lack of availability of ammonium nitrate, forage producers increasingly use urea-based fertilizers, which are at greater risk of nitrogen (N) loss to ammonia volatilization. Environmentally Smart Nitrogen (ESN[®], Agrium Advanced Technologies, Brantford, Ontario) is a polymer-coated N fertilizer that controls the release of N through temperature-controlled diffusion. The objectives of this study were to determine the effect of different proportions of ESN and untreated urea (0, 50, 75, and 100% ESN with the balance as urea) on agronomic performance and nutritive quality of 'Russell' bermudagrass [Cynodon dactylon (L.) Pers.], as compared to conventional treatments of AN and urea. The study was conducted at two experiment station facilities (near Eatonton and Rome, GA, respectively) in small plots (2.13 m x 4.57 m) using a randomized complete block design with four replications. Nitrogen was applied at 336 kg N ha⁻¹ season⁻¹, but was split over the season into two equal applications for the ESN treatments and four equal applications for the AN and urea conventional treatments. The 50 and 75% ESN blends were 10 and 6.1% higher in total DM yield, and 14.4 and 19.5% more in total N removal (respectively) when compared to a conventional urea treatment, while still being comparable to AN. As the proportion of ESN increased, the amount of N lost through volatilization decreased, with the 75 and 100% ESN blends being comparable to the control plots. These ESN blends decreased nitrate accumulation by an average 16.8% from the conventional AN treatment. These results support the development of a recommendation of blending ESN at a rate of 50 and 75% with urea as a substitute for AN.

Introduction

Nitrogen (N) fertilization is a critical component of bermudagrass [*Cynodon dactylon* (L.) Pers.] hay and forage production. In the past, ammonium nitrate (AN) was the primary source of N fertilizer. Because of the regulatory burden on agribusiness that sell and distribute AN, most forage producers have been unable to acquire AN fertilizer in recent years and have shifted to the use of urea-based fertilizers as a replacement. With the increased use of these surface applied urea fertilizers on pastures and hayfields, the risk of ammonia volatilization loss is substantially greater (Hargrove and Kissel, 1979; Rawluk, 2001; Silveira et al., 2007; Massey et al., 2011).

Research has focused on improving urea-based fertilizers and minimizing economic and environmental risks. Several enhanced efficiency (EE) fertilizers have been produced to reduce this risk of N loss. Theoretically, these fertilizers are able to inhibit the rapid conversion of urea to ammonia by chemically inhibiting the urease enzyme activity in the soil or physically slowing the release of the fertilizer.

Environmentally Smart Nitrogen (ESN[®], Agrium Advanced Technologies, Brantford, Ontario, Canada) is a polymer-coated, controlled-release N fertilizer. While ESN was very effective in reducing volatilization loss (Connell et al., 2011), yields from ESN treated bermudagrass were lower than alternative N sources. This lead the authors to conclude that the N was released too slowly from the polymer coating to be an effective source (as formulated in that study) during growth periods early in the season.

To relieve this delay in N release, a potential solution would be to blend the polymer-coated ESN with untreated urea. Blending ESN and urea may reduce the risk of ammonia volatilization while providing the immediate release of N needed for early
bermudagrass harvest yields. If forage yields and quality were to increase, ESN/urea blends could be a justifiable substitute for AN as an N source strategy in forage systems.

Using ESN/urea blends could lead to reducing the number of N fertilizer applications per season. The current recommendation of splitting urea in four equal applications could be reduced to two. Theoretically, this reduction would be made possible due to the slow release of ESN, resulting in consistent bermudagrass forage yields throughout the growing season.

Therefore, the goal of this research project was to evaluate the potential of blending ESN and untreated urea (0, 50, 75, and 100% ESN) in two equally split applications relative to the conventional recommendation of applying AN or urea split four times throughout the growing season. The objectives of this study were to compare these ESN blends and conventional systems for: total seasonal forage production and yield distribution throughout the growing season, forage nutritive quality, amount of ammonia lost through volatilization, recovery of the total N applied, and forage nitrate accumulation.

Methods And Materials

Sites

The experiment was conducted over three years (2010-2012) and at two sites. One site was on the University of Georgia's Northwest Georgia Research and Education Center's Floyd County Unit near Rome, GA (Latitude 34.3° N, Longitude 85.1° W, elevation 184m). The soils at this site were classified as Ketona silt loam (Fine, mixed, superactive, thermic Vertic Epiaqualfs) and had a high yield potential of 31 Mg ha⁻¹ and a

pH value of 6.03. The second site was on the University of Georgia's Central Georgia Research and Education Center near Eatonton, GA (Latitude 33.4° N, Longitude 83.5°, elevation 165m). These soils were classified as Davidson loam (Fine, kaolinitic, thermic Rhodic Kandiudults) and have a moderate yield potential of 18 Mg ha⁻¹ and a pH value of 5.85. Table 3.1 shows the soil chemical attributes for both sites.

Treatments

There were seven treatments evaluated (Table 3.2). All seven of the treatments received a total season application rate of 336 kg N ha⁻¹. The two conventional treatments, ammonium nitrate (AN) and untreated urea (Urea), were split into four equal applications with one at green-up (on or around 15 April; GU), after the first harvest (H1), after the second harvest (H2), and after the third harvest (H3). The other ESN:Urea blend treatments (0, 50, 75, AND 100% ESN) were split equally and applied twice during the season with one at GU and one after H2. The ESN:Urea blend treatments included 0% ESN/ 100% untreated urea (0 ESN:100 Urea), 50% ESN/ 50% untreated urea (50 ESN:50 Urea), 75% ESN/ 25% untreated urea (75 ESN:25 Urea), and 100% ESN/ 0% untreated urea (100ESN:0Urea). Finally, a control treatment (CON) was included where no N was applied.

Experimental Design

The experimental design was a randomized complete block with four replications within each year and site. Plots $(2.1 \times 4.6 \text{ m})$ were delineated within a previously established stand of improved hybrid bermudagrass (cv. 'Russell') at both sites. To avoid potential residual N interference from the previous year, the plots were moved to a

different field location each year. Fertilizer treatments were applied by hand onto their respective plots. Plots were harvested four times per growing season with the first harvest generally on or about 15 June and subsequent harvests occurring at approximately monthly intervals (Table 3.3).

Forage Harvesting and Analysis

The forage was cut to a height of approximately 5 cm with a forage plot harvester and the mass was measured to an accuracy of ± 0.05 kg. Herbage grab samples of the harvested mass from each respective plot were also weighed, dried at 60°C for 48 hours, and dry weights were recorded. Dry samples were ground to pass through a 1-mm sieve for sample analysis.

Total N was measured on each sample using a FOSS NIR Systems model 6500 scanning monochromator (FOSS NIR Systems, Silver Spring, MD) that had been calibrated (SEC = 0.977, SECV = 1.04, $r^2 = 0.98$) using a subset of bermudagrass forage samples analyzed for total N via the combustion method using a LECO FP-428 nitrogen analyzer (LECO Corporation, St. Joseph, Michigan). The percentage of N recovery of was calculated using the following equation as described by Silveira et al., (2007).

Eq. 3.1. N Recovery (%) =
$$\frac{N_{removed}(fertilized \ plot) - N_{removed}(control \ plot) \times 100}{N_{rate} \ applied}$$

Forage nutritive value was also assessed using the FOSS NIR Systems model 6500 scanning monochromator along with the NIRS consortium (Hillsboro, WI) calibration for grass hay (13GH50-2 equation; Anonymous, 2013). Subsamples were

analyzed for nitrate (NO₃-N) concentration using the nitration of salicylic acid method described by (Cataldo et al., 1975). A Shimadzu UV-2450 spectrophotometer was used to measure the absorbance of the chromophore produced from the nitration of salicylic acid. The absorbance of the chromophore is directly proportional to the amount of NO₃-N present in the samples. Forage nutritive value and nitrate concentrations were analyzed over the full season by taking the mean forage quality produced by each experimental unit's four harvests. A complete analysis of the forage quality data is available in the Appendix.

Baseline for Urease Activity

Before fertilizer was applied on the day of H2, soil core samples were taken at both locations to determine the baseline urease activity in the respective soils. Cores were taken from random locations within the replications where ammonia volatilization traps were to be installed and separated into 0-5 cm and 5-10 cm depth interval segments. The soil samples were kept frozen in plastic storage bags until urease activity was analyzed using the no buffer method described by Tabatabai (1994), with analysis conducted on an ALPKEM rapid auto analyzer with a urea manifold.

Ammonia Volatilization Trap

Immediately following the N application after the second harvest (H2), ammonia (NH₃) volatilization was measured using an acid trap within an enclosed chamber. The fertilizer applied was calculated for the area of the chamber and carefully applied by hand to the area under the trap. The acid trap contained 100 mL of 0.1N H₂SO₄. This trap contained 10 meq H⁺ and had the capability of trapping up to 140 mg N. Although the

majority of ammonia volatilization occurs within 15 days after fertilizer application, Soares et al. (2012) found that ammonia volatilization peaks at three days after urea fertilizer application and gradually decreases after 6 days. The sampling period, 7 days, was designed so that the amount of NH₃ trapped would not exceed 50% of the trap's capacity to ensure adequate NH₃ trapping.

The acid trap (Fig. 3.1) was retained within a chamber constructed of a 32.5 cm length of schedule 12 PVC pipe (30.5 cm in diameter) that was placed 5 cm into the soil surface and covered with a PVC end-cap, giving the chamber volume to be 5880 cm³. Within the PVC chamber, the acid trap was contained in a 125-mL Nalgene (Thermo Fisher Scientific, Inc., Waltham, Massachusetts) plastic bottle within a loop of heavy wire, suspending the trap approximately 14 cm off the soil surface. The chambers were installed by first pressing an iron pipe (same diameter as the chamber) with a hydraulic post driver to make a 5-cm deep impression in the soil. The acid traps were then installed into the center of the impression and covered by the capped PVC chamber. The chambers were hammered into the previously made impression using a rubber mallet until it was 5 cm deep into the soil, ideally below the organic matter/ thatch layer. These acid traps and chambers were left on the plots for 7 days following this H2 fertilizer application. The acid traps were kept frozen until analysis.

The PVC enclosures create a microclimate that likely affects the trap environment and rate of volatilization. Although this procedure alters the natural volatilization environment and cannot be considered a true measurement of volatilization, this semiquantitative measurement allows the comparison of the relative differences among the fertilizer treatments. The method used in this experiment is semi-quantitative and is in no way meant to represent the total amount of volatilization from each plot.

The ammonia gas released from the fertilizer treatment and trapped in the H_2SO_4 was quantified using a RFATM-30 automated analyzer and salicylate-hypochlorite reagents in the procedure described by Crooke and Simpson (1971). Volatilization data were reported as NH₄-N (mg kg⁻¹). The extract was analyzed for NH₄-N (Mulvaney, 1996) on an Alpkem auto-analyzer (RFA-300; Alpkem Corp., Clackamas, OR).

Environmental Measurements

Data collected by weather stations located at each experiment station were used when considering their effect on ammonia volatilization. The parameters considered include: daily rainfall (mm), maximum and minimum daily temperatures (°C), volumetric water content (cm³ water cm⁻³ soil), and mean relative humidity (%). Volumetric water content was measured to a depth of 0.31 meters.

Statistics

The data were analyzed using PROC MIXED (SAS Institute, 2009) with treatments, site, and year as fixed effects and replications as random effects. The Tukey's method of mean separation was used to make pair-wise comparisons on treatments. The statistical analysis was conducted on nine response variables: total seasonal yield, yield distribution within the growing season (H1, H2, H3, and H4), N concentration, N recovery, NO₃-N concentration, NH₄-N concentration, CP, TDN, and RFQ index. Total seasonal yield and N recovery were recorded on an annual level, while all other variables were recorded by harvest (H1, H2, H3, H4). Analysis was done for each response

variable for all seven treatments using data from the three years. Differences among treatments were considered significant at $\alpha = 0.05$.

Results And Discussion

Weather

In 2010, the site in Rome was subjected to a prolonged drought with total rainfall from June through August 49% lower than the 30-year average (Table 3.4). Eatonton had above average rainfall early in the growing season in 2010, but received 23% lower rainfall in July and August than the 30-year average. In 2011, the rainfall in Rome during the growing season was 29% lower than the 30-year average. Eatonton was also dry and below the 30-year average through most of the growing season, but that site received a heavy rain event (49.8 mm) in late July. Then, in 2012, monthly rainfall was at or above the 30-year average for both locations except during the month of June.

Total Forage Yield 2010-2012

Though there were differences among years and between locations (P < 0.0001), but there were no significant (P > 0.25) interactions of site and/or year effects with the treatment effects on total seasonal yield (Table 3.5). Therefore, the season-long data was pooled across both sites and the three years to compare the effect of fertilizer treatment on forage yield (Table 3.6).

All fertilizer treatments resulted in higher seasonal yields than the control (5,516 kg DM ha⁻¹). Ammonium nitrate applied four times throughout the season (AN) resulted in the highest seasonal yield (13,300 kg DM ha⁻¹). It has been well documented that AN

produces higher yields than other sources of N (Osborne et al., 1999; Silveira et al., 2007; Connell et al., 2011; Massey et al., 2011).

Unadulterated urea, whether applied in four (Urea) or two (0 ESN:100 Urea) equally split applications, produced similar forage yields (11,868 vs 11,896 kg DM ha⁻¹, respectively), but both yielded less than AN. When ESN was blended with untreated urea, either in a 50:50 (50 ESN:50 Urea) or 75:25 ratio (75 ESN:25 Urea), total forage production (13,078 and 12,588 kg DM ha⁻¹, respectively) was comparable to that of the AN standard. However, the 75 ESN:25 Urea blend was intermediate between the AN and untreated urea treatments, though not different than either. The 100% ESN treatment (100 ESN: 0 Urea) yielded less than the AN and 50% ESN blend, which is consistent with previous findings (Connell et al., 2011) and supports the assertion that the release of N by ESN (as tested) is too slow to use without blending it with other, more readily available forms of N.

<u>N Uptake</u>

In the analysis of N uptake in forage, there was a significant (P = 0.0032) interaction between year and treatment (Table 3.5). Therefore, the N removal data are presented by year across the two sites (Table 3.7). In 2010, the 50 and 75% ESN blends resulted in the highest N yields, both with 251 kg N ha⁻¹. Ammonium nitrate and 100% ESN yielded similar N content to all fertilizer treatments except the conventionally split urea, and those were all greater than the control. Ammonium nitrate and the 75% ESN blend removed the most N in 2011 (311 and 281 kg N ha⁻¹, respectively). However, the 75% ESN blend was not different (P > 0.10) than all other fertilizer treatments, and all treatments removed more N than the control. There was little variability in N removal

among treatments in 2012. All fertilizer treatments exhibited similar N removal and all the treatments where more than 50% of the applied N was urea (Urea, 0 ESN:100 Urea, and 50 ESN:50 Urea) were similar to the control.

Nitrogen Recovery

As with the seasonal forage yield data, there were no significant (P > 0.25) interactions of site and/or year effects with the treatment effects on N recovery (Table 3.8). Therefore, the data are pooled across the two locations and three years (Table 3.9). The highest N recovery (47.0%) was achieved by the conventional AN treatment. This is consistent with the findings by Silveira et al. (2007) and Connell et al. (2011) showing it to be the source of N that provides the greatest N recovery and consistently superior to urea. Massey et al. (2011) showed that AN recovered 14% more of the applied N than untreated urea. In this study, urea split into two or four applications recovered the least amount of N (34.1 and 31.4%, respectively). However, the 50, 75, and 100% ESN blends achieved N recovery levels that were not different than ammonium nitrate. The use of this technology and blending method to develop urea-based fertilizers that are as efficient as AN is a significant advance.

Ammonia Volatilization Loss

Weather conditions during the three days before the N application dates and seven days thereafter (i.e., when the NH₃-N trapping occurred) varied considerably by year and location. Figures 3.2 and 3.4 show the maximum and minimum daily temperatures (°C), amount of rainfall (mm), relative humidity, and volumetric water content in Rome and Eatonton, respectively, for the two years when the ammonia traps were employed (2011 and 2012). In 2011, Rome received a low 11.2 mm rain during the 10-day observation period and had the lowest average VWC at 0.205 cm³ water cm⁻³ soil. Eatonton received a large (49.8 mm) rain event on the day of fertilizer application and another 14.5 mm on day 5 of observation in 2011. The site in Rome received 49.5 mm rainfall after the application of fertilizer in 2012 and had the high average humidity of 86.6%. In Eatonton, the plots received 22.1 mm rain within 3 days before application in 2012 but did not receive more rain until days 4 and 5 after application; Eatonton also had a consistent VWC throughout the observation period, averaging 0.249 cm³ water cm⁻³ soil. Figure 3.4 shows the fluctuation in VWC throughout the growing season at each site and each year, indicating each harvest.

Soils at the Rome and Eatonton sites were evaluated for urease activity and found not to differ (P > 0.10) at both the 0-5 cm and 5-10 cm depths (167 and 164 μ g urea g soil⁻¹, respectively, when pooled across sites). Consequently, there were no significant (*P* > 0.25) interactions of site and/or year effects with the treatment effects on the concentration of ammonium (NH₄-N) caught in the acid traps (Table 3.10), despite the aforementioned differences in weather immediately prior to and during the ammonia trapping assessment. Therefore, the data are pooled across the site-years (Table 3.11). Though the method used alters the natural environment and cannot be said to estimate true ammonia loss, it does permit the relative comparison of the ammonia volatilization between the treatments. Of the urea-based fertilizers compared in this study, the 75 and 100% ESN blends were most effective in reducing the concentration of ammonium (NH₄-N) caught in the acid traps, being comparable to the control treatment where no N was applied. By using 100% ESN, ammonia loss was reduced by 88% when compared to urea applied twice season. This is consistent with previous research by Connell et al. (2011) where ESN reduced volatilization loss by 81%. Moreover, the 75 and 100% ESN blends resulted in significantly less trapped ammonia as compared to the 0 ESN:100 Urea and 50 ESN:50 Urea treatments applied similar rates.

The highest concentration of ammonium (NH₄-N) was in the acid traps associated with the 0% ESN (0 ESN:100 Urea) fertilizer treatment (53.0 mg NH₄-N L⁻¹), but blending in ESN at a rate of 50% ESN (50 ESN:50 Urea) did not significantly lower (41.1 mg NH₄-N L⁻¹) the amount of ammonium that was trapped. Additionally, the 50 ESN:50 Urea tended (P < 0.10) to have more volatilization loss than conventionally split urea (41.1 vs. 15.8 mg NH₄-N L⁻¹, respectively), despite having the same amount of unadulterated urea (84 kg N ha⁻¹) present under the trap. More research is needed to determine if that outcome is representative or merely an artifact of our method, which artificially increases relative humidity and moisture creating the opportunity for more dissolved urea to exit the polymer coating and be subject to volatilization.

It is noteworthy that the urea, applied in accordance with the conventionally recommended practice of splitting into four equal applications, resulted in ammonia losses that were no different than the control treatment. Further, the higher N rate for the urea split twice (0 ESN:100 Urea) compared to when the urea was split across four applications (168 vs. 84 kg N ha⁻¹) did not result in trapped ammonia concentrations that were proportionate with the quantities of unadulterated urea present (53.0 vs. 15.8 mg NH₄-N L⁻¹). This supports the current recommendation of splitting applications into four equal applications.

Forage Quality

The analysis of variance showed there were no significant (P > 0.25) interactions among site and/or year with each treatment with regard to the seasonal averages of crude protein (CP), total digestible nutrients (TDN), or relative forage quality (RFQ) (Table 3.12). Therefore, these data are presented as means pooled across both sites and the three years.

The mean CP was found to be highest in bermudagrass fertilized with AN (Table 3.13). The 75 and 100% ESN blends were comparable to AN (136.8 and 136.0 vs. 139.0 g kg⁻¹, respectively). The 100% ESN blend was also similar to the 50% ESN blend, which was similar to urea applied two and four times throughout the growing season. All treatments resulted in CP levels higher than the control. Total digestible nutrient concentrations in harvested forage was greatest for AN, 50 ESN: 50 Urea, and 75 ESN:25 Urea (Table 3.13). The 100 ESN: 0 Urea treatment resulted in the lowest TDN content of the treatments, but was still similar to the urea treatments and the 50% ESN blend. There was only a 1.9% difference in the TDN range between AN and 100 ESN: 0 Urea, showing slight variability among treatments. The mean RFQ index showed little variability among treatments, with all treatments except 100 ESN:0 Urea being comparable to AN (Table 3.13). All treatments were higher in RFQ than the control.

Nitrate Accumulation

It is important to note that bermudagrass can develop concentrations of nitrates during periods of drought or growth-limiting stress that can be toxic to ruminant livestock, especially if the amount of N available in the soil is excessive and results in luxury consumption. At levels less than 2500 mg NO₃-N kg⁻¹, forage is safe for most

ruminant livestock classes and poses little risk of nitrate toxicosis. Sub-clinical toxicosis is possible and may be a result if ruminant livestock consume a diet that contains 2500-4500 mg NO₃-N kg⁻¹. Ruminant livestock fed forage containing more than 4500 mg NO₃-N kg⁻¹ are at risk of acute nitrate toxicosis, unless the forage is diluted in the diet to a concentration of less than that amount (Davidson et al., 1941; Wright and Davison, 1964; Lovelace et al., 1968; Hojjati et al., 1972). In general, nitrate accumulation in bermudagrass is more likely to be observed in the forage produced during the third growth period in the southeastern U.S., because this growth period is most frequently subjected to drought stress (Wright and Davison, 1964; Connell et al., 2011).

When nitrate accumulation was averaged over each season, the analysis of variance (Table 3.14) showed that there was a significant interaction of site and treatment (P = 0.0624). However, upon further analysis, it was determined that this interaction was magnitudinal in nature (ex. both locations showed similar trends, but nitrate concentration was higher at one site when compared to the other). For that reason, nitrate concentrations were averaged over both sites and the three years. Ammonium nitrate produced the highest risk of nitrate accumulation (Table 3.15) at 2651 mg NO₃-N kg⁻¹ forage. The use of the 50 and 75% ESN blends did reduce the risk of nitrate accumulation by 15.6 and 17.9%, respectively when compared to AN. Of the treatments, Urea did result in the lowest nitrate concentrations, nearly 52% less than AN.

Conclusion

Using ESN at rates of 50 or 75% of the blends with urea and applied in two equally-split applications resulted in total seasonal forage production that is similar to

that of conventionally applied AN split into four equal applications during the growing season. The 50 and 75% ESN blends also had similar concentrations of N uptake as the AN treatment. As the proportion of ESN increased in each blend, the amount of ammonium caught in the acid traps decreased, indicating that these blends are effective in reducing N loss from ammonia volatilization. Due to the slow release of the ESN, the 50 and 75% blends split twice were able to recover a similar amount of the N applied as AN split into four equal applications. Although there was little variation among treatments in terms of forage quality (CP, TDN, and RFQ), the 50 and 75% ESN were consistently comparable to that of AN. The use of ESN blends also reduced the accumulation of nitrates in the bermudagrass forage when compared to AN. The use of ESN:Urea blends have the potential to be effective N fertilizer sources for bermudagrass forage producers. The 50 ESN:50 Urea and 75 ESN:25 Urea treatments applied twice per season demonstrated to be comparable to the standard AN. These ESN blends can serve as an alternative to AN as a sufficient N fertilization strategy for bermudagrass forage production.

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	Equiv.		Extractable nutrients				
	water pH	OM	Р	K	Ca	Mg	
		%		mg kg	·1		
Rome	6.03	3.88	29.9	164	947	139	
Eatonton	5.85	5.12	21.5	219	859	104	

Table 3.1. Soil chemical attributes in the 0- to 10-cm depth prior to treatment application.

Table 3.2. Treatments, number of applications, and application rates at green-up and after each harvest (H1, H2, H3, H4).

				Applicatio	on Rate at:			
Treatment	Apps	Green	After	After	After	After	Total	
		Up	H1	H2	H3	H4		
		kg of actual N ha ⁻¹						
AN	4	84	84	84	84	0	336	
Urea	4	84	84	84	84	0	336	
0 ESN:100 Urea	2	168	0	168	0	0	336	
50 ESN:50 Urea	2	168	0	168	0	0	336	
75 ESN:25 Urea	2	168	0	168	0	0	336	
100 ESN:0 Urea	2	168	0	168	0	0	336	
Control	0	0	0	0	0	0	0	

Table 3.3. Harvest dates for Rome and Eatonton sites in 2010, 2011, and 2012.

Table 3.3.	Table 3.3. Harvest dates for Rome and Eatonton sites in 2010, 2011, and 2012.							
Site	Year	Harvest 1	Harvest 2	Harvest 3	Harvest 4			
Rome	2010	21 June	29 July	26 Aug.	20 Oct.			
	2011	2 June	12 July	16 Aug.	21 Oct.			
	2012	5 July	9 Aug.	6 Sept.	11 Oct.			
Eatonton	2010	17 June	21 July	25 Aug.	21 Oct.			
	2011	1 June	20 July	26 Aug.	7 Nov.			
	2012	3 July	1 Aug.	29 Aug.	10 Oct.			

Rainfall Temperatu				nperature	re (Max./Min.)			
Month				30 yr				30 yr
	2010	2011	2012	mean	2010	2011	2012	mean
Rome		m	m			°	C	
January	141	110	170	134	7/-4	7/-4	13/1	12/-2
February	95	72	64	130	7/-3	14/0	15/3	14/0
March	81	243	166	158	14/2	17/4	23/10	18/4
April	120	151	17	121	24/7	23/9	24/10	23/8
May	140	59	146	110	27/14	26/12	28/15	27/12
June	25	90	67	102	32/19	32/18	31/18	31/17
July	88	77	111	116	33/19	33/21	34/21	32/19
August	44	4	93	92	33/20	34/19	31/19	32/18
September	106	146	114	106	31/14	26/15	28/15	29/15
October	58	58	41	85	24/6	21/6	22/9	23/8
November	116	177	38	108	17/2	17/5	17/1	17/3
December	36	145	176	155	6/-5	14/2	14/4	13/-1
Eatonton								
January	142	89	77	116	10/-2	10/-2	16/1	13/1
February	98	107	101	113	10/-1	17/2	17/3	15/2
March	117	140	67	147	17/3	19/6	24/10	19/6
April	59	110	12	100	26/9	26/10	25/10	24/10
May	247	4	90	90	29/16	29/13	29/16	28/14
June	137	41	71	100	33/21	35/19	31/17	32/19
July	107	218	125	129	34/21	34/21	34/21	33/20
August	82	52	113	104	33/22	35/21	31/20	32/20
September	153	49	95	84	32/16	29/16	29/16	30/17
October	69	52	41	72	26/8	23/8	24/10	25/11
November	98	56	32	79	19/4	20/4	18/3	19/5
December	36	95	142	107	10/-3	17/3	16/4	14/2

Table 3.4. Monthly rainfall (mm), 30 yr mean monthly rainfall (mm), and mean maximum and minimum air temperature (°C) for the Rome and Eatonton sites in 2010, 2011, and 2012.

Source: The Georgia Automated Environmental Monitoring Network http://www.georgiaweather.net/ accessed 28 March 2013.

Effect	df	F value	P > F	F value	P > F	
		DM `	Yield	N Uptake		
Site	1	199.57	< 0.0001	147.22	<.0001	
Year	2	16.78	< 0.0001	6.06	0.0031	
Site x Year	2	71.99	< 0.0001	28.87	<.0001	
Treatment	6	55.13	< 0.0001	29.27	<.0001	
Site x Treatment	6	0.9	0.4954	1.14	0.3405	
Year x Treatment	12	0.4	0.9623	2.67	0.0032	
Site x Year x Treatment	12	1.25	0.2581	0.88	0.5706	

Table 3.5. Analysis of variance for the effects and interactions of treatment, site, and year on bermudagrass forage DM and N uptake during a 3-yr period.

Table 3.6. Mean total seasonal forage yield averaged across two sites and the 2010, 2011, and 2012 seasons.

	Seasonal Forage Yield
Fertilizer Treatment	kg ha ⁻¹
AN	13300 a [†]
Urea	11868 b
0 ESN: 100 Urea	11896 b
50 ESN: 50 Urea	13078 a
75 ESN: 25 Urea	12588 ab
100 ESN: 0 Urea	12050 b
Control	5516 c
$LSD_{0.05}$	1013.0
SE	361.9

	Seasonal N Uptake						
Fertilizer Treatment	kg N ha ⁻¹						
	2010	2011	2012				
AN	241 ab [†]	311 a	263 a				
Urea	212 c	242 b	203 ab				
0 ESN: 100 Urea	219 bc	258 b	207 ab				
50 ESN: 50 Urea	251 a	257 b	243 ab				
75 ESN: 25 Urea	251 a	281 ab	252 a				
100 ESN: 0 Urea	240 ab	264 b	268 a				
Control	66 d	92 c	182 b				
$LSD_{0.05}$	26.30	44.03	65.35				
SE	9.19	15.63	25.04				

Table 3.7. Mean seasonal N uptake averaged across two sites for the 2010, 2011, and 2012 seasons.

Table 3.8 Analysis of variance for the effects and interactions of treatment, site, and year on the amount of N recovered in bermudagrass forage during a 3-yr period.

Effect	df	F value	P > F
			N Recovery
Site	1	16.3	0.0001
Year	2	45.5	< 0.0001
Site x Year	2	11.5	< 0.0001
Treatment	5	2.12	0.0682
Site x Treatment	5	0.24	0.9445
Year x Treatment	10	0.34	0.9673
Site x Year x Treatment	10	0.21	0.9946

	N Recovery
Fertilizer Treatment	%
AN	47.0 a [†]
Urea	31.4 c
0 ESN: 100 Urea	34.1 bc
50 ESN: 50 Urea	40.7 abc
75 ESN: 25 Urea	44.0 ab
100 ESN: 0 Urea	42.9 abc
Control	-
$LSD_{0.05}$	11.7
SE	4.8

Table 3.9. Mean percentage of N applied that is recovered in the harvested forage during the whole season as a mean across two sites and 2010, 2011, and 2012 seasons.

Table 3.10. Analysis of variance for the effects and interactions of treatment, site, and year on the amount of ammonium trapped in acid traps following the H2 fertilizer application during a 2-yr period.

Effect	df	F value	P > F
		NH ₄ -N Trapped	
Site	1	8.28	0.0060
Year	2	1.92	0.1728
Site x Year	2	6.40	0.0149
Treatment	5	4.54	0.0019
Site x Treatment	5	1.26	0.2965
Year x Treatment	5	0.65	0.6657
Site x Year x Treatment	5	0.71	0.6165

	Trapped Ammonium	
Fertilizer Treatment	mg NH ₄ -N L ⁻¹	
Urea	$15.8 \text{ ab}^{\dagger}$	
0 ESN: 100 Urea	53.0 c	
50 ESN: 50 Urea	41.1 bc	
75 ESN: 25 Urea	9.1 a	
100 ESN: 0 Urea	7.0 a	
Control	6.2 a	
$LSD_{0.05}$	26.74	
SE	9.55	

Table 3.11. The amount of ammonium in the ammonia volatilization acid traps following the H2 application of treatments averaged over the 2011 and 2012 seasons and both sites.

Table 3.12. Analysis of variance for the effects and interactions of treatment, site, and year on bermudagrass forage crude protein (CP), total digestible nutrients (TDN), and relative forage quality (RFQ) during a 3-yr period.

Effect	df	F value	P > F	F value	P > F	F value	P > F
		СР		TD	N	RFQ	
Site	1	69.5	<.0001	22.9	<.0001	25.82	<.0001
Year	2	1.45	0.2348	45.76	<.0001	35.2	<.0001
Site x Year	2	49.22	<.0001	69.96	<.0001	67.88	<.0001
Treatment	6	22.72	<.0001	5.81	<.0001	9.55	<.0001
Site x Treatment	6	0.67	0.6754	0.49	0.8125	0.47	0.8328
Year x Treatment	12	0.51	0.9107	0.66	0.7897	0.74	0.714
Site x Year x Treatment	12	0.63	0.8186	0.27	0.9939	0.35	0.9786

	Forage Quality		
Fertilizer Treatment	СР	TDN	RFQ
	g kg ⁻¹		
AN	139 a [†]	496 a	91.8 a
Urea	130 c	489 bc	90.4 ab
0 ESN: 100 Urea	132 c	489 bc	90.3 ab
50 ESN: 50 Urea	133 bc	491 abc	90.6 ab
75 ESN: 25 Urea	137 a	493 ab	91.3 a
100 ESN: 0 Urea	136 ab	486 c	89.4 b
Control	103 d	464 d	80.8 c
$LSD_{0.05}$	3.71	6.31	1.90
SE	1.13	2.27	0.69

Table 3.13. Mean crude protein (CP), total digestible nutrients (TDN), and relative forage quality (RFQ) in harvested forage samples averaged across two sites and three years.

Table 3.14. Analysis of variance for the effects and interactions of treatment, site, and year on the accumulation of nitrate in bermudagrass forage across two sites and three years.

Effect	df	F value	P > F
		Nitrate Accumulation	
Site	1	56.61	<.0001
Year	2	4.15	0.0162
Location x Year	2	1.94	0.1448
Treatment	6	10.97	<.0001
Site x Treatment	6	2.01	0.0624
Year x Treatment	12	1	0.4459
Site x Year x Treatment	12	1.12	0.3407

	Mean Nitrate Accumulation
Fertilizer Treatment	(mg NO ₃ -N kg ⁻¹)
AN	2651 e [†]
Urea	1280 b
0 ESN: 100 Urea	1846 c
50 ESN: 50 Urea	2236 d
75 ESN: 25 Urea	2177 cd
100 ESN: 0 Urea	1868 c
Control	382 a
$LSD_{0.05}$	418.0
SE	208.6

Table 3.15. Mean nitrate (NO₃-N) accumulation in harvested forage averaged across two sites and three years.



Figure 3.1. Ammonia volatilization traps installed immediately after H2 (A) and enclosed by the PVC pipe chambers (B) for 7 days in the field.



Figure 3.2. Rainfall (gray bars), maximum daily temperature (black circles), minimum daily temperature (white circles), volumetric water content (black squares), and mean relative humidity (white squares) for three days before and seven days after the H2 fertilizer application in 2011 (A) and 2012 (B) in Rome.



Figure 3.3. Rainfall (gray bars), maximum daily temperature (black circles), minimum daily temperature (white circles), volumetric water content (black squares), and mean relative humidity (white squares) for three days before and seven days after the H2 fertilizer application in 2011 (A) and 2012 (B) in Eatonton. (*The Day 0 rain event in 2011 produced 49.78 mm total rainfall.)



Figure 3.4. Volumetric water content (cm³ water cm⁻³ soil) fluctuation throughout the growing season of Rome in 2010 (a), 2011 (b), 2012 (c) and of Eatonton in 2010 (d), 2011 (e), and 2012 (f). Arrows denote the timing of the first (H1), second (H2), third (H3), and fourth (H4) harvests during the 2010, 2011, and 2012 growing seasons.

CHAPTER 4

BASIC COST ANALYSIS OF ESN:UREA BLENDS COMPARED TO CONVENTIONAL AN AND UREA SYSTEMS ON BERMUDGRASS HAY PRODUCTION¹

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Abstract

As a result of the lack of availability of ammonium nitrate, forage producers increasingly use urea-based fertilizers, which are at greater risk of nitrogen loss to ammonia volatilization. Environmentally Smart Nitrogen (ESN[®], Agrium Advanced Technologies, Brantford, Ontario) is a polymer-coated N fertilizer that controls the release of nitrogen through temperature-controlled diffusion. This study was designed to examine the cost-effectiveness of different ESN: untreated urea blends (0, 50, 75, and 100 percent ESN) on 'Russell' bermudagrass [Cynodon dactylon (L.) Pers.] compared to conventional treatments of AN and urea. The yield data used for each treatment in this analysis was obtained from field research completed at two sites (Eatonton and Rome, GA) for three years (2010-2012; Chapter 3). The prices of each fertilizer were based on assumption of current market prices: urea at \$1.54 kg⁻¹ N; AN at \$1.87 kg⁻¹ N; and ESN at \$1.70 kg⁻¹ N. The net revenue accrued from each hectare of forage produced was calculated for comparison of each fertilizer strategy. The 50 ESN:50 Urea blend provided the highest profit margins associated with both the conventional AN and urea systems at \$87.61 and \$119.93 ha⁻¹, respectively. It can be recommended from this study that 50 and 75% ESN and urea blends are cost-effective options as a N fertilizer strategy for forage bermudagrass.

Introduction

Nitrogen (N) fertilization is a critical component of bermudagrass [*Cynodon dactylon* (L.) Pers.] hay and forage production. In the past, ammonium nitrate (AN) was the primary source of N fertilizer. As a consequence of a significant regulatory burden on agribusinesses that sell and distribute AN, most forage producers have been unable to purchase AN fertilizer in recent years and have shifted to the use of urea-based fertilizers as a replacement. With the increased use of these surface applied urea fertilizers on pastures and hayfields, the risk of ammonia volatilization loss is substantially greater (Hargrove and Kissel, 1979; Rawluk, 2001; Silveira et al., 2007; Massey et al., 2011).

Research has focused on improving urea-based fertilizers and minimizing economic and environmental risks. Several enhanced efficiency (EE) fertilizers have been produced to reduce this risk of nitrogen loss. Theoretically, these fertilizers are able to inhibit the rapid conversion of urea to ammonia by chemically inhibiting the urease enzyme activity in the soil or physically slowing the release of the fertilizer.

Environmentally Smart Nitrogen (ESN[®], Agrium Advanced Technologies, Brantford, Ontario, Canada) is a polymer-coated, controlled-release nitrogen fertilizer. The polymer coating acts as a physical barrier to the wetting and release of urea into the soil (Connell, 2011). Although Connell et al. (2011) found that ESN was effective in reducing volatilization loss by 81% when compared to untreated urea, it released N too slowly to be effective on early harvest yields. To relieve this delay in N release, the polymer-coated ESN could be blended with a more readily-available form of N, such as untreated urea. Blending ESN and urea holds the capacity to reduce the risk of ammonia volatilization while providing the immediate release of nitrogen needed for early bermudagrass harvest yields. If forage yields and quality were to increase, ESN and urea blends could be an economical substitution for AN as an N source strategy in forage systems.

Using blends of ESN and urea could also lead to reducing the number of N fertilizer applications per season. Currently, the recommendation is to split the total N to be applied during the growing season into equal applications applied at the beginning of each anticipated growth cycle. Thus, if the total N to be applied is 240 kg N ha⁻¹ yr⁻¹ and the producer plans four harvests per year, then 60 kg N ha⁻¹ should be applied.

The research presented previously (Chapter 3) shows that the slow release of N from ESN could enable the forage producer to reduce the number of applications to two without compromising agronomic performance (i.e., decreasing total forage yield, resulting in inconsistent forage distribution during the season, lowering quality, or increasing the nitrate risk to unacceptable levels). The goal of this study was to evaluate the economics of blending ESN and untreated urea (0, 50, 75, and 100% ESN) in two equally split applications relative to the conventional recommendation of applying AN or urea split four times throughout the growing season. To accomplish this goal, a partial budget approach was used to compare these ESN blends and conventional systems.

Methods and Materials

Systems Compared

The systems compared in this analysis were the six N fertilizer sources evaluated for agronomic performance as individual treatments in Chapter 3 (Table 3.2). All six of the treatments received a total season application rate of 336 kg N ha⁻¹. The two

conventional treatments, ammonium nitrate (AN) and untreated urea (Urea), were split into four equal applications. The other ESN:Urea blend treatments (0, 50, 75, AND 100% ESN) were split equally and applied twice throughout the season. The ESN:Urea blend treatments included 0% ESN/ 100% untreated urea (0 ESN:100 Urea), 50% ESN/ 50% untreated urea (50 ESN:50 Urea), 75% ESN/ 25% untreated urea (75 ESN:25 Urea), and 100% ESN/ 0% untreated urea (100 ESN:0 Urea).

Assumptions

The hay is valued at \$0.10 kg⁻¹ DM (ca. \$90/2000 lb). The total price for each fertilizer blend was calculated based on the assumption that current fertilizer prices were as follows: urea at \$1.54 (kg N)⁻¹; AN at \$1.87 (kg N)⁻¹; and ESN at \$1.69 (kg N)⁻¹ (generally priced 10% more expensive than standard urea). These fertilizer prices were based on personal contact with local fertilizer suppliers within the vicinity of the Athens, GA area. The cost for each trip across the field for one fertilizer application was assumed to be \$12.40 ha⁻¹ (ca. \$5/acre). Thus, the AN and Urea treatments receiving 4 split applications per season would require application costs of \$49.60 ha⁻¹, while the blend treatments applied only twice per season would require application costs of \$24.80 ha⁻¹.

Economic Comparisons

A partial budget approach (Eq. 4.1) was employed to compare the conventional system of either ammonium nitrate (AN) or untreated urea (Urea) split into four equal applications and the alternative systems of 0 ESN:100 Urea, 50 ESN:50 Urea, 75 ESN:25 Urea, or 100 ESN:0 Urea split into two equal applications. Partial budgeting is very

useful in evaluating one or two simple changes in a system, making it an ideal tool for this type of comparison. The general partial budgeting format can be specified as

Eq. 4.1. Net Returns =
$$(AR + RC) - (AC + RR)$$

where AR = added revenue

RC = reduced costs

AC = additional costs, and

RR = reduced revenue

If Net Returns (NR) are greater than zero, then a risk neutral producer should adopt the proposed change. If NR are less than or equal to zero, a risk neutral producer should not adopt the change. In this experiment, NR from using one or more of the ESN blends are compared to the baseline, which are conventional treatments of AN and urea.

In this analysis, changes associated with input costs were calculated and the yield data from the research trial (Table 3.6) was used to calculate yield loss/gain associated with the compared systems.

Results and Discussion

The economic analysis compared each ESN:Urea system to the conventional AN and Urea systems (Table 4.1). When comparing the 0 ESN:100 Urea system to AN split equally into four applications, there was a \$4.72 ha⁻¹ loss. Although this system reduced costs by decreasing the number of fertilizer applications and the use of a cheaper N source, the AN yield advantage was too substantial to result in a profit. When compared to the Urea system, 0 ESN:100 Urea reduced application costs and produced slightly more forage, resulting in a \$27.60 ha⁻¹ profit.

The 50 ESN: 50 Urea system reduced costs by eliminating two additional trips across the field for fertilizer application. When compared to AN, 50 ESN: 50 Urea resulted in an \$87.61 ha⁻¹ profit by reducing fertilizer cost in addition to the reduced application cost, despite a slight (but agronomically insignificant; Table 3.6) yield decrease. The 50 ESN: 50 Urea system provided a \$119.93 ha⁻¹ profit when compared to Urea as a result of higher yields and reduced application costs, even though it employed a more expensive N source.

As the proportion of ESN in the blends increases, the price of application also increases. The 75 ESN: 25 Urea system also reduced costs by cutting down from four equally-split applications to two equally-split applications. Although there was a slight (but agronomically insignificant; Table 3.6) yield decrease, 75 ESN: 25 Urea was still \$25.67 ha⁻¹ more profitable than AN as a result of the reduced input costs. This system was \$57.99 ha⁻¹ more profitable than the conventional urea system. Again, this is a more expensive N source, but the profit is associated with increased yields and reduced application costs relative to the conventional urea system.

When compared to AN, the 100 ESN: 0 Urea system showed a \$41.06 ha⁻¹ loss as a result of a significant (Table 3.6) yield reduction. Being a more expensive N source, this system also showed an \$8.74 ha⁻¹ loss when compared to the conventional urea system, despite a slight (but agronomically insignificant; Table 3.6) yield increase and reduced application costs. Consequently, the losses associated with this fertilization strategy make it uneconomical in a bermudagrass hay production system given the assumptions of this analysis.

Conclusion

Finding a cost-effective N fertilization system that produces similar agronomic performance to the standard AN has been a challenge faced by many forage producers. Through a partial budget economic analysis, it was observed that the 50 and 75% ESN blends split into two equal applications were the most profitable fertilizer systems when compared to the conventional systems of AN and Urea. In addition to the agronomic performance of these systems being comparable to the conventional system of fertilizing with AN (see Chapter 3), employing these ESN blends in two applications per year proves to be the most cost-effective N fertilization strategy of the options evaluated here.
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	Net	Return of ESN	N:Urea Blend	System	
		0 ESN:	50 ESN:	75 ESN:	100 ESN:
Compared to:		100 Urea	50 Urea	25 Urea	0 Urea
AN			\$ h	a ⁻¹	
A.	AC + RR	657.84	565.51	627.45	694.18
B.	AR + RC	653.12	653.12	653.12	653.12
	[†] Net Return (B-A)	-4.72	87.61	25.67	-41.06
Urea					
A.	AC + RR	517.44	543.31	556.25	569.18
B.	AR + RC	545.04	663.24	614.24	560.44
	Net Return (B-A)	27.60	119.93	57.99	-8.74

Table 4.1. Profits or losses (\$/ha) associated with implementing ESN:Urea blend systems when compared to conventional AN and Urea.

[†]Net Returns (NR) of each system is a function of B - A; B = Additional Revenue + Reduced Costs; A = Additional Costs + Reduced Revenue.[†]All treatments received a seasonal total of 336 kg N ha⁻¹.

CHAPTER 5

SUMMARY AND CONCLUSION

As a result of the lack of availability of ammonium nitrate, forage producers increasingly use urea-based fertilizers. In addition to being less agronomically effective, urea-based fertilizers are at greater risk of nitrogen loss to ammonia volatilization. Environmentally Smart Nitrogen (ESN[®], Agrium Advanced Technologies, Brantford, Ontario) is a polymer-coated N fertilizer that controls the release of nitrogen through temperature-controlled diffusion. Although ESN is effective in reducing N loss through volatilization, it releases N too slow to be effective on early harvest yields. The objectives of this study were to determine the effect of different proportions of ESN and untreated urea (0, 50, 75, and 100% ESN with the balance as urea) on agronomic performance, nutritive quality of 'Russell' bermudagrass [Cynodon dactylon (L.) Pers.], and costeffectiveness as compared to conventional treatments of AN and urea. This study showed that the 50 and 75% ESN blends were higher in total DM yield and N removal when compared to a conventional urea treatment, while still being comparable to AN. As the proportion of ESN increased, the amount of N lost through volatilization decreased, with the 75 and 100% ESN blends being comparable to the control plots. While there was little variation among forage quality parameters, the 50 and 75% ESN blends remained comparable to AN. These ESN blends decreased nitrate accumulation by an average 16.8% from the conventional AN treatment. A partial budget economic analysis revealed that the 50 and 75% ESN blends were the most profitable N fertilization systems when compared to conventional AN and Urea systems. Because this study found the 50 and 75% ESN blends to be cost-effective and to display high agronomic performance, it can be recommended that blending ESN at a rate of 50 and 75% with urea is a viable substitute for AN.

APPENDIX A

SELECT TABLES AND FIGURES

Product	H1		H2		H3		H4	
Rome					g CP kg ⁻¹			
AN	9.77	d†	18.7	а	18.1	ab	16.8	a
Urea	10.24	cd	17.0	b	17.4	b	15.5	ab
0 ESN: 100 Urea	11.07	cd	15.2	c	17.1	b	12.7	c
50 ESN: 50 Urea	11.67	bc	15.5	c	18.2	ab	14.8	b
75 ESN: 25 Urea	13.16	ab	15.9	bc	18.7	а	15.9	ab
100 ESN: 0 Urea	14.17	а	15.6	c	17.2	b	13.2	c
Control	9.71	d	13.1	d	13.0	c	10.2	d
SE	0.545		0.586		0.423		0.506	
LSD _{0.05}	1.558		1.154		1.256		1.446	
Eatonton								
AN	9.7	c	12.9	а	12.5	c	13.5	a
Urea	9.1	c	11.3	b	11.2	d	11.7	b
0 ESN: 100 Urea	10.1	bc	10.0	bc	12.9	bc	11.3	b
50 ESN: 50 Urea	10.9	b	10.5	b	13.9	ab	11.1	b
75 ESN: 25 Urea	12.0	а	9.8	bc	13.9	ab	11.4	b
100 ESN: 0 Urea	12.9	а	11.3	b	14.4	а	11.3	b
Control	8.1	d	8.9	c	9.3	e	8.1	c
SE	0.35		0.50		0.45		0.47	
LSD _{0.05}	1.04		1.49		1.29		1.26	

Table. A.1. Crude protein concentration in forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2010.

Product	H1		H2		Н3		H4	
Rome					g CP kg ⁻¹			
AN	16.0	b [†]	15.6	-	13.1	bc	13.6	-
Urea	16.8	ab	13.3	-	12.5	c	12.2	-
0 ESN: 100 Urea	16.9	ab	14.6	-	14.2	ab	13.4	-
50 ESN: 50 Urea	18.9	а	13.4	-	14.2	ab	12.6	-
75 ESN: 25 Urea	17.6	ab	14.2	-	13.8	abc	12.1	-
100 ESN: 0 Urea	17.0	ab	14.0	-	15.4	а	12.3	-
Control	13.5	c	11.4	-	9.5	d	11.9	-
SE	0.765		0.893		0.609		1.016	
LSD _{0.05}	2.271		2.653		1.601		3.272	
Eatonton								
AN	9.9	abc	17.5	a	12.2	а	12.3	a
Urea	9.1	bc	14.8	b	10.8	b	10.8	abc
0 ESN: 100 Urea	11.2	а	14.6	b	12.4	а	10.8	abc
50 ESN: 50 Urea	9.8	bc	14.0	b	11.6	ab	9.4	cd
75 ESN: 25 Urea	10.3	ab	14.9	b	12.8	а	11.1	ab
100 ESN: 0 Urea	8.7	c	15.3	b	12.3	а	10.0	bc
Control	8.5	c	12.0	c	8.5	c	8.1	d
SE	0.518		0.591		0.481		0.549	
LSD _{0.05}	1.347		1.530		1.294		1.637	

Table. A.2. Crude protein concentration in forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2011.

Product	H1		H2		Н3		H4	
Rome					g CP kg ⁻¹			
AN	11.0	cd^{\dagger}	10.5	ab	16.2	b	14.9	а
Urea	10.7	cd	11.0	а	16.5	ab	13.0	ab
0 ESN: 100 Urea	11.7	bc	10.0	ab	16.3	ab	13.2	ab
50 ESN: 50 Urea	13.4	ab	9.9	ab	17.4	ab	11.5	bc
75 ESN: 25 Urea	14.8	а	10.4	ab	18.2	а	13.2	ab
100 ESN: 0 Urea	12.4	bc	9.4	ab	17.1	ab	13.2	ab
Control	9.7	d	9.1	b	11.5	c	9.6	c
SE	0.758		0.652		0.638		1.139	
LSD _{0.05}	1.996		1.826		1.883		3.169	
Eatonton								
AN	9.5	bc	17.6	ab	15.2	b	16.6	а
Urea	8.9	cd	17.8	а	14.9	b	14.8	ab
0 ESN: 100 Urea	11.8	а	15.6	c	17.5	а	12.6	bc
50 ESN: 50 Urea	10.2	b	15.2	cd	16.8	а	13.3	bc
75 ESN: 25 Urea	9.9	bc	16.0	bc	16.1	ab	12.1	cd
100 ESN: 0 Urea	10.2	b	17.9	а	17.5	а	13.6	bc
Control	8.3	d	13.7	d	11.7	c	10.0	d
SE	0.408		0.587		0.619		0.893	
LSD _{0.05}	1.160		1.645		1.549		2.483	

Table. A.3. Crude protein concentration in forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2012.

Product	H1		H2		H3		H4	
Rome					g TDN kg ⁻¹			
AN	53.2	ab [†]	53.8	a	55.2	а	54.1	а
Urea	52.1	b	53.1	a	54.2	a	53.5	а
0 ESN: 100 Urea	52.2	b	50.5	bc	54.1	a	50.6	bc
50 ESN: 50 Urea	53.0	ab	51.5	ab	55.1	a	53.0	ab
75 ESN: 25 Urea	54.0	a	52.4	ab	54.7	a	53.4	а
100 ESN: 0 Urea	54.4	a	49.9	bc	51.9	b	51.7	ab
Control	49.2	c	48.7	c	50.0	c	48.8	c
SE	0.677		0.956		0.637		1.027	
LSD _{0.05}	1.798		2.598		1.696		2.521	
Eatonton								
AN	50.3	-	51.0	а	50.4	a	50.1	a
Urea	50.1	-	50.5	ab	50.0	а	50.2	а
0 ESN: 100 Urea	49.1	-	48.8	abc	50.0	а	49.5	а
50 ESN: 50 Urea	50.9	-	47.7	c	50.8	а	49.1	а
75 ESN: 25 Urea	49.9	-	48.3	bc	49.8	а	49.2	а
100 ESN: 0 Urea	50.0	-	48.6	abc	50.6	а	48.7	a
Control	49.2	-	47.4	c	47.5	b	45.3	b
SE	0.590		0.828		0.662		0.932	
$LSD_{0.05}$	1.713		2.475		1.966		2.580	

Table. A.4. Total digestible nutrient concentration in forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2010.

Product	H1	H2	H3	H4
Rome		{	g TDN kg ⁻¹	
AN	47.7 -	52.2 a [†]	51.3	a 51.5 -
Urea	49.3 -	49.8 a	49.6	a 49.5 -
0 ESN: 100 Urea	49.7 -	51.4 a	51.7	a 51.1 -
50 ESN: 50 Urea	52.4 -	51.3 a	51.5	a 50.5 -
75 ESN: 25 Urea	48.4 -	52.1 a	52.6	a 50.3 -
100 ESN: 0 Urea	48.1 -	51.2 a	52.2	a 49.3 -
Control	46.2 -	46.6 b	43.4	b 49.7 -
SE	1.46	1.10	1.07	1.30
LSD _{0.05}	4.33	3.19	3.17	4.19
Eatonton				
AN	44.7 -	51.2 a	46.4	ab 39.7 -
Urea	43.3 -	49.6 b	45.8	b 35.7 -
0 ESN: 100 Urea	45.7 -	49.7 b	49.5	a 36.2 -
50 ESN: 50 Urea	43.2 -	48.5 bc	46.5	ab 38.1 -
75 ESN: 25 Urea	44.8 -	49.7 b	48.7	ab 39.1 -
100 ESN: 0 Urea	41.1 -	49.8 b	46.3	b 37.4 -
Control	43.7 -	47.8 c	42.1	c 35.0 -
SE	1.44	0.45	1.14	1.13
$LSD_{0.05}$	3.42	1.35	3.19	3.42

Table. A.5. Total digestible nutrient concentration in forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2011.

Product	H1	H2	Н3	H4
Rome			g TDN kg ⁻¹	
AN	50.6	- 52.1	- 47.5	- 35.4 -
Urea	49.8	- 52.6	- 50.0	- 33.0 -
0 ESN: 100 Urea	47.7	- 51.7	- 50.1	- 34.8 -
50 ESN: 50 Urea	50.4	- 50.0	- 51.3	- 32.0 -
75 ESN: 25 Urea	52.5	- 50.8	- 51.0	- 33.8 -
100 ESN: 0 Urea	48.3	- 51.8	- 49.7	- 33.8 -
Control	48.8	- 50.1	- 47.8	- 31.2 -
SE	1.22	1.23	1.41	2.26
LSD _{0.05}	3.26	3.64	4.20	6.43
Eatonton				
AN	46.1	b [†] 53.6	a 50.5	- 50.9 -
Urea	45.1	b 53.3	a 52.2	- 50.6 -
0 ESN: 100 Urea	48.1	a 52.2	ab 52.4	- 47.2 -
50 ESN: 50 Urea	46.0	b 50.8	b 53.4	- 50.0 -
75 ESN: 25 Urea	46.4	b 51.1	b 50.8	- 48.8 -
100 ESN: 0 Urea	46.6	ab 53.4	a 52.3	- 49.6 -
Control	45.9	b 48.1	c 51.1	- 49.4 -
SE	0.58	0.63	0.93	1.22
LSD _{0.05}	1.71	1.79	2.76	3.62

Table. A.6. Total digestible nutrient concentration in forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2012.

Product	H1		H2		Н3		H4	
Rome				(unitless inde	ex)		
AN	101	bc [†]	97	-	103	а	106	ab
Urea	99	c	101	-	103	а	107	а
0 ESN: 100 Urea	99	c	94	-	103	а	97	bc
50 ESN: 50 Urea	102	bc	96	-	102	а	105	ab
75 ESN: 25 Urea	107	ab	99	-	99	ab	106	ab
100 ESN: 0 Urea	109	a	92	-	94	b	101	ab
Control	87	d	90	-	96	b	89	c
SE	2.68		2.70		2.15		3.19	
LSD _{0.05}	6.99		8.24		6.08		9.43	
Eatonton								
AN	90.7	ab	97.4	а	93.2	а	96.3	а
Urea	88.5	abc	95.6	ab	90.9	а	95.0	а
0 ESN: 100 Urea	87.1	bc	87.9	bc	90.5	а	92.3	а
50 ESN: 50 Urea	95.0	а	84.8	c	93.5	а	91.1	а
75 ESN: 25 Urea	92.0	ab	85.8	c	90.6	а	91.4	а
100 ESN: 0 Urea	91.6	ab	88.9	bc	91.4	a	90.1	а
Control	82.4	c	81.1	c	80.7	b	72.4	b
SE	2.48		2.86		1.86		3.06	
$LSD_{0.05}$	7.37		8.74		5.53		8.61	

Table. A.7. Relative forage quality of forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2010.

Product	H1		H2		Н3		H4	
Rome				(unitless inde	ex)		
AN	85	-	95	-	100	ab [†]	98	-
Urea	89	-	91	-	93	b	91	-
0 ESN: 100 Urea	91	-	95	-	102	ab	95	-
50 ESN: 50 Urea	99	-	95	-	101	ab	91	-
75 ESN: 25 Urea	87	-	98	-	104	a	93	-
100 ESN: 0 Urea	85	-	95	-	101	ab	91	-
Control	81	-	83	-	73	c	91	-
SE	4.60		3.25		2.97		4.35	
LSD _{0.05}	13.66		9.58		8.82		13.99	
Eatonton								
AN	75.4	-	98.3	а	85.4	ab	65.5	a
Urea	70.4	-	95.1	ab	82.1	b	58.7	ab
0 ESN: 100 Urea	78.9	-	95.7	а	93.5	а	57.8	ab
50 ESN: 50 Urea	70.7	-	90.5	bc	85.2	ab	59.9	а
75 ESN: 25 Urea	76.2	-	93.8	ab	92.0	а	63.9	а
100 ESN: 0 Urea	64.8	-	94.0	ab	84.7	ab	59.6	а
Control	68.9	-	87.1	c	66.8	c	51.6	b
SE	4.05		1.57		3.55		2.60	
LSD _{0.05}	9.98		4.66		9.36		7.65	

Table. A.8. Relative forage quality of forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2011.

Product	H1		H2		Н3		H4	
Rome				(unitless inde	ex)-		
AN	95	-	98	-	88	-	55	-
Urea	92	-	102	-	93	-	51	-
0 ESN: 100 Urea	86	-	96	-	92	-	54	-
50 ESN: 50 Urea	95	-	92	-	97	-	49	-
75 ESN: 25 Urea	102	-	95	-	97	-	53	-
100 ESN: 0 Urea	87	-	95	-	90	-	53	-
Control	86	-	90	-	86	-	48	-
SE	5.07		4.45		4.23		3.85	
$LSD_{0.05}$	12.48		13.21		12.57		10.56	
Eatonton								
AN	78	bc [†]	105	а	98	-	99	-
Urea	74	c	103	a	104	-	97	-
0 ESN: 100 Urea	89	а	99	ab	103	-	88	-
50 ESN: 50 Urea	79	bc	95	b	108	-	96	-
75 ESN: 25 Urea	79	bc	95	b	99	-	92	-
100 ESN: 0 Urea	81	b	104	а	105	-	95	-
Control	74	c	86	c	98	-	89	-
SE	2.16		2.23		3.43		3.71	
LSD _{0.05}	6.26		6.27		10.20		11.01	

Table. A.9. Relative forage quality of forage bermudagrass by harvest (H1, H2, H3, H4) in Rome and Eatonton in 2012.

	Additional Costs 336 kg N as urea x \$1.54 kg N as urea = \$517.44	Additional Revenue0 kg/ha yield gain x \$0.10 kg DM = \$0.00	00
0 ESN:100 Urea vs	Reduced Revenue 1404 kg/ha yield loss x \$0.10 kg DM = \$140.40	Reduced Costs336 kg N as AN x \$1.87 kg N as AN = \$628.32 applications x \$12.40 per ha = \$24.80	8.32 .80
	A Total Additional Costs + Reduced Revenue \$657.84	B Total Additional Revenue + Reduced Costs \$653.1	B 3.12
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	Additional Costs	Total Profit (B-A) = -\$4.72   Additional Revenue	.72
	336 kg N as urea x \$1.54 kg N as urea = \$517.44	$28 \text{ kg/ha yield gain x $0.10 \text{ kg DM} = $2.80$	0
0 ESN:100 Urea vs	Reduced Revenue 0 kg/ha yield loss x \$0.10 kg DM = \$0.00	Reduced Costs336 kg N as AN x \$1.54 kg N as urea = \$517.42 applications x \$12.40 per ha = \$24.80	7.44
200	A Total Additional Costs + Reduced Revenue \$517.44	B Total Additional Revenue + Reduced Costs \$545.0	<b>B</b> 5.04
		Total Profit (B-A) = \$27.6	.60
Figure A.1. Partia	al budget economic analysis comparing the 0 ESN:100 Ur	rea treatment to the conventional AN and Urea fertiliz	lizer

systems. Total profits (B-A) in bold black indicate an economic profit (\$/ha), while in bold red indicates an economic loss (-\$/ha).

	<b>Additional Costs</b>	<b>Additional Revenue</b>	
	168 kg N as urea x \$1.54 kg N as urea = \$258.72	$0 \text{ kg/ha yield gain x $0.10 \text{ kg DM} = $0.00}$	
	168 kg N as ESN x \$1.69 kg N as ESN = \$284.59		
	Reduced Revenue	Reduced Costs	
SU ESN:SU Urea	222 kg/ha yield loss x \$0.10 kg DM = \$22.20	336 kg N as AN x \$1.87 kg N as AN = \$628.32	32
S N N		2 applications x $\$12.40$ per ha = $\$24.80$	0
	A	B	
	Total Additional Costs + Reduced Revenue \$565.51	Total Additional Revenue + Reduced Costs \$653.12	12
		Total Profit (B-A) = \$87.61	51
	<b>Additional Costs</b>	Additional Revenue	
	168  kg N as urea x \$1.54 kg N as urea = \$258.72	1210 kg/ha yield gain x \$0.10 kg DM = \$121.00	00
	168 kg N as ESN x \$1.69 kg N as ESN = \$284.59		
	Reduced Revenue	Reduced Costs	
50 ESN:50 Urea	0  kg/ha yield loss x  0.10  kg DM = 0.00	336 kg N as Urea x \$1.54 kg N as Urea = \$517.44	44
VS ITrea		2 applications x $\$12.40$ per ha = $\$24.80$	0
	Α	B	
	Total Additional Costs + Reduced Revenue \$543.31	<b>Total Additional Revenue + Reduced Costs</b> \$663.24	24
		Total Profit (B-A) = \$119.93	.93
Figure A.2. Partial	Il budget economic analysis comparing the 50 ESN:50 U	rea treatment to the conventional AN and Urea fertilizer	izer

systems. Total profits (B-A) in bold black indicate an economic profit (\$/ha), while in bold red indicates an economic loss (-\$/ha).

	<b>Additional Costs</b>	<b>Additional Revenue</b>
	84 kg N as urea x \$1.54 kg N as urea = \$129.36	0  kg/ha yield gain x  0.10  kg DM = 0.00
	252 kg N as ESN x \$1.69 kg N as ESN = \$426.89	
	Reduced Revenue	Reduced Costs
72 ESN:22 Urea	712 kg/ha yield loss x $0.10$ kg DM = $71.20$	336 kg N as AN x \$1.87 kg N as AN = \$628.32
		2 applications x $12.40$ per ha = $24.80$
	Α	B
	Total Additional Costs + Reduced Revenue \$627.45	Total Additional Revenue + Reduced Costs \$653.12
		Total Profit (B-A) = \$25.67
	<b>Additional Costs</b>	<b>Additional Revenue</b>
	84 kg N as urea x \$1.54 kg N as urea = \$129.36	720 kg/ha yield gain x \$0.10 kg DM = \$72.00
	252 kg N as ESN x \$1.69 kg N as ESN = \$426.89	
	Reduced Revenue	Reduced Costs
75 ESN:25 Urea	$0 \text{ kg/ha yield loss x $0.10 \text{ kg DM} = $0.00$	336 kg N as Urea x \$1.54 kg N as Urea = \$517.44
vs Hrea		2 applications x $12.40$ per ha = $24.80$
	Α	B
	Total Additional Costs + Reduced Revenue \$556.25	Total Additional Revenue + Reduced Costs \$614.24
		Total Profit (B-A) = \$57.99
Figure A.3. Partia	Il budget economic analysis comparing the 75 ESN:25 U	rea treatment to the conventional AN and Urea fertilizer

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	Additional Costs 336 kg N as ESN x \$1.69 kg N as ESN = \$569.18	Additional Revenue 0 kg/ha yield gain x \$0.10 kg DM = \$0.00
100 ESN:0 Urea vs	Reduced Revenue1250 kg/ha yield loss x \$0.10 kg DM = \$125.00	Reduced Costs 336 kg N as AN x \$1.87 kg N as AN = \$628.32 2 applications x \$12.40 per ha = \$24.80
	A Total Additional Costs + Reduced Revenue \$694.18	B Total Additional Revenue + Reduced Costs \$653.12
	Additional Costs 336 kg N as ESN x \$1.69 kg N as ESN = \$569.18	<b>Total Profit (B-A) = -\$41.06</b> <u>Additional Revenue</u> 182 kg/ha yield gain x \$0.10 kg DM = \$18.20
100 ESN:0 Urca vs Urea	Reduced Revenue0 kg/ha yield loss x \$0.10 kg DM = \$0.00	Reduced Costs   336 kg N as Urea x \$1.54 kg N as Urea = \$517.44     2 applications x \$12.40 per ha = \$24.80
	A Total Additional Costs + Reduced Revenue \$569.18	B Total Additional Revenue + Reduced Costs \$560.44
		Total Profit (B-A) = $-$ <b>\$8.74</b>
Figure A.4. Partia	I budget economic analysis comparing the 100 ESN:0 L	rea treatment to the conventional AN and Urea tertilizer

systems. Total profits (B-A) in bold black indicate an economic profit (\$/ha), while in bold red indicates an economic loss (-\$/ha).