

**Nitrogen Rate and Source Effects on Biomass Yield of Teff Grown for Livestock Feed in
the Mid-Atlantic Region**

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in
partial fulfillment of the requirements for the degree of

Master of Science
in
Crop and Soil Environmental Sciences

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April 19th, 2011

Blacksburg, Virginia

Keywords: teff, nitrogen, nitrates, forage, poultry litter

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ABSTRACT

Teff (*Eragrostis tef* (Zucc.)), an annual warm-season grass from Ethiopia, has potential to provide forage during periods when cool-season grass growth is limited by high temperatures. An experiment was conducted at three Virginia locations in 2009 and 2010 to determine the effect of nitrogen (N) fertilization rate and source on the yield, nutritive value, and nitrate content of teff. Nitrogen (N) was applied at 0, 45, 90, and 135 kg plant available N ha⁻¹ as a single application of either ammonium nitrate (AN) or broiler litter (BL) at seeding. The experimental design was a randomized complete block with a two-factor factorial treatment design (N rate and source) and four replications. Biomass yield typically peaked at the 90 kg N ha⁻¹ rate, but rarely showed an increase beyond the 45 kg N ha⁻¹ rate. Yield ranged from 2325 to 7542, 1477 to 6151, and 1805 to 8875 kg DM ha⁻¹ for the Blacksburg, Southern Piedmont, and Shenandoah Valley locations, respectively. Crude protein and total digestible nutrients ranged from 70 to 240 g kg⁻¹ and 460 to 700 g kg⁻¹, respectively. Nitrate concentrations increased with increase in N fertilization but source had no effect on nitrate concentration. Typically, nitrates only posed a health risk for ruminant livestock at N rates above 90 kg N ha⁻¹, but dangerous levels were present occasionally at the 0 and 45 kg N ha⁻¹ rates. The results from this study indicate that teff responds to moderate rates of N and could provide summer forage for grazing livestock in the mid-Atlantic region.

DEDICATION

To my parents, Dave and Sarah, and my brothers, Dan and Bill, for their love and support over all the years in whatever I chose to pursue. You taught me to face challenges head on and to believe in myself.

Also to Ozzie, my Blacksburg Mama, you've helped me grow and develop into the person I am today. I would not have gotten here without you.

To my roommates and dear friends Leah and Sarah, you have always found time to encourage and support me, even when you had your own work to do. I am lucky to have friends like you.

And to Roy, I could have never made it through without you. Thank you for your patience, love, and unwavering support.

ACKNOWLEDGEMENTS

I wish to thank all who aided in the success of this project. Below are only a few names out of the many that have helped to make it happen.

Thank you.

Dr. A. Ozzie Abaye

Dr. Chris D. Teutsch

Dr. Benjamin F. Tracy

Dr. Rory O. Maguire

Dr. Mark A. McCann

Christie Newman

Mac Tilson

David Fiske and the crew at McCormick Farm

Jon Wooge and the crew at Kentland Farm

Agronomy Farm Crew

The Teff Company

Target Seed Company

USDA Grass-fed Beef Initiative

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CHAPTER I

INTRODUCTION

Cow-calf operations in the mid-Atlantic region rely predominantly on the use of cool-season perennial grasses, particularly tall fescue. Cool-season perennial grasses' peak production occurs in the spring months with a minor secondary peak of vegetative growth in early fall (Barnes et al., 2003). These grasses however, experience a reduction in growth during the mid-summer months of July and August - known as the "summer slump" (Moser et al., 1996). Management systems that predominantly utilize cool-season grasses expose growers to risk of feed shortage during mid-summer months. Mid-summer reduction in growth leaves a gap in forage production that often requires hay feeding to carry the animals through these months, which is costly to growers. Warm-season annual grasses can offer an alternative, cost effective option for producers interested in having a year-round forage based system.

Unfortunately, producers have very few options of warm-season annual forages that can be used both for hay and grazing and are free of toxicity. Although the adaptability, use, and management schemes have are not fully understood, teff (*Eragrostis tef* (Zucc.) Trotter), can potentially be used as an alternative warm-season annual grass in Mid-Atlantic region. Based on limited work, teff, a warm-season, annual, bunch-grass has shown yield advantage over the cool-season grasses during mid-summer months. Its quick establishment and ability to survive and produce adequate forage mass under drought conditions offers a viable alternative to other commonly used warm-season annuals such as sorghum sudangrass (*Sorghum bicolor*) or pearl millet (*Pennisetum americanum*).

Teff has a shallow, massive, fibrous root system that is able to survive in both drought stressed and waterlogged soil conditions (Ketema, 1997, Roseberg et al., 2005). Teff grows

successfully on marginal soils, including high acidity and poor fertility (Ketema, 1997; Gressel, 2008). In its native habitat, maximum production occurs with a growing season rainfall of 43.2 to 55.9 centimeters and a temperature range of 10°C to 29.4 °C ((Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006; Hunter et al., 2008). Little information is available on the agronomic characteristics and management of teff such as establishment, productivity, persistence, cultivar variation, response to cutting, and fertilization.

The objective of this experiment was to examine the yield response of teff to nitrogen sources and rates across three Virginia geographic regions and the effects on nutritive values of teff. Additionally, this experiment examined the effect of nitrogen rate and source on nitrate accumulation in teff.

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CHAPTER II

Literature Review

One of the greatest expenses for cattle producers is conserved forage. Farm profitability is highly impacted by low feed costs and avoiding the risk of feed scarcity in mid summer. This is particularly true when growers minimize their cost by relying on predominantly cool-season grass pasture and expose themselves to the risk of fluctuating forage yields in the mid summer months. Use of drought tolerant warm-season annual forages is one simple way to diversify forage systems to help reduce risk associated with high temperature and drought during the summer months. Producers have limited choices of warm-season annual species to plant and many can be toxic under certain environmental conditions. Other, non-toxic, warm-season annual species are available, but their management and suitability for both livestock and hay production can be challenging. A new forage species to the mid-Atlantic that could provide relief during these slumps is teff (*Eragrostis tef* (Zucc.) Trotter), a summer-annual grass from Ethiopia.

Origin and Adaptation

Teff, which means “lost” in Amharic (Ethiopia), is an annual, C₄, warm-season grass. Teff’s roots in history can be traced back to 3359 BC (Mengesha, 1965) and is commonly grown as a grain crop in Ethiopia. In Ethiopia, teff grain provides two-thirds of the human nutrition (Gressel, 2008). It is an intermediate between a tropical and temperate grass (Hunter et. al, 2008; Stallknecht et al. 1993). It has several advantages that make it a viable alternative over other summer annual forages, including its ability to thrive both in moisture-stressed and waterlogged soils (Seyfu, 1997; Roseberg et al., 2005). Although it can grow in a wide variety of soil moisture conditions, teff is gaining popularity due to its tolerance of drought conditions. In

addition, teff grows successfully on marginal soils, including soils with high acidity and poor fertility (Seyfu, 1997; Gressel, 2008). In its native habitat, maximum production occurs with a growing season rainfall of 43 to 56 centimeters and a temperature range of 10°C to 30 °C (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006; Hunter et. al, 2008).

Plant Characteristics

The plant is a fine-stemmed, bunch-grass with large crowns and many tillers (Roseberg et al., 2005) (Figure 2-1). It grows 25 to 127 centimeters tall with smooth, narrow, long leaves and slender culms (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006; Hunter et. al, 2008; Norberg et al., 2009). The leaves are narrow and hairless and grow nearly as tall as the seedhead (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006). The inflorescence is an open panicle ranging from loose to compact and produces numerous small seeds (0.3 - 0.4g/1000 seeds). Teff has a very shallow, fibrous, massive growing root system (Davidson and McKnight, 2004). The seed color ranges from white, red, brown and almost black, depending on variety (Davidson and McKnight, 2004).



Figure 2-1. The Teff plant has a bunch type of growth habit

Teff as Forage

Teff is rarely grown outside of Ethiopia as a grain crop. Both South Africa and Kenya have experimented with growing teff as a forage crop and are now cultivating it for forage sporadically throughout the countries (Seyfu, 1997). In the United States, teff is grown intermittently throughout the country, typically as a specialty crop for Ethiopian restaurants (Evert et al., 2009). Because of its wide range of adaptability, drought tolerance, palatability, and high nutritive values, teff is becoming a promising source of forage in the United States.

Management

Planting and Establishment

Planting date and depth are very critical to a successful establishment of teff. In a study conducted in growth chambers, the ideal planting depth of teff was tested using five different depths along with different day/night temperatures to measure which temperatures optimum establishment occurs (Evert et al., 2009). Seeds were planted at 0, 0.6, 1.25, 2.5, and 5 centimeter depths and at 15/19, 19/23, 23/27, 27/31 °C daytime/nighttime temperatures (Evert et al., 2009). The study concluded that teff grows best when planted 0.6 to 1.25 centimeter deep,

and teff planted at 5 centimeter depth did not emerge (Evert et al., 2009). Under ideal growing conditions (adequate moisture and warm soil temperatures (16+ °C)), teff can germinate and emerge in as little as 3 days after planting (Evert et al., 2009). However, in less ideal conditions, such as low soil temperature (nearing 10°C) or inadequate moisture, teff can take up to 12 days to germinate. On average, teff will have a germination period of 5 days (Gressel, 2008) (Table 2-1).

Table 2-1. General information on days to: germination, heading, maturity and plant height straw yield plant⁻¹ and total shoot biomass plant of teff⁻¹ (Seyfu, 1993)

Item	Minimum	Maximum	Mean
Days to germination	4	12	5
Days to heading	26	54	37
Days to heading to maturity	26	76	56
Plant height (inches)	31	155	99
Grain yield plant ⁻¹ (oz.)	.14	.78	.28
Straw yield plant ⁻¹ (oz.)	.71	3.17	1.45
Total shoot biomass/plant (g)	.92	3.70	1.73

In the same study focusing on the day/night temperature's affect on emergence, teff emerged slowest at the 15/19° F daytime/nighttime temperature (Evert et al., 2009). Three days after planting (DAP), the two cooler temperatures (15/19°C, 19/23°C) had fewer plants emerge initially than in the warmer temperatures (23/27 °C, 27/31 °C) (Evert et al., 2009). Four days after planting, the only differences in emergence rates were measured between the coldest (15/19°C) and warmest (27/31 °C) temperatures (Evert et al., 2009). The differences between the coldest and warmest temperatures continued through 9 DAP. After 9 DAP the slow germination due to cooler temperatures caught up and the emergence rates showed no significant difference (Evert et al., 2009). The author concluded that temperature greatly influences the rate of emergence. Due to low tolerance of cold soil temperature, teff should not be planted before the soil temperature reaches at least 10 °C but will benefit from warmer soils (nearing 16 °C).

Establishing teff can be difficult due to small seed size, containing about 2.75 million seeds per kilogram (Hunter et al., 2007). Seeding rate varies from 2.5 to 9 kg ha⁻¹, with 4.5 to 8 kg ha⁻¹ being the general recommendation (Hunter et al., 2009). Teff seeds can also come coated to make planting easier; seeding rates would typically double with coated seeds. For successful establishment, it is important to have a firm, weed-free seedbed (Seyfu, 1997). Once the seedbed is prepared, the seed can be either broadcasted or drilled using a Brillion or cultipacker seeder for optimum results (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006).

Rainfall early in the growing season is critical to the development of teff, but after the early growth stages, the plant survives with little to no water (Gressel, 2008). Mengistu (2009) conducted an experiment to investigate the effect of water stress on growth stages of teff. The growth stages included were establishment (emergence to four leaf stage); vegetative (five leaves until booting); flag leaf-1 (stage immediately before emergence of flag leaf) and grain filling (pollination to milky ripeness). Water stress was induced by allowing the soil conditions to dry to 50% field capacity and 25% field capacity. These conditions were maintained through the growth stage (by watering accordingly). Once the growth stage was completed, the plants were watered back to field capacity and field capacity levels were maintained through the completion of the experiment. The author concluded that teff was able to fully recover from the water stress during the first three growth stages, but the grain filling stage was adversely affected by water stress (Mengistu, 2009). This study strongly supports the claim that teff can successfully cope with drought stress, particularly when grown for forage.

While it is often noted for its successful growth under drought conditions, teff can also tolerate water-logged soil conditions. Aside from rice, it is the grain most tolerant of these

saturated soil conditions (Seyfu, 1997). Teff also grows well in a wide range of altitudes. It is grown from sea level up to 3000 meters in the mountains of Ethiopia (Engels et al., 1991). Because of its wide range of growing conditions and versatility, it is grown across diverse ecological zones, temperature and soil regimes making it the staple food crop in Ethiopia.

Fertility

Although teff requires significantly less N than other warm-season annuals, N fertilization has resulted in yield response (Gressel, 2008). In a study conducted in New York, N rates for teff were compared under one, two, and three cut systems, and yields monitored (Hunter et al., 2008). The cutting system was determined based on the individual location. Four rates were applied – 0, 60, 90, and 120 kg of plant available N ha⁻¹ rate (Hunter et al., 2008). The authors concluded the optimum rate of application to be 60 kg N ha⁻¹ of plant available N with no major increases in yield as rates increased (Hunter et al., 2008). These results are in agreement with the current recommendation of N for teff which is 45-70 kg N ha⁻¹. While applying N does lead to a significant increase in yields, when used excessively, teff is likely to lodge, leading to a large loss in yield and prohibiting mechanical harvest for both forage and grain (Rockstrom et al., 2008). Fertilization with P and K only increases yields in all crops when soils test is low in these nutrients.

As nitrogen fertilization is increased to stimulate yield, the chance of nitrate accumulation in commonly used summer annual grasses also increases, especially when growth is limited by moisture stress (Crawford et al., 1966; Emerick, 1974; Hanway and Englehorn, 1958; May et al., 1990; Murphy and Smith, 1967; Wright and Davison, 1964). Observations and limited research have implicated manure application in nitrate accumulation in both cool and warm-season annual grasses (Hanway and Englehorn, 1958; Wright and Davison, 1964).

Hanway and Englehorn (1958) found that significant amounts of nitrate accumulated in corn stalks that had been fertilized with manure. However, the N content of the manure was not documented making it hard to draw any firm conclusions as to the effect of nitrogen source and rate on the accumulation of nitrate in forages.

Accumulation of nitrate in forage plants can pose serious health problems for livestock (Murphy and Smith, 1967). Estimates of the nitrate concentration in forage that causes acute nitrate toxicity varies due to a number of factors, including rate and amount ingested, forage type, energy level of the diet, adaptation to a high nitrate ration, general health and condition of the animal, and pregnancy (Wright and Davison, 1964). Maximum nitrate concentrations in forages reported as safe range from 2,500 to 10,000 mg kg⁻¹ nitrate (Baker and Tucker, 1971; Cheeke, 1998; Crawford et al., 1966; Emerick, 1974; Gilbert et al., 1971; Wright and Davison, 1964).

Readily available organic nitrogen sources such as biosolids and broiler litter could provide an economical fertilizer source for teff grown as forage. However, the tendency of teff to accumulate nitrates and the effect of supplying nitrogen as organic sources on the nitrate content of teff are unknown.

Pest Control

Currently, there is no herbicide labeled for teff. However, in most cases, the quick establishment of teff can provide ground canopy cover that reduces weed pressure. However, if present, weeds can reduce the potential yield of teff by up to 50% (Gressel, 2008). Broadleaf weeds in teff can be controlled with chemical and or mechanical mean, whereas annual grasses can cause major competition problems (Seyfu, 1997). Close clipping may reduce competition, but due to the shallow rooted characteristics of teff, close grazing to control grass competition

may not be a viable management practice. Since there are no labeled herbicides for teff currently, successful establishment that ensures good stand of teff is crucial. Successful establishment of teff includes variety selection, firm soil bed preparation, and timely planting.

Harvesting

Teff for hay should be harvested in the late vegetative stages – pre-boot to early-boot stage (Hunter et al., 2007; Hunter et al., 2008). The first harvest can occur approximately 50 to 55 days after planting the teff, with subsequent harvests 40 to 45 days after cutting, depending on the environmental conditions (Hunter et al., 2007). Since the re-growth of teff is highly dependent on leaf area left (aftermath), it is important to cut teff no shorter than 8 to 10 centimeters so re-growth will occur; any shorter cutting will stunt the crop. Teff can also be harvested as a high moisture crop and ensiled (Hunter et al., 2007, Hunter et. al, 2008).

Grazing Teff

Although little grazing data is available, in addition to being used for hay and silage, teff can also be used for grazing (Figure 2-2). Under grazing conditions, it is important to graze teff at the pre-boot stage or earlier so that animals do not pull the teff out from the ground. It is also important to prevent forage loss from the animals trampling the plant, causing it to lodge. To prevent trampling, the first growth of teff should be cut for hay and graze the aftermath. This management practice will allow the teff plant to establish a stable root system that would help minimize being uprooted by the grazing animal.



Figure 2-2. Animals grazing teff near Blacksburg, Virginia – August 2010.

Additionally, teff fits nicely into a cool-season perennial grass-based system as alternative forage when the perennial grass experiences a reduction in growth during the summer months. Due to teff's quick establishment, low water and nutrient requirements, teff can be used as an emergency crop during the summer months. This can be accomplished either by planting teff in a separate field or by inter-seeding teff into a dormant cool-season grass or legume stand (Figure 2-3).



Figure 2-3. Teff inter-seeded into tall fescue pasture in West Virginia, 2010.

Productivity and Nutritive Value

Teff is growing in popularity as a forage crop not only because of its drought resistance and quick emergence, but also because it is a good quality hay crop. When harvested at vegetative/early boot stages and adequate N is supplied, crude protein of the teff is generally between 15 and 16 % on dry matter basis (Hunter et al., 2007) (Table 2-2). The nutritive value of teff (crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF)) for livestock has been reported to be similar to most grasses used as hay or silage/haylage (Table 2-2). Teff is also high in amino acids and iron content (Gressel, 2008). A wide range of biomass yield has been reported throughout the teff growing states.

Table 2-2. Sample yield and quality data throughout the United States.

References	Biomass yield Mg hectare ⁻¹	Nutritive value		
		Crude Protein g kg ⁻¹	NDF g kg ⁻¹	ADF g kg ⁻¹
California (Hunter et al., 2007)	5.6 – 6.5	---	---	---
Mississippi (Lemus, 2009)	8.8	160-170	570 – 600	---
Montana (Hunter et al., 2007)	0.5 – 3.2	96-137	---	---
Nevada (Davison, 2006)	3.5-2.8	162	637	347
New York (Hunter et al., 2007)	3.9 - 4.9	150 – 160	607	---
Oregon (Norberg et al., 2009)	4.0 - 6.0	110-130	601 - 620	362 - 428
Pennsylvania (Hall, 2007)	4.6 - 6.9	---	---	---
South Dakota (Twidwell et al. 2002)	1.3 - 5.3	107 - 174	---	---
Virginia (Newman et al., 2010)	2.2 – 3.4	91 - 168	---	---
Wisconsin (Hunter et al., 2007)	5.8 - 6.7	---	---	---

Conclusions

Summary and Conclusion

Incorporating warm-season grasses into a cool season forage system offers a low cost alternative, because less hay would need to be fed during the hottest part of summer. The main benefit of incorporating these forages into a system is that warm-season annual grasses are most productive during hot weather and can provide badly needed forage during times of water deficit. Teff is an annual warm-season grass from Ethiopia that has potential to help fulfill this need. Teff has several advantages that make it a viable alternative over other summer annual forages, including its ability to thrive both in moisture-stressed and waterlogged soils, and its lack of anti-quality compounds as found in sorghum-related annuals. However, because it is an annual crop, production costs will be higher compared to use of perennial forage. During extremely dry summers such as 2007, a crop such as teff might make the difference between financial success and disaster.

Climate change in the coming decades may well require a shift from a cool-season forage base (that requires high moisture and soil fertility) to forages that use resources more efficiently and that can be grown in a wide array of soils. Before teff can be adapted widely throughout the nation, more work must be done in order to evaluate its ability to thrive in different climates and soils. Primarily, research has been conducted in western and mid-western states, with little done in the mid-Atlantic and south-eastern regions. Although Teff has potential for grazing and hay production, more information about its cultural practice, establishment and overall management is needed before it can be widely adopted in forage production systems.

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CHAPTER III

Effect of Nitrogen Rate and Source on Biomass Yield of Teff Grown for Livestock Feed in the Mid-Atlantic Region

Abstract

Teff is an annual warm-season grass that is well adapted to various environmental conditions including drought and low soil fertility. Experiments were conducted at three Virginia locations (Blacksburg, Steeles Tavern, and Blackstone) in 2009 and 2010 to determine the effect of nitrogen (N) fertilization rate and source on the yield, nutritive value, and nitrate content of teff (*Eragrostis tef* (Zucc.)). Nitrogen was applied at 0, 45, 90, and 135 kg plant available N (PAN) ha⁻¹ as a single application of either ammonium nitrate (AN) or broiler litter (BL). Nitrogen treatments were applied at seeding and incorporated into the seedbed. The experimental design was a randomized complete block with a two-factor factorial treatment design (N rate and source) with four replications. Biomass yield varied by year, location, and harvest dates. In most cases, N source had no effect on teff biomass yield. The N rate where biomass yield increased varied across locations. Overall, biomass yields peaked between the 90 and 135 kg N ha⁻¹ rate, but typically there was no yield increase above the 45 kg N ha⁻¹ rate. Although, in some cases, the higher rates showed higher biomass yield, the yield increase beyond the 45 kg N ha⁻¹ rate may not be economically justifiable. Biomass yield over all locations ranged from 2330 to 5360 kg DM ha⁻¹ in 2009, while this range was much higher in 2010 at 2320 to 8875 kg DM ha⁻¹. At the southern Piedmont location where the June and July rainfall in 2010 averaged less than 4 cm, biomass yield ranged from 3285 to 4922 kg DM ha⁻¹. A much higher biomass yield range was observed for the Shenandoah Valley location which was 1805 to 6203 and 3455 to 8875 kg DM ha⁻¹ for the 2009 and 2010 growing seasons respectively. The biomass yield increase in 2010 compared to 2009 should be noted considering 2010 was a

much hotter and drier year across locations. In most cases, nutritive value of teff was within acceptable range for brood cow needs. Nitrate levels were reported at both dangerous and toxic levels to livestock, generally at the 90 and 135 kg N ha⁻¹ rates from the first harvest in 2010. Our experiment showed that teff can be used as an alternative summer emergency crop under minimum input including below-average rainfall.

Introduction

Throughout the mid-Atlantic region, farmers rely predominantly on cool-season pasture for their cow-calf grazing operations. This reliance exposes producers to risk during the winter and mid-summer months due to a reduction in the growth of these cool-season species. This can be costly to producers because they need to rely on hay feed to carry them through until the cool-season grasses pick up in growth. An alternative to hay feeding in the mid summer months is to incorporate a warm season annual grass into the grazing system, which will reduce risk and alleviate costs from feeding hay. Unfortunately, many warm-season annual species can be difficult to manage for both hay and grazing and others can be toxic to livestock. A new alternative in grazing systems may be the warm-season annual grass, teff (*Eragrostis tef* (Zucc.) Trotter).

Teff is commonly utilized as a grain crop in its native country, Ethiopia, where it can be traced back over 5000 years (Mengesha, 1965). It is a C-4 bunch grass that has several advantages that make it a viable forage crop for mid-summer production, including its ability to thrive in both drought-stressed and water-logged conditions (Seyfu, 1997; Roseberg et al., 2005). It can grow successfully on soils with high acidity and poor fertility and at altitudes as high as 3000 meters (Seyfu, 1997; Gressel, 2008; Engels et al., 1991). In its native habitat, maximum production occurs with a growing season rainfall of 43 to 56 cm and a temperature range of 10°C

to 30 °C (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006; Hunter et. al, 2008).

The plant is a fine-stemmed, shallow rooted, bunch-grass that grows 25 to 127 centimeters tall with large crowns and many tillers (Roseberg et al., 2005; Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006; Hunter et. al, 2008; Norberg et al., 2009). The leaves are narrow and hairless and grow nearly as tall as the seedhead (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006). The inflorescence is an open panicle ranging from loose to compact and produces numerous small seeds (0.3-0.4 g/1000 seeds). The seed color ranges from white, red, brown and almost black, depending on variety (Davidson and McKnight, 2004).

Planting depth and seedbed preparation are extremely important in establishing teff due to its small seed size. It is important to have a firm, weed free seedbed (Seyfu, 1997). Seeds should be planted from 0.5 to 1.25 centimeters deep – any deeper they will struggle to emerge (Evert et al., 2009). Seeding rates vary from 2.5 to 9 kg ha⁻¹, with 4.5 to 8 kg ha⁻¹ being the general recommendation (Hunter et al., 2009). Seeds can be broadcasted or drilled using a Brillion or cultipacker seeder, but seed to soil contact is vital due to the small size (Davidson and McKnight, 2004; Davidson and Peraldo, 2005; Davidson, 2006).

Rainfall early in the growing season is critical to the establishment of teff. After early growing stages the plant survives on little to no water (Gressel, 2008). Teff is able to grow with low fertility levels, particularly compared to other warm season annuals. While it has a low nutrient requirement, N fertilization has resulted in yield response (Gressel, 2008). No herbicides are labeled for teff, and therefore it is important to have a weed free seed bed. Quick

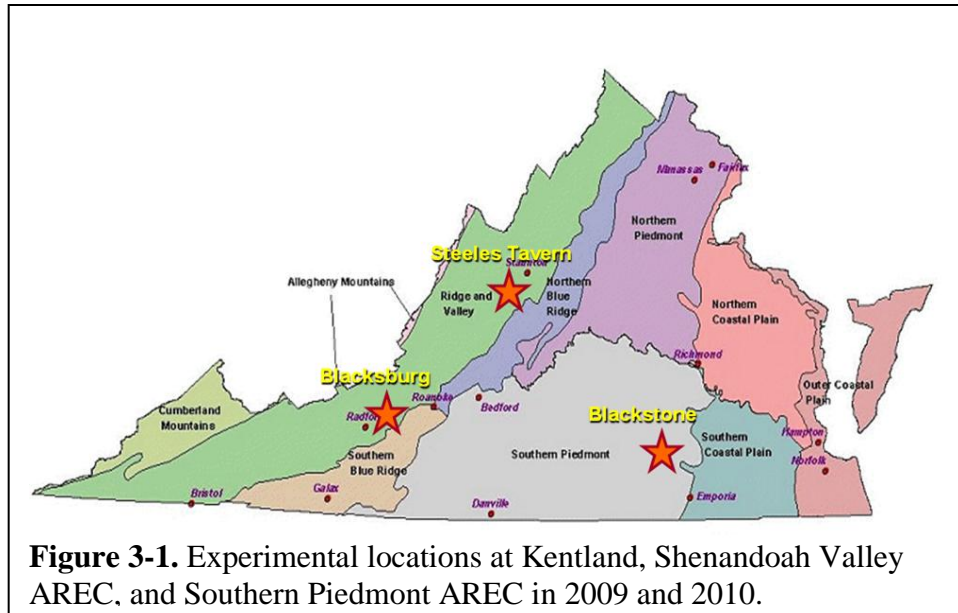
establishment by the plant allows it to out-compete most competitors, but if present weeds can reduce yields by 50% (Gressel, 2008).

Teff is rarely grown outside Ethiopia as a grain crop, typically only for specialty markets and Ethiopian restaurants (Evert et al., 2009). It has been sporadically used in Kenya and South Africa as forage, and is gaining popularity in the United States as a forage crop due to its wide range of adaptability, drought tolerance, palatability, and high nutritive values (Seyfu, 1997). Teff can either be cut for hay, grazed, or ensiled as a high moisture crop (Hunter et al., 2007, Hunter et. al, 2008). Because re-growth is highly dependent on leaf area, teff should not be cut or grazed below 8 to 10 centimeters. Teff for hay should be harvested in the late vegetative stages – pre-boot to early-boot stage (Hunter et al., 2007; Hunter et al., 2008). The first harvest can occur approximately 50 to 55 days after planting the teff, with subsequent harvests 40 to 45 days after cutting, depending on the environmental conditions (Hunter et al., 2007).

Because using teff as a forage is relatively new, little is known about proper management in regards to optimum fertilization rate, weed control, pest control, and other agronomic practices. The objective of this experiment was to determine the effect of N fertilization rate and source on the yield, nutritive value, and nitrate content of teff (*Eragrostis tef* (Zucc.)) grown for forage.

Methods and Materials

Small plot experiments were conducted in 2009 and 2010 at three geographical locations in Virginia: Kentland Research Farm in Blacksburg, VA; Shenandoah Valley AREC in Steeles Tavern, VA; and the Southern Piedmont AREC in Blackstone, VA (Figure 3-1). Plots were established to determine the effect of N fertilization rate and source on the yield, nutritive value, and nitrate content of teff.



‘Tiffany’ teff was established in early June 2009 and 2010 on a conventional seedbed. Each plot measured 2.74 x 4.57 meters. Plots were seeded using a Carter no-till drill at a seeding rate of 6.7 kg PLS ha⁻¹ (Table 3-1). A randomized complete block design with a two-factor factorial treatment arrangement (N rate and source) was utilized. Each treatment was replicated four times. Prior to fertilization, soil samples were taken randomly from each experimental location (Table 3-2).

Table 3-1. 2009 and 2010 planting dates at Kentland, Shenandoah Valley AREC, and Southern Piedmont AREC.

Year	Planting Date		
	Kentland	SVAREC	SPAREC
2009	June 2, 2009	June 2, 2009	June 11, 2009
2010	June 1, 2010	June 1, 2010	June 9, 2010

Table 3-2. Site soil description for 2009 and 2010 research locations.

Location	Year	Soil Series	Soil Description	pH	P	K
					mg/kg	
Kentland	2009	Unison and Braddock	Fine, mixed, semi-active, mesic, typic, hapludults	6.02	10 (Medium-)	71 (Medium)
	2010			6.06	11 (Medium)	70 (Medium)
SPAREC	2009	Helena Sandy Loam	Fine, mixed, semi-active, thermic, aquic, hapludults	6.35	13 (Medium)	81 (Medium+)
	2010			6.23	21 (High-)	68 (Medium)
SVAREC	2009	Frederick - Christian Silt Loam	Fine, mixed, semi-active, mesic, typic, paleudults	5.48	34 (High)	48 (Medium-)
	2010			6.05	20 (High-)	84 (Medium+)

Nitrogen treatments were applied at rates of 0, 45, 90, and 135 kg plant available N (PAN) ha⁻¹ as single applications of ammonium nitrate or broiler litter at planting. Prior to seeding, the fertilizer was incorporated into the seedbed. Plant available nitrogen for the broiler litter was calculated by multiplying organic-nitrogen by 0.6, ammonia-nitrogen by 0.9 and summing the two (VADCR, 2005).

Forage Assessment

The plots were harvested at a 10 cm clipping height when the teff reached the late boot stage (Table 3-3) by clipping a 0.8 x 4.57 m strip through the center of each plot using a self-propelled mechanical forage harvester. Wet weights were recorded and then a subsample of fresh forage was collected from each plot and dried in a forced air oven for 5 days at 60 °C. Biomass was determined on dry matter basis. Samples were ground to pass through a 1 mm screen using a Wiley sample mill (Thomas Scientific, Swedesboro, NJ) and analyzed for nutritive value and nitrate accumulation.

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP) were predicted using near infrared spectroscopy (NIRS). WINISI II software was used to select a calibration data set for wet chemistry determination (Infrasoft International, Port Matilda, PA). Levels of NDF and ADF for calibration sets were determined using the ANKOM filter bag system (ANKOM Technology, Macedon, NY). Total N was determined by combustion using a

modified Dumsa procedure (Elementar Americas, Mt. Laurel, NJ). Crude protein was calculated as total N x 6.25. Total digestible nutrients was calculated as TDN = 100.32 - 1.118 x ADF.

Table 3-3. Harvest dates for Kentland, Shenandoah Valley AREC, and Southern Piedmont AREC: 2009 and 2010.

Kentland	SVAREC	SPAREC
2009		
July 14, 2009	July 15, 2009	July 28, 2009
August 11, 2009	August 10, 2009	August 10, 2009
	September 8, 2009	September 11, 2009
	October 6, 2009	
2010		
August 3, 2010	July 15, 2010	July 28, 2010
September 6, 2010	August 10, 2010	August 10, 2010
	September 8, 2010	September 11, 2010
	October 6, 2010	July 28, 2010

Nitrate concentrations in plant tissue were determined colorimetrically using a modified salicylic acid method (Cataldo et al., 1975). Nitrates were extracted by placing 1 g of dried forage material in a 250 ml Erlenmeyer flask along with 100 ml of distilled water. This mixture was shaken for an hour and then filtered through Whatman #4 filter paper. A 200 µl aliquot of sample extracts and nitrate standards (0, 10, 20, 30, 40, 60, 80, and 100 mg kg⁻¹ nitrate-N) were pipetted into 30 ml glass bottles along with 800 µl of salicylate/sulfuric acid reagent and swirled. Sample blanks were prepared by pipetting a second 200 µl aliquot of sample extracts into 30 ml glass bottles along with 800 µl of reagent grade sulfuric acid. After 20 minutes, 19 ml of 2N NaOH were pipetted into each bottle. After 60 minutes the absorbance of the standards, samples, and sample blanks were read on a spectrophotometer set to 410 nm and zeroed using a blank (distilled water + salicylate/sulfuric acid reagent + NaOH). A regression equation was

determined for the standards and this equation was used to calculate nitrate-N concentrations in the extracts after the absorbance of the corresponding sample blank is subtracted out. This value was multiplied by 443 and reported as mg kg^{-1} nitrate. Maximum nitrogen fertilization rates were calculated for risk thresholds of 2500, 5000, and 15000 mg kg^{-1} nitrate using corresponding regression equations.

Rainfall and temperature data was collected for each location from the National Weather Service (NOAA) to evaluate the influence on forage growth and nutritive value throughout the season and between years. The 2009 and 2010 rain fall data were compared against a historic average.

Data was analyzed using the general linear model procedure from SAS (SAS Institute, Cary, NC). Regression analysis was preformed on raw data using Sigma Plot 11.0 (Systat, Point Richmond, CA). Effect of treatment, location, harvest, and year were tested, along with all possible interactions. Significance was tested at the 5% level unless noted different.

Results and Discussions

Environmental Conditions

Blacksburg

In 2009, at planting, temperature at Kentland farm was similar to the average historic temperature recorded (Figure 3-2A). Part of June, July, and August, however, the temperature was below the historic average. Temperature in 2010 was above the 2009 growing season and the historic average. Total rainfall during the 2009 growing season exceeded the historical average and the 2010 growing season each month except May (Figure 3-2B). The 2010 growing season was drier during the months of April, May, June, July, and October compared with the 2009 growing season and the historic average. Both in terms of temperature and rainfall, 2010 was hotter and drier than the 2009 growing season and the historic average.

Southern Piedmont

In 2009, with the exception of June, July and August, temperature was similar to the historic average but lower than the 2010 average. In 2010, however, temperature was higher than both the 2009 and the historic average (Figure 3-3A). In 2009, rainfall was similar in April and October, higher in May, June, and September, and lower in July and August than the historic average. In 2010, rainfall was higher in May, August and September than the historic average and 2009 but lower in June, July and October. Overall, rainfall was noticeably higher June of 2009 and May, August and September of 2010 compared to the historic average (Figure 3-3B)

Shenandoah Valley

In terms of temperature, 2009 and 2010 were lower than the historic average. Generally, the 2010 growing season was much cooler than the historic average and 2009 average temperature (Figure 3-4A). There was notably more rainfall accumulation prior to planting in 2009 as compared to the historic norm, but remained similar in July and lower for the rest of the growing season (Figure 3-4B). In 2010, rainfall was lower April - July but higher August - October compared with the historic and 2009 average (Figure 3-4B).

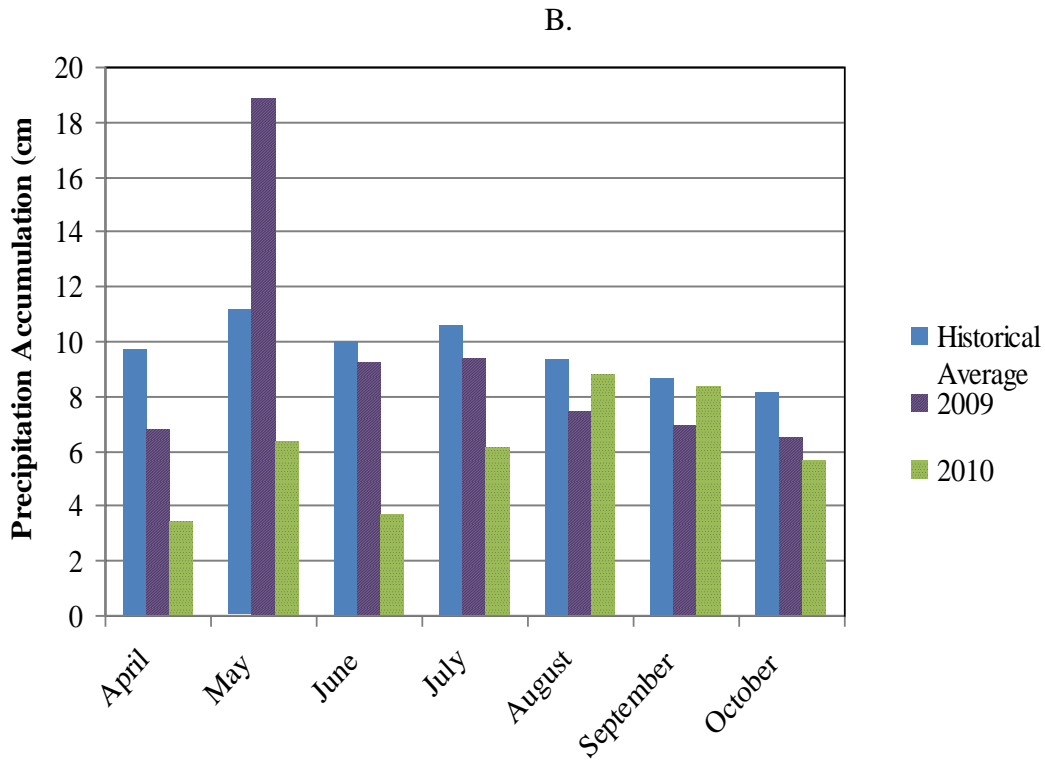
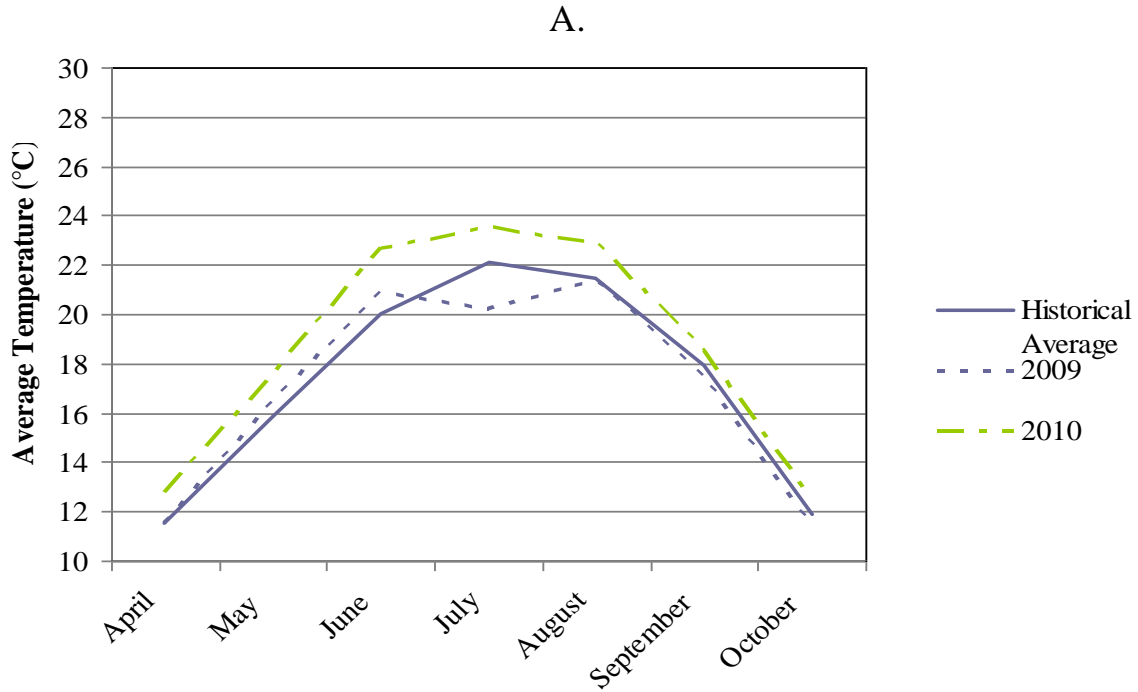


Figure 3-2. Monthly and the historic average temperature (A) and precipitation (B) recorded in Blacksburg, VA during the 2009 and 2010 growing seasons.

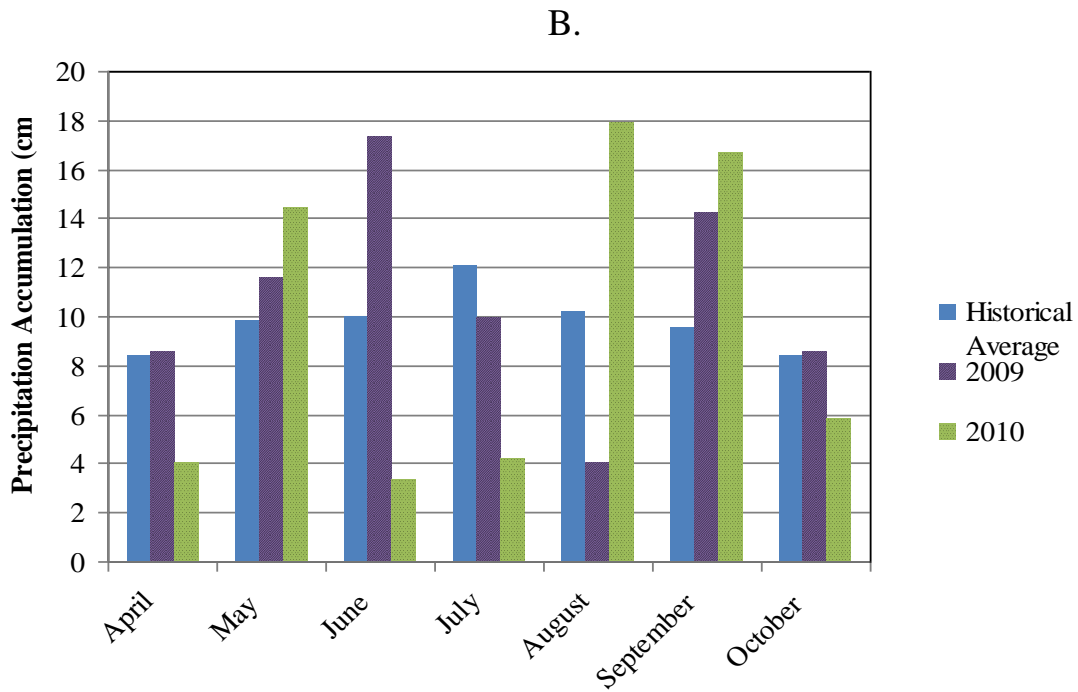
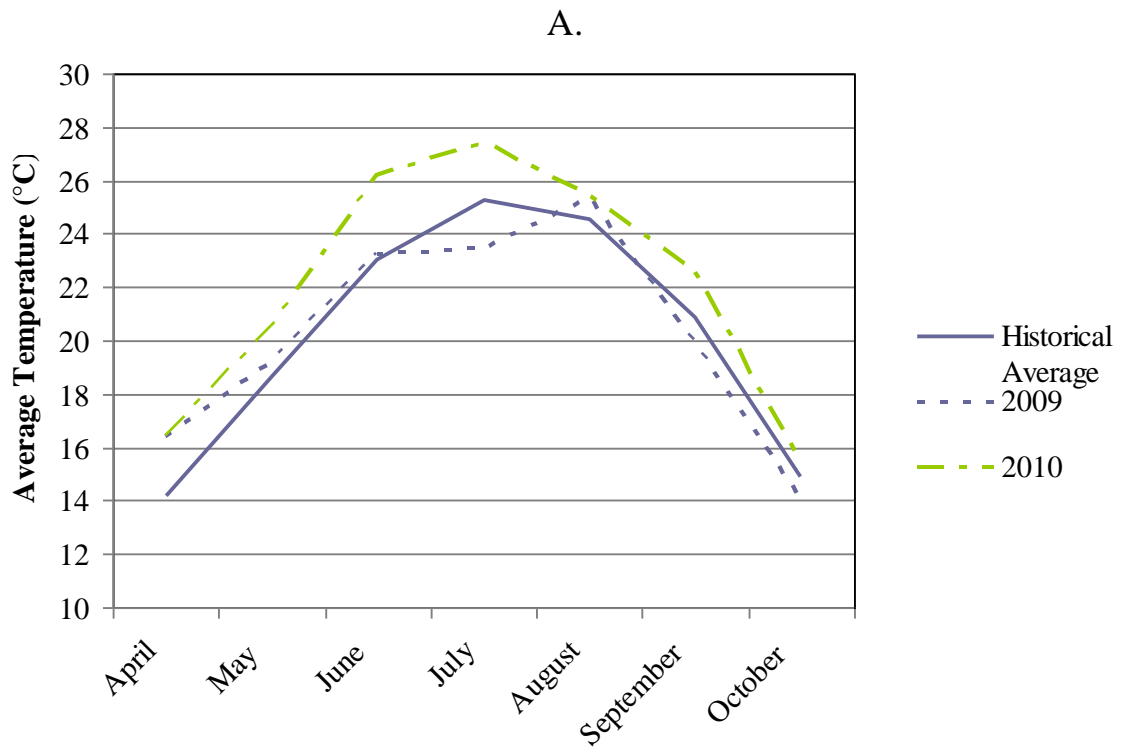


Figure 3-3. Monthly and the historic average temperature (A) and precipitation (B) recorded in Blackstone, VA during the 2009 and 2010 growing seasons.

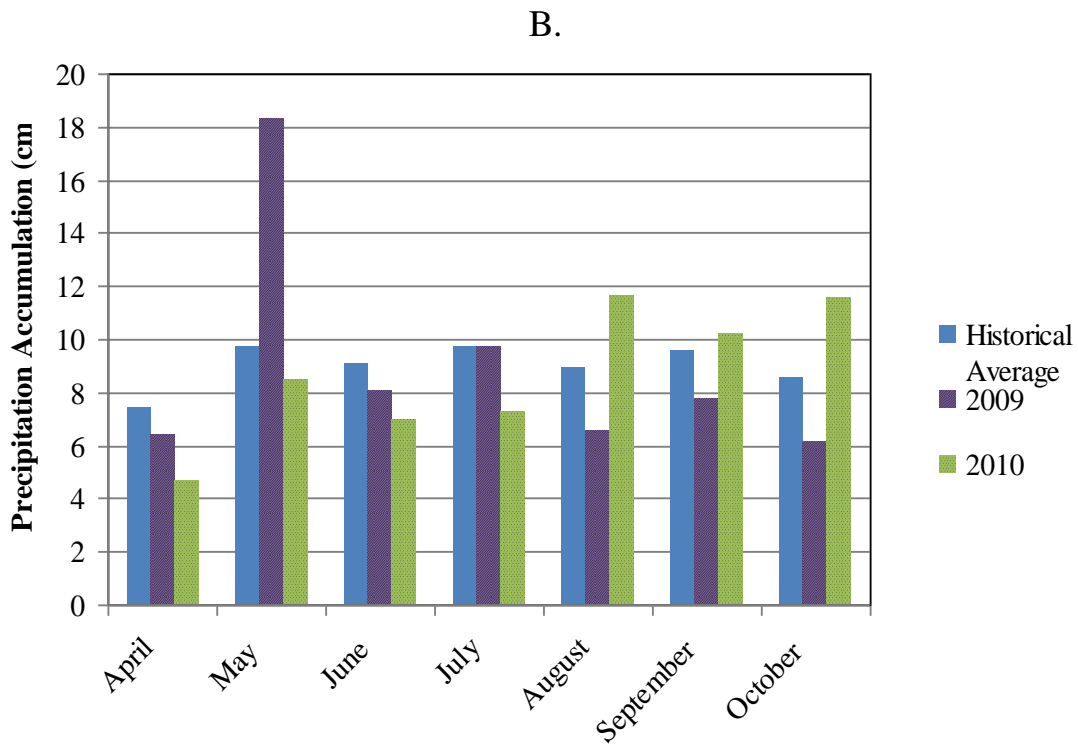
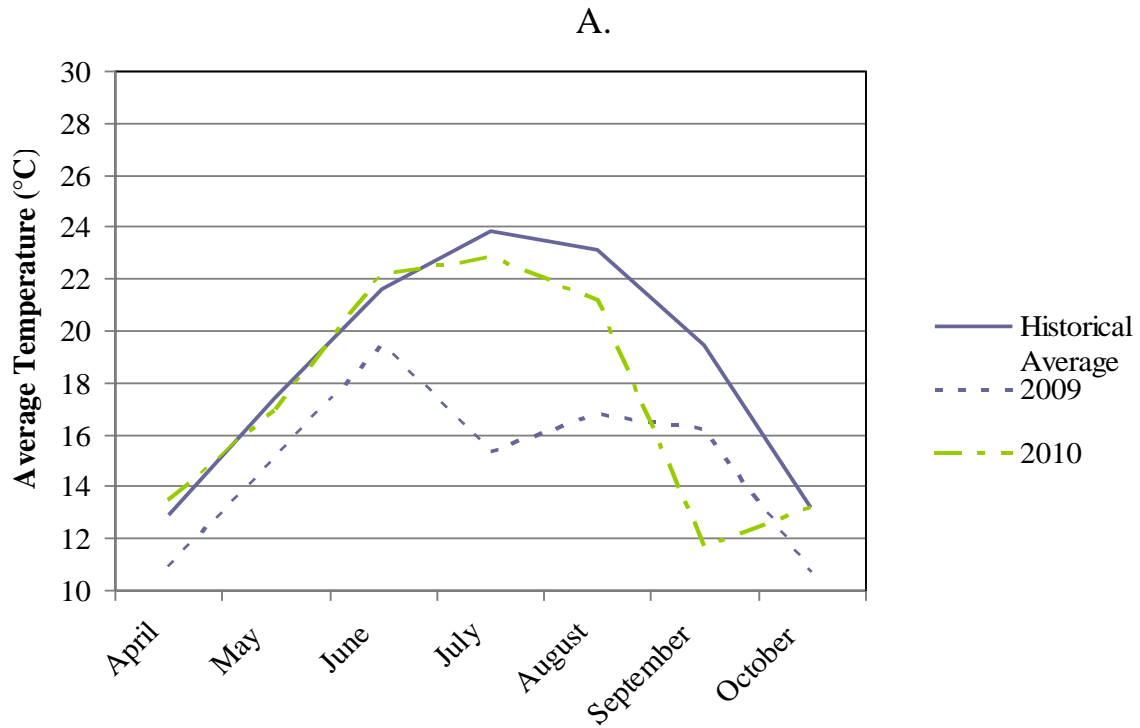


Figure 3-4. Monthly and the historic average temperature (A) and precipitation (B) recorded in Steeles Tavern, VA during the 2009 and 2010 growing seasons.

Biomass Yields

Main effects as well as all possible interactions were tested. Environment (location - year) x N rate and environment x N source interactions were present ($P < 0.001$). Therefore, data is presented by year and location (Table 3-3).

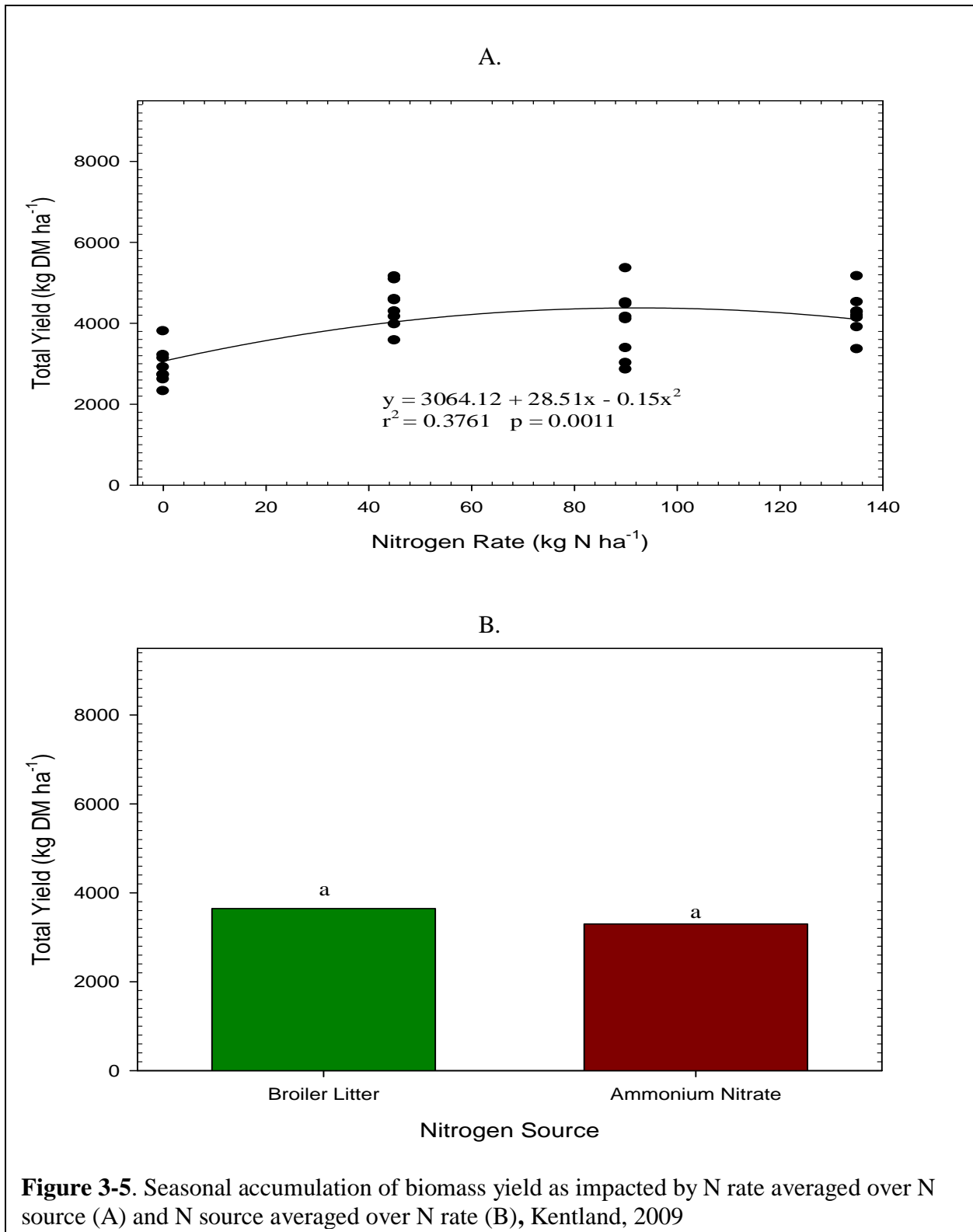
Blacksburg

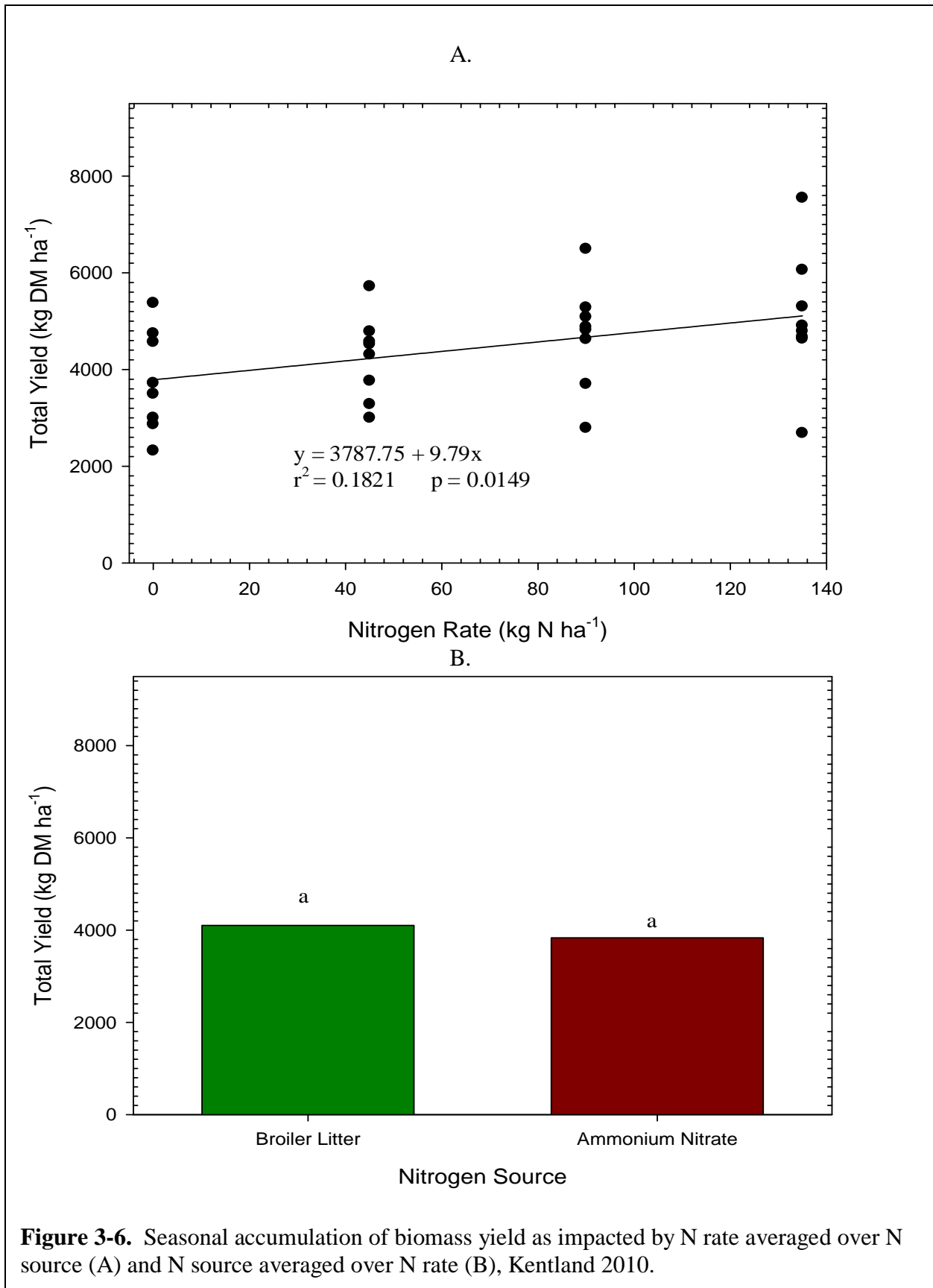
For both 2009 and 2010, no N rate x N source interactions were present, therefore main effects are presented. In 2009 yield increased quadratically whereas in 2010 it responded linearly. In 2009, yield response to N fertilization beyond 45 kg N ha⁻¹ rate was not observed (Figure 3-5A). Similar results were obtained by Hunter et al. (2008) where they concluded that optimum rate of N application to be 60 kg N ha⁻¹. Total biomass accumulations for 2009 ranged from 2330 to 5360 kg DM ha⁻¹. There was no difference in biomass accumulation between N sources (Figure 3-5B). The N rate where biomass yield increased differed between 2009 and 2010. In 2009, no yield increase was evident beyond 45 kg N ha⁻¹ while in 2010, biomass yield increase was observed for the 135 kg N ha⁻¹ rate (Figure 3-6A). Generally in 2010, seasonal yield accumulations were much higher than 2009 (2320 to 7550 kg DM ha⁻¹). This is likely due to the short growing season in 2009, where weeds over took the teff plots and limited production to two harvests early in the growing season. The higher biomass yield in 2010 is rather important considering the fact that the 2010 growing season was much hotter and drier than that of 2009. There was no difference in biomass yield between N sources (Figure 3-6-B).

Table 3-4. ANOVA table by individual and interaction effects on biomass yield, forage quality, and nitrate accumulation.

	Environment	N Source	N Rate	N Source * N Rate	Environment * Source	Environment * Rate	Environment * Source * Rate
Harvest 1	***	ns	***	ns	***	***	**
Harvest 2	***	ns	ns	ns	ns	ns	ns
Harvest 3	***	ns	**	**	ns	*	ns
Harvest 4	***	ns	ns	ns	ns	ns	ns
Total	***	ns	***	ns	**	***	ns
CP1	***	***	***	**	ns	**	**
CP2	***	***	***	**	ns	ns	ns
CP3	***	ns	***	ns	ns	**	*
CP4	***	ns	**	ns	ns	*	ns
ADF1	***	***	*	**	ns	ns	*
ADF2	***	**	***	ns	ns	ns	ns
ADF3	***	ns	**	*	*	ns	ns
ADF4	***	ns	*	ns	ns	*	ns
NDF1	***	***	*	*	ns	ns	ns
NDF2	***	*	**	ns	ns	ns	ns
NDF3	***	ns	*	ns	*	ns	ns
NDF4	***	ns	ns	ns	ns	ns	ns
TDN1	***	***	*	**	ns	ns	ns
TDN2	***	**	***	ns	ns	ns	ns
TDN3	***	ns	**	ns	*	ns	ns
TDN4	***	ns	ns	ns	ns	ns	ns
Nitrates1	***	**	***	***	ns	***	ns
Nitrates2	***	**	***	**	ns	**	ns
Nitrates3	---	ns	**	**	---	---	---
Nitrates4	---	ns	**	ns	---	---	---

ns = non-significant * = p < 0.05 ** = p < 0.01 *** = p < 0.001

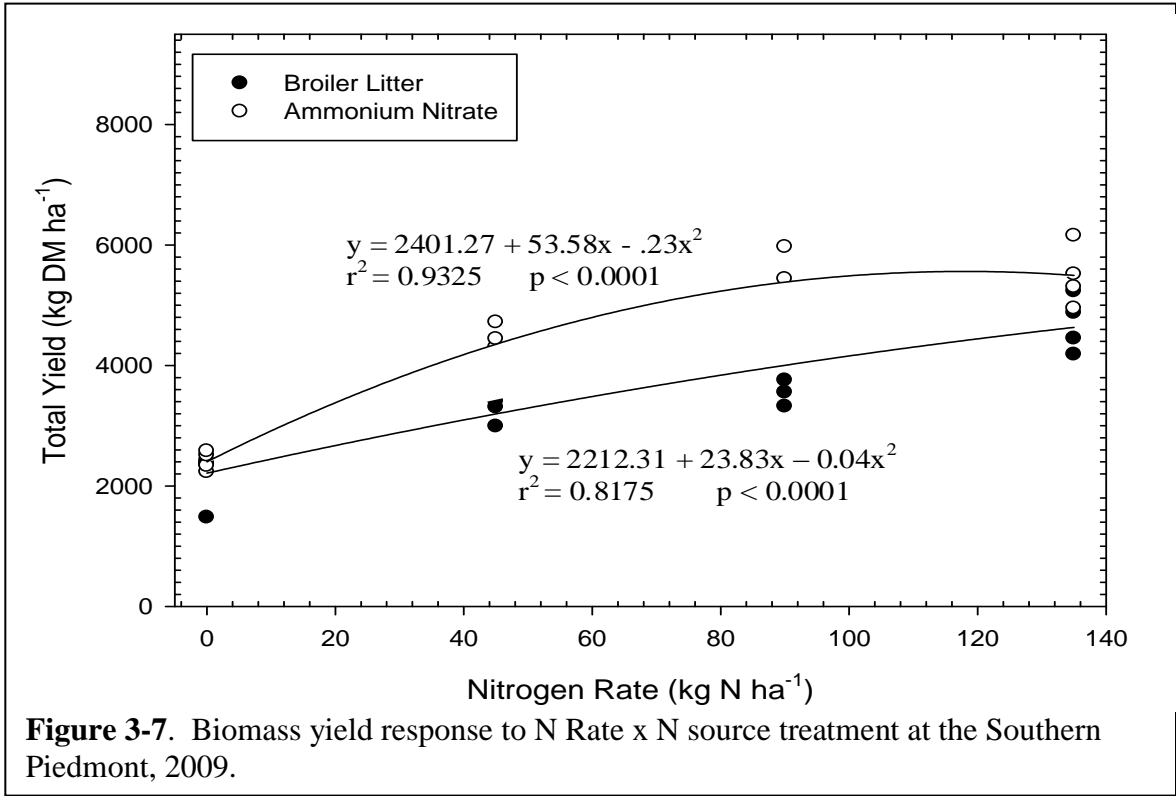


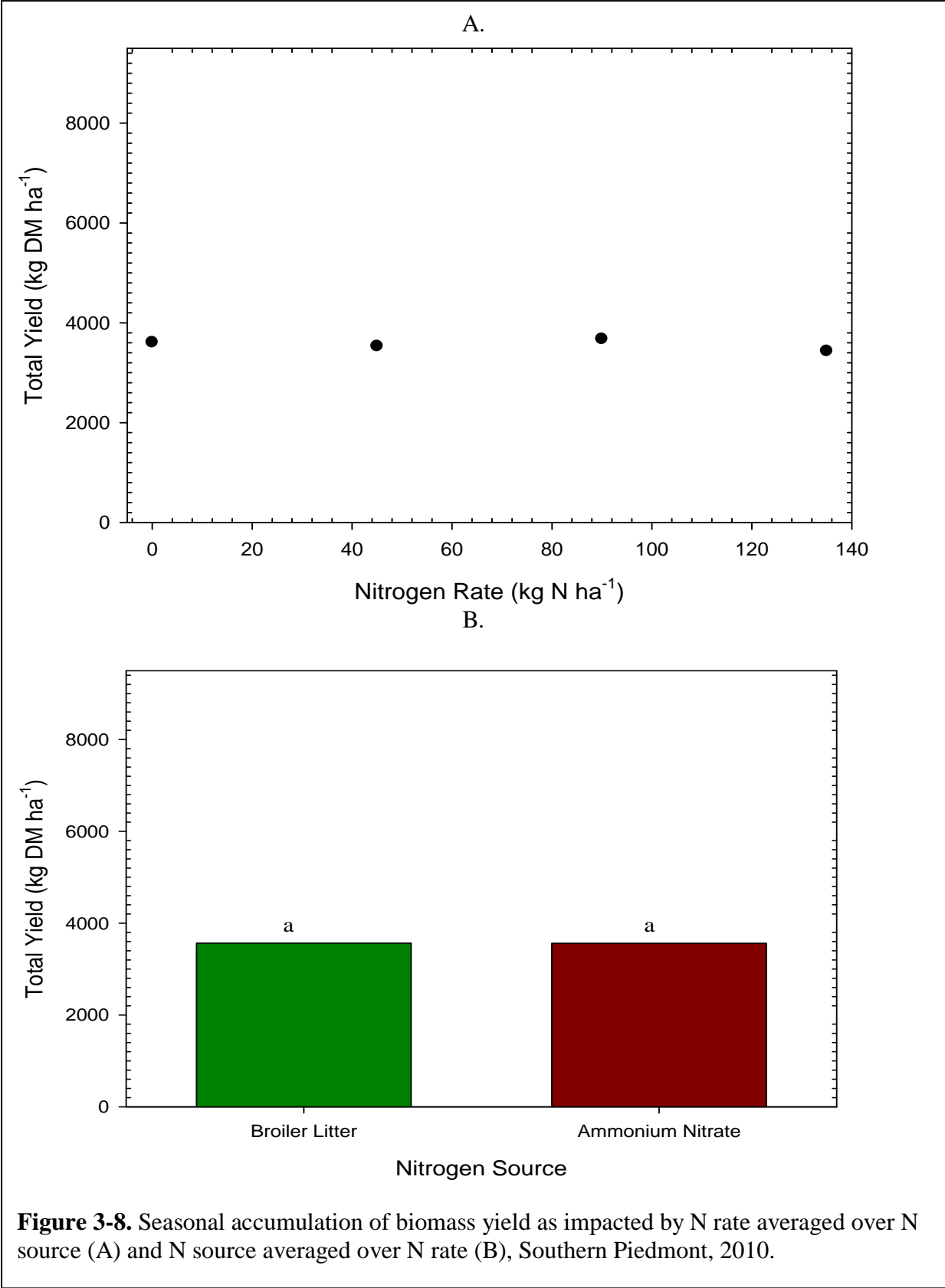


Southern Piedmont

In 2009, biomass yield from the Southern Piedmont location showed significant N rate x N source interaction ($p = 0.0335$) and therefore interaction means are presented (Figure 3-7). Quadratic response to increasing N rate was observed for both N sources (Figure 3-7). Unlike the Blacksburg location, at this location, differences in N sources were observed in 2009. This difference in N source was shown by the difference in DM yield increase for each unit of N applied. The high yield response to N rate and source can be attributed to both adequate rainfall during the early growing season and the timely availability of ammonium nitrate versus broiler litter. Overall in 2009, biomass yield ranged from 1417 to 6151 kg DM ha⁻¹.

In 2010, N source x N rate interaction effects were not significant at the Southern Piedmont thus, results are presented by the main effects. Biomass yield showed no response to N source (Figure 3-8B) or an increasing N rate (Figure 3-8A). The yield response, or lack there of in 2010 was most likely due to the severe drought experienced at the Southern Piedmont location throughout the 2010 growing season. Biomass yield ranged from 3285 to 4922 kg DM ha⁻¹. Overall, in 2009, the yield response to both N rate and source was similar for Blackstone and Blacksburg locations. However, in 2010, no yield response to N rate and source was observed, most likely due to a lack of rainfall at the Blackstone location (Figs. 3-8 A and B).



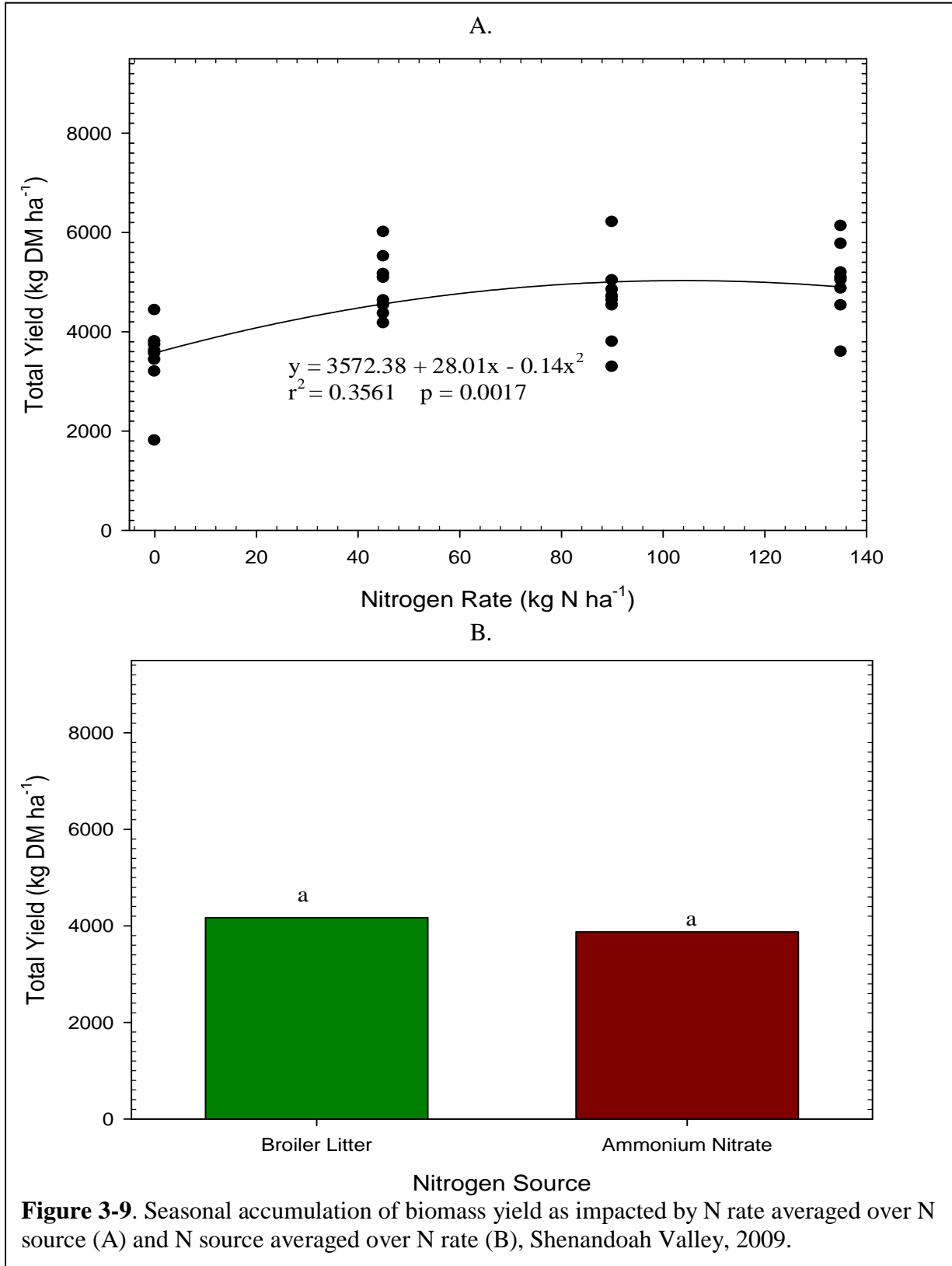


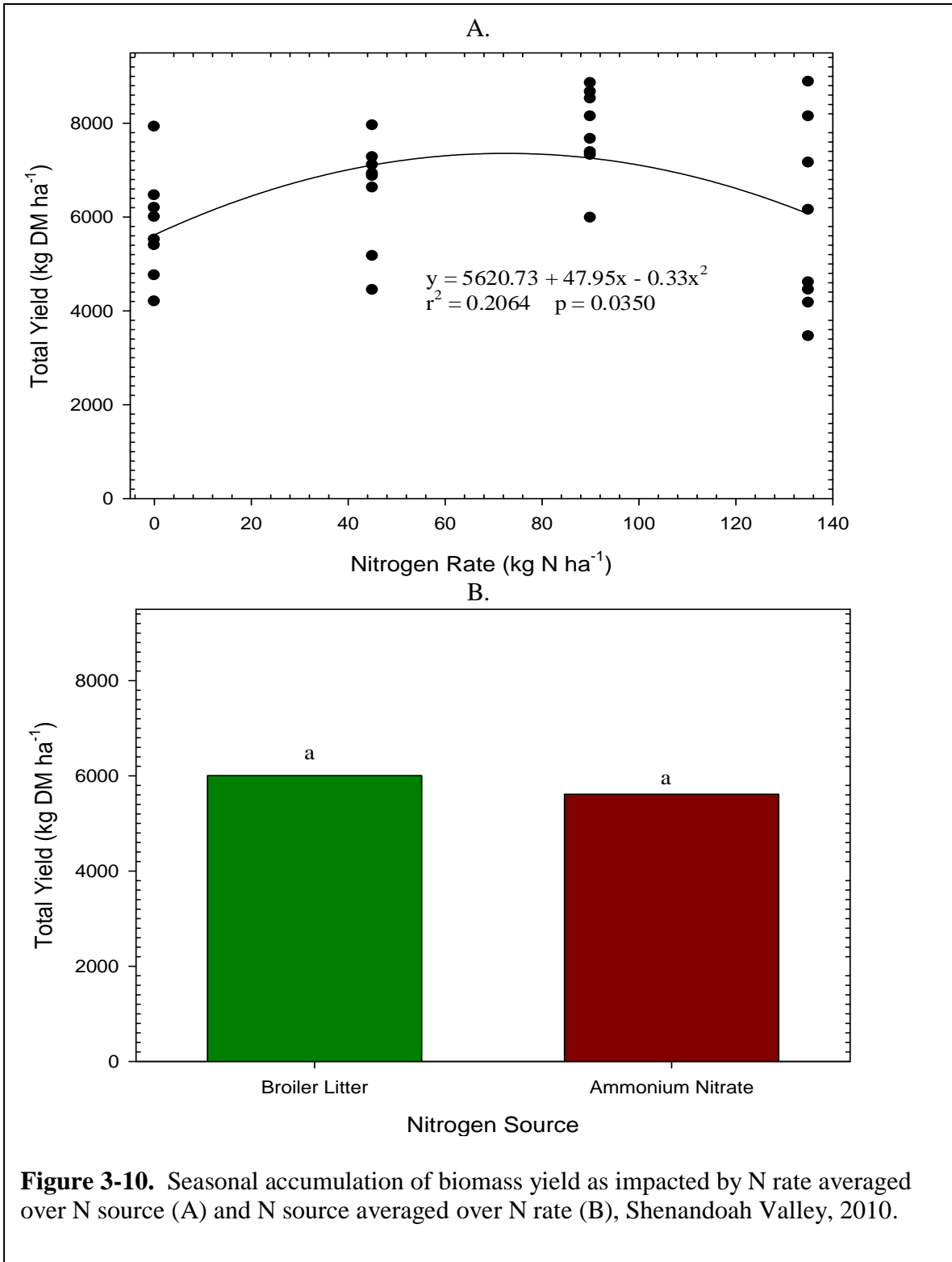
Shenandoah Valley

In both 2009 and 2010, no N rate x N source interaction was present. Therefore the main effects of N rate (Figure 3-9A and 3-10A) and source (Figure 3-9B and 3-10B) are presented. Biomass yield had a quadratic response to increasing N rate in both 2009 and 2010 (Figure 3-9A; 3-10A). The increase in DM kg unit N⁻¹ added was almost identical to the Blacksburg location. Again, similar to the Blacksburg location, no differences were observed between N sources (Figure 3-9B; 3-10B). Dry matter yields ranged from 1805 to 6203 kg DM ha⁻¹ in 2009. The yield response to N rate and the N rate where yield peaked, 90 kg N ha⁻¹, was similar at SVAREC between 2009 and 2010 growing seasons (Figs. 3-9A and 3-10A). Biomass yields from the Shenandoah Valley in 2010 ranged from 3455 to the highest yield of 8875 kg DM ha⁻¹. The yield range for this location was by far the largest over all locations.

Overall at the Shenandoah Valley location, 2009 and 2010 biomass yield response to both N rate and N source were similar. Unlike the Southern Piedmont location where yield was low in 2010, the Steeles Tavern location produced the highest yield response to increasing N rates. The difference in yield response between the two locations may have been due to differences in the amount of rainfall received during the growing season. At both Blacksburg and Southern Piedmont locations, the 2010 growing season was much drier and hotter than that of the 2009 growing season. Gresssel (2008) and Mengistu (2009) stated that rainfall early in the growing season is critical to the development of teff, but after the early growth stages, the plant survives with little to no water. Our results indicated similar outcome where in 2010, due to early season drought, teff basically stopped growing at both Blacksburg and Blackstone locations for extended periods but resumed growing when the locations received average to less than average rainfall. Our results show that although teff is said to be tolerant of drought conditions, it also

responds well to above average rainfall.





Forage Nutritive Value

Forage nutritive values showed significant N rate x environment interactions and N source x environment interactions for certain harvests and therefore data will be presented by location and year.

Crude Protein

Nitrogen rate x N source interactions were significant for the majority of harvests, thus interaction means are presented (Table 3-4). At the Blacksburg location in 2009, although not all significant, CP values for the first and second cut (second cut after 45 kg N ha⁻¹) increased across N rates for ammonium nitrate. This value ranged from 107 g kg⁻¹ for the 0 rate to 165 g kg⁻¹ for the 135 kg N ha⁻¹ rate. Similar trends were observed for broiler litter across N rates (Table 3-4) for both the first and the second cuts. Crude protein levels for the BL source did not reach values as high as the AN source 107-165 versus 110-136 g kg⁻¹. In Blacksburg, 2010, although average CP was higher across rates and sources, the effect of harvest date was similar to that of 2009. At the Blackstone location, similar to the Blacksburg location, the significant effect of N rate and source on CP varied. However, contrary to the Blacksburg location, CP increased from harvest one to three across rates and source. The CP values for this location ranged from 75 to 120 across N rates and sources. This range was much lower than the Blacksburg location. Similar to the Blacksburg location, at Blackstone in 2010, CP was higher for the first harvest versus the second across rates and locations (Table 3-4). Overall at the Blackstone location in 2010, CP was much higher than 2009 (80 - 120 vs. 90 - 170).

Again, significant differences in CP values in response to rates and source varied in both 2009 and 2010. In 2010, although significant levels varied, there was a clear pattern

in the effect of harvest dates on CP values. Overall, CP values for the Steeles Tavern location was higher than all other locations. Values ranged from 120-220 g kg⁻¹.

Table 3-5. Crude protein interaction means by location, year, and harvest.

Harvest	Ammonium Nitrate				Broiler Litter				Standard Error
	0	45	90	135	0	45	90	135	
	kg N ha ⁻¹				kg N ha ⁻¹				
Blacksburg, 2009	g kg ⁻¹								
Harvest 1	107.5	145.0	155.0	165.0	110.0	125.0	115.0	136.0	6.5
Harvest 2	102.5	92.5	122.5	135.0	90.0	95.0	95.0	115.0	3.6
Blackstone, 2009									
Harvest 1	75.0	77.5	90.0	110.0	750.0	750.0	77.5	80.0	3.8
Harvest 2	97.5	97.5	105.0	107.5	97.5	102.5	107.5	107.5	3.4
Harvest 3	105.0	107.5	117.5	117.5	110.0	115.0	117.5	120.0	2.7
Steeles Tavern, 2009									
Harvest 1	107.5	102.5	122.5	150.0	112.5	117.5	107.5	115.0	7.1
Harvest 2	87.5	95.0	90.0	125.0	87.5	90.0	97.5	105.0	4.0
Harvest 3	110.0	102.5	97.5	110.0	105.0	102.5	107.5	110.0	5.4
Harvest 4	97.5	92.5	87.5	97.5	92.5	92.5	92.5	100.0	4.4
Blacksburg, 2010									
Harvest 1	147.5	167.5	180.0	175.0	167.5	155.0	160.0	152.5	7.3
Harvest 2	117.5	135.0	147.5	155.0	125.0	130.0	137.5	132.5	7.1
Blackstone, 2010									
Harvest 1	125.0	150.0	147.5	162.5	117.5	142.5	147.5	175.0	6.0
Harvest 2	100.0	105.0	120.0	145.0	97.5	95.0	112.5	107.5	6.3
Steeles Tavern, 2010									
Harvest 1	197.5	187.5	187.5	220.0	175.0	185.0	187.5	190.0	9.8
Harvest 2	175.0	182.5	190.0	205.0	180.0	172.5	167.5	195.0	9.6
Harvest 3	125.0	150.0	167.5	182.5	140.0	137.5	162.5	145.0	8.6
Harvest 4	142.5	137.5	152.5	172.5	135.0	142.5	147.5	160.0	7.7

Overall, crude protein content of teff increased with increasing N rates. Crude protein levels ranged from 70 to 240 g kg⁻¹, but the average across year, location, rates and source was around 125 g kg⁻¹. These results were similar to findings from South Dakota (Twidwell et al. 2002), Montana (Hunter et al., 2007), and Oregon (Norberg, 2009). In most cases, the CP values reported meet the minimum requirement for brood cows which is 70 g kg⁻¹ (Ball et al., 2007). If we had applied the N fertilizer as split versus single application as we did, the CP values for each cut may have been different

from what we reported. In our study, overall, crude protein levels peaked at the 90 kg N ha⁻¹ and show no increase beyond this rate.

ADF

The interaction between N rate x N source was significant for some of the harvests, therefore interaction means will be presented (Table 3-5). At the Blacksburg location in 2009, the effect of N source on ADF was observed. The first harvest showed no response to N rate whereas the second harvest showed effect of N at the 135 kg N ha⁻¹ rate. The ADF value ranged from 330-440 g kg⁻¹ across N rates and sources for the first harvest in 2009 while the range was higher for the second harvest at 430 to 480 g kg⁻¹ (Table 3-5). ADF values, in general, were lower in 2010 than 2009. In 2010, N source effect on ADF was observed for the second but not the first harvest. The first harvest of 2010 showed a difference between N rates 0 and 135 kg N ha⁻¹ whereas the second harvest showed no response. The ADF values across N rates and sources ranged from 280 - 340 and 270-320 g kg⁻¹ for the first and the second harvest, respectively.

Similar to the Blacksburg location, at the Southern Piedmont location in both 2009 and 2010, effect of N rates and N sources on ADF varied across harvest dates. No response to N source was observed for the first and second harvests in 2009, unlike the third harvest. The first harvest showed no response to N rate over the 45 kg N ha⁻¹ rate while no response to N rate was observed the second harvest. The third harvest at the Blackstone location in 2009 showed a response between 0 and 135 kg N ha⁻¹ rates. This was similar to the first harvest of 2010 at the Blacksburg location. In 2009, the ADF values from the second harvest were the highest, followed by the first harvest and then the third. The range of ADF values for the first, second, and third harvest were 380 to

410 g kg⁻¹, 400 to 430 g kg⁻¹, and 340 to 400 g kg⁻¹, respectively. Similar to harvests one and two of 2009, no response to N source was observed in 2010. Both harvests of 2010 showed different responses between the 45 and the 135 kg N ha⁻¹ rates. The ADF values from 2010 ranged from 290 to 350 g kg⁻¹ and 370 to 410 g kg⁻¹ for the first and second harvest, respectively. The range ADF values were higher in 2009 compared with 2010.

At the Shenandoah Valley location in 2009, no responses to N sources were observed (Table 3-5). Harvests one and four showed no response to N rates, whereas harvest two showed a response at the 135 kg N ha⁻¹ rate. For harvest three, the only difference in responses to N rates were observed between 45 versus 135 kg N ha⁻¹ rates and between 90 versus 135 kg N ha⁻¹ rates. In 2009, ADF values ranged from 320 to 430 g kg⁻¹, 360 to 440 g kg⁻¹, 340 to 400 g kg⁻¹, and 390 to 450 g kg⁻¹ for the first, second, third and fourth harvests, respectively. In 2010, similar to 2009, differences in ADF due to treatments varied across harvest dates. No differences in response to N source were reported in 2010 with the first harvest being the exception. The first, second and third harvests showed no response to N rate, whereas harvest four showed differences between rates. The ADF values ranged from harvest one ranged from 320 to 390, 300 to 380, 310 to 370, and 320 to 370 g kg⁻¹ for the first, second, third, and fourth harvests, respectively.

Overall, there was very little effect of N rate on ADF values. Mixed responses were observed for N sources. In general, ADF values increased with the harvest dates. The ADF values ranged from 271 to 483 g kg⁻¹, with an average ADF value of 374 g kg⁻¹. These results are similar to those found in Oregon (Norberg, 2009) and New York (Hunter, 2008) where increases in ADF values were observed with subsequent harvests. Ball et al, 2002, under quality standard for legume, grass, or grass-legume hay listed ADF

value < 310 to be of a prime quality while values greater than 450 as a lower quality.

Overall, the quality of teff we reported, regardless of N rates and sources, resulted in ADF levels acceptable to support all classes of livestock beyond maintenance level (277-447 g kg⁻¹)

Table 3-6. ADF interaction means by location, year, and harvest.

Harvest	Ammonium Nitrate				Broiler Litter				Standard Error
	0	45	90	135	0	45	90	135	
	kg N ha ⁻¹				kg N ha ⁻¹				
Blacksburg, 2009	g kg ⁻¹								
Harvest 1	397.5	377.5	365.0	360.0	375.0	387.5	410.0	390.0	10.2
Harvest 2	450.0	456.0	445.0	435.0	462.5	462.5	465.0	447.5	4.7
Blackstone, 2009									
Harvest 1	385.0	397.5	405.0	395.0	390.0	400.0	402.5	400.0	4.7
Harvest 2	420.0	415.0	415.0	412.5	420.0	417.5	420.0	417.5	3.6
Harvest 3	387.5	380.0	370.0	362.5	365.0	367.5	370.0	360.0	6.2
Steeles Tavern, 2009									
Harvest 1	377.5	405.0	382.5	367.5	382.5	380.0	397.5	387.5	7.7
Harvest 2	405.0	405.0	407.5	372.5	407.5	412.5	395.0	392.5	6.4
Harvest 3	377.5	390.0	395.0	370.0	382.5	387.5	385.0	380.0	5.7
Harvest 4	422.5	422.5	432.5	417.5	417.5	415.0	425.0	415.0	6.6
Blacksburg, 2010									
Harvest 1	310.0	305.0	305.0	317.5	297.5	315.0	325.0	325.0	6.9
Harvest 2	292.5	287.5	277.5	282.5	287.5	297.5	292.5	300.0	5.3
Blackstone, 2010									
Harvest 1	335.0	330.0	317.5	312.5	332.5	342.5	335.0	335.0	5.4
Harvest 2	385.0	390.0	390.0	377.5	392.5	395.0	390.0	390.0	4.2
Steeles Tavern, 2010									
Harvest 1	357.5	372.5	375.0	350.0	372.5	377.5	377.5	377.5	8.4
Harvest 2	357.5	367.5	362.5	350.0	360.0	370.0	353.5	360.0	9.9
Harvest 3	355.0	337.5	335.0	325.0	345.0	347.5	345.0	350.0	6.2
Harvest 4	352.5	357.5	345.0	332.5	350.0	355.0	345.0	340.0	4.8

NDF

In both 2009 and 2010, N rate x N source was significant at certain harvests, therefore interaction means are presented (Table 3-6). At Blacksburg in both 2009 and 2010, similar to ADF, the effect of N source and rate on NDF varied (Table 3-6). There was no N source effect on NDF values in 2009 or 2010. In both 2009 and 2010, NDF values responded differently to the N rates, but overall, the effect of N rates on NDF was

minimal. The NDF values were 620 to 720 g kg⁻¹ and 690 to 760 g kg⁻¹ for the first and second harvests in 2009, respectively, while the NDF in 2010 ranged from 540 to 610 g kg⁻¹ and 510 to 560 g kg⁻¹, for the first harvest and the second, respectively. Generally, the ranges of values for NDF were lower in 2010 compared with 2009.

In 2009 at the Southern Piedmont location, N rate effect on NDF was only observed for the first harvest. The rest of the differences (harvest two and three) were only observed between the low and high rates. However, the effect of N source on NDF values was observed for the first and third harvests, while the second harvest showed no response to either N source or rate. Values from 2009 ranged from 660 to 790 g kg⁻¹, 660 to 690 g kg⁻¹, and 590 to 650 g kg⁻¹ for harvests one, two, and three, respectively. In 2010, the first and second harvests showed response to the different N sources. Responses in N rate were different between the low and high rates in 2010. Values ranged from 570 to 640 g kg⁻¹ and 650 to 690 g kg⁻¹. Values from harvest one in 2010 were much lower than 2009, however harvest two showed little variance between years.

In 2009 and 2010 at the Shenandoah Valley location, there is no effect of N source on NDF values. Harvests three and four of 2009 and one and two of 2010 did not show a response to N rate either. However, N rate did affect NDF quantities differently in harvests one and two of 2009. Harvest one and two both showed differences in response at the 135 kg N ha⁻¹ rate. Harvest three of 2010 showed significance between 0 and the other N rates whereas harvest four showed differences between the low N rates and the 135 kg N ha⁻¹ rate. Values for NDF ranged from 630 to 730 g kg⁻¹, 670 to 750 g kg⁻¹, 670 to 720 g kg⁻¹, and 690 to 740 g kg⁻¹ in 2009 and 560 to 670 v, 530 to 630 g kg⁻¹, 560 to 610 g kg⁻¹ and 570 to 640 g kg⁻¹ in 2010, respectively. Overall, values were higher in

2010 opposed to 2009, which is similar to results found at the other locations. No major differences in NDF values were observed between subsequent harvests in both 2009 and 2010.

Overall, there was no major effect of N rates or sources on NDF values. The NDF values ranged from 507 g kg⁻¹ to 758 g kg⁻¹, with an average NDF value of 646 g kg⁻¹. These values are slightly higher than those found in Oregon (Norberg, 2009), New York (Hunter et al., 2007), Nevada (Davison, 2006), and Mississippi (Lemus, 2009). According to Ball et al. (2007), NDF values ranging from 420 to 600 g kg⁻¹ are acceptable to support all classes of livestock beyond maintenance level. However, the average values reported in our experiment may be higher than the acceptable range for all classes of livestock beyond maintenance level.

Table 3-7. NDF interaction means by location, year, and harvest

Harvest	Ammonium Nitrate				Broiler Litter				Standard Error
	0	45	90	135	0	45	90	135	
	kg N ha ⁻¹				kg N ha ⁻¹				
Blacksburg, 2009	g kg ⁻¹								
Harvest 1	665.0	660.0	652.5	650.0	655.0	662.5	677.5	667.5	8.0
Harvest 2	705.0	730.0	705.0	702.5	707.5	717.5	715.0	707.5	7.6
Blackstone, 2009									
Harvest 1	702.5	690.0	685.0	675.0	697.5	707.5	705.0	695.0	5.1
Harvest 2	670.0	677.5	675.0	670.0	680.0	675.0	682.5	677.5	4.3
Harvest 3	642.5	632.5	635.0	627.5	622.5	622.5	630.0	617.5	6.6
Steeles Tavern, 2009									
Harvest 1	665.0	715.0	692.5	667.5	680.0	687.5	702.5	690.0	11.6
Harvest 2	702.5	717.5	710.0	680.0	712.5	720.0	690.0	697.5	6.9
Harvest 3	697.5	705.0	710.0	695.0	702.5	702.5	700.0	695.0	6.7
Harvest 4	710.0	712.5	710.0	705.0	707.5	705.0	710.0	705.0	6.6
Blacksburg, 2010									
Harvest 1	582.5	575.0	575.0	587.5	560.0	585.0	595.0	592.5	8.1
Harvest 2	532.5	527.5	515.0	527.5	525.0	532.5	532.5	542.5	5.2
Blackstone, 2010									
Harvest 1	610.0	607.5	592.5	587.5	610.0	627.5	617.5	612.5	7.6
Harvest 2	680.0	675.0	670.0	655.0	685.0	682.5	675.0	672.5	4.8
Steeles Tavern, 2010									
Harvest 1	615.0	627.5	635.0	597.5	640.0	640.0	635.0	632.5	13.6
Harvest 2	597.5	607.5	602.5	590.0	602.5	617.5	592.5	597.5	12.0
Harvest 3	597.5	582.5	575.0	567.5	592.5	585.0	580.0	590.0	5.2
Harvest 4	610.0	615.0	600.0	592.5	610.0	615.0	602.5	595.0	7.7

TDN

At the Blacksburg location in 2009, response to N source was observed for both harvest dates, whereas in 2010 only the second harvest showed response. In both 2009 and 2010, the effects of N rates on TDN values were mixed (Table 3-7). Harvest one of 2009 and harvest two of 2010 showed no response to different N rates, whereas harvest two of 2009 and one of 2010 showed differences between the upper and lower rates. The ranges of TDN values in 2009 were 510 to 630 g kg⁻¹ and 460-530 g kg⁻¹ for the first and second harvests and 620 to 690 g kg⁻¹ and 650 to 700 g kg⁻¹ for the 2010 harvest one and two, respectively.

In 2009 at the Southern Piedmont research location, the first, second, and third harvests showed no response to N sources whereas in 2010, responses for first and

second harvests were observed. Harvest one of 2009 and 2010 along with harvest three of 2009 showed response to N rate whereas harvest two of both years showed no response to N rates. The ranges of TDN values in 2009 were 540 – 580 g kg⁻¹, 520- 560 g kg⁻¹, and 560-620 g kg⁻¹, for the first, second, and third harvests, respectively. While differences in response to N application rates were present, no major differences in TDN values were observed between harvests.

Shenandoah Valley TDN values for 2009 and 2010 showed no response to different N sources. Harvests one and four of 2009 and one and two of 2010 showed no response to N rates. Harvests two and three of 2009 showed differences at the highest N rates compared to the others. The ranges of TDN values in 2009 were 520 - 640, 520 - 600, 550 - 630, and 500 - 570 g kg⁻¹, for the first, second, third, and fourth harvest dates respectively. The differences between the low and high values were, 10, 80, 80, and 70 g kg⁻¹ for the first, second, third, and fourth harvest dates, respectively. Harvests three and four of 2010 showed differences between the lower rates (0 and 45 kg N ha⁻¹) and the 135 kg N ha⁻¹ rate. Values for TDN in 2010 ranged from 560 to 650, 570 to 670, 590 to 660, and 590 to 640 g kg⁻¹ for harvests one, two, three, and four, respectively.

Overall, TDN values showed little to no response to the 0-90 kg N ha⁻¹ rates. The only response of TDN to N was at the 135 kg N ha⁻¹ rate. Nitrogen source was significant at some of the locations, particularly Blackstone, which is most likely due to the lack of rainfall. Generally, the TDN values ranged from 463 g kg⁻¹ to 670 g kg⁻¹, with an average TDN value of 586 g kg⁻¹. The ranges reported are within values listed (460-670 g kg⁻¹) for cool-season perennial legumes and grasses as well as warm season perennial and annuals (Ball et al, 2002).

Table 3-8. TDN interaction means by location, year, and harvest.

Harvest	Ammonium Nitrate				Broiler Litter				Standard Error
	0	45	90	135	0	45	90	135	
	kg N ha ⁻¹				kg N ha ⁻¹				
Blacksburg, 2009	g kg ⁻¹								
Harvest 1	562.5	582.5	592.5	597.5	582.5	565.0	545.0	565.0	11.2
Harvest 2	500.0	482.5	507.5	517.5	487.5	487.5	480.0	500.0	5.7
Blackstone, 2009									
Harvest 1	570.0	560.0	552.5	562.5	567.5	552.5	550.0	555.0	5.3
Harvest 2	532.5	540.0	537.5	545.0	537.5	547.5	535.0	535.0	4.2
Harvest 3	570.0	580.0	590.0	597.5	595.0	590.0	590.0	602.5	6.8
Steeles Tavern, 2009									
Harvest 1	577.5	555.0	577.5	590.0	575.0	580.0	557.5	570.0	8.2
Harvest 2	552.5	552.5	550.0	585.0	550.0	542.5	560.0	565.0	6.0
Harvest 3	580.0	567.5	562.5	590.0	572.5	567.5	575.0	577.5	7.8
Harvest 4	532.5	535.0	520.0	540.0	537.5	537.5	530.0	537.5	6.6
Blacksburg, 2010									
Harvest 1	655.0	660.0	662.5	647.5	672.5	650.0	637.5	637.5	7.2
Harvest 2	677.5	682.5	692.5	687.5	682.5	672.5	677.5	670.0	5.4
Blackstone, 2010									
Harvest 1	630.0	630.0	645.0	655.0	630.0	622.5	627.5	632.5	5.9
Harvest 2	572.5	570.0	570.0	577.5	565.0	560.0	567.5	567.5	4.5
Steeles Tavern, 2010									
Harvest 1	602.5	587.5	587.5	610.0	590.0	577.5	582.5	582.5	9.7
Harvest 2	602.5	592.5	600.0	610.0	602.5	587.5	610.0	602.5	11.0
Harvest 3	605.0	622.5	630.0	640.0	615.0	617.5	620.0	612.5	7.3
Harvest 4	612.5	607.5	615.0	627.5	615.0	605.0	620.0	622.5	5.4

Nitrate Accumulation

Significant N rate x location and N source x location interactions were observed.

Therefore interaction means are presented (Table 3-3). In order to examine the effect of N rates and sources on nitrate accumulation in teff, samples were screened from the first two harvests at the highest (90 and 135 kg N ha⁻¹) N rate applications. Samples for all locations and years were tested. The results were compared to Table 3-8 which shows the potential toxicity of forages containing varying concentrations of nitrate. If samples from high N rate treatments showed high nitrate levels, all samples from the harvest were analyzed. In 2009, the first harvest from Blacksburg location showed nitrates at toxic

levels; therefore all samples from that harvest were tested. In 2010, samples from several locations showed nitrate at high toxic levels, therefore all locations and harvests were tested.

Table 3-9. Potential toxicity of forages containing varying concentrations of nitrate.

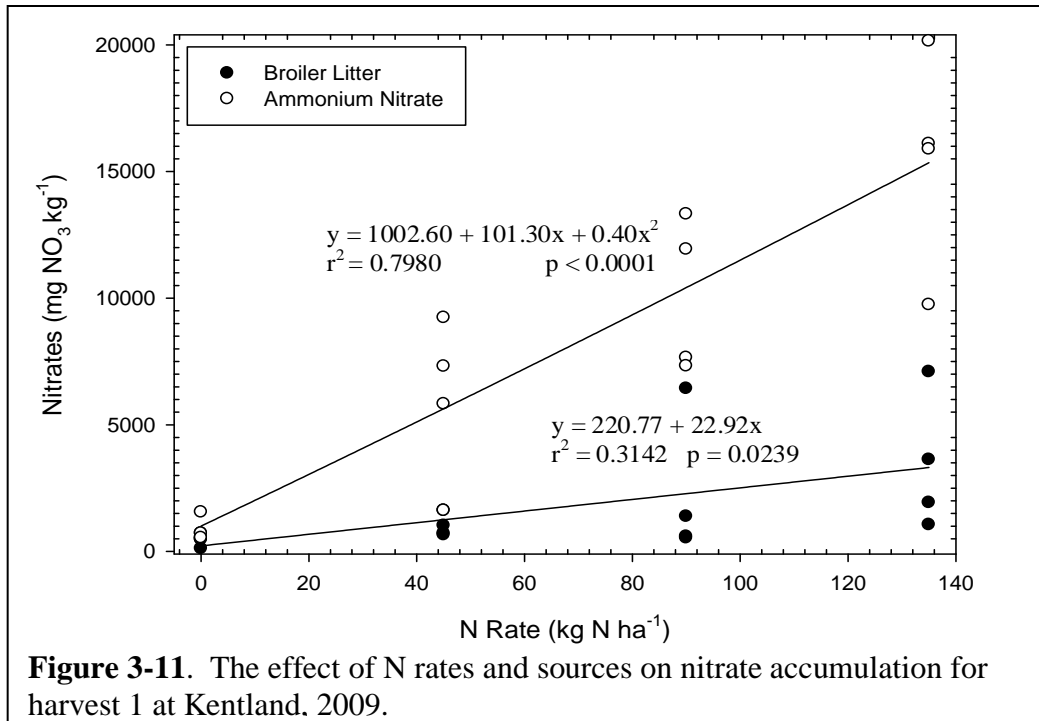
Nitrate in Forage	Rating	Comments
mg kg ⁻¹ NO ₃ ⁻ 0 – 2,500	SAFE	Considered safe in most circumstances.
2,500 – 5,000	GENERALLY SAFE	Safe when fed with balanced ration. Limit to ½ of ration for pregnant animals. Check water for nitrates.
5,000 – 15,000	DANGER	Limit to ¼ of ration. Feed with a well balanced ration. May encounter production losses and reproductive problems.
15,000 +	TOXIC	Do not feed free choice. Feed only in a total mixed ration with high nitrate feed composing less than 15% of total ration.

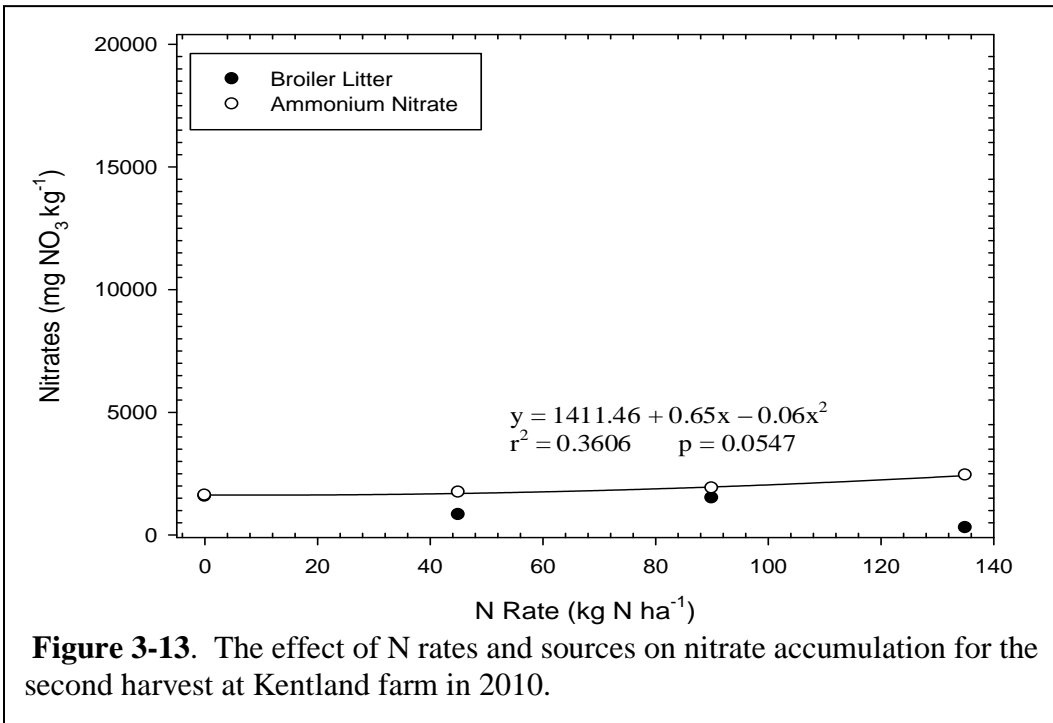
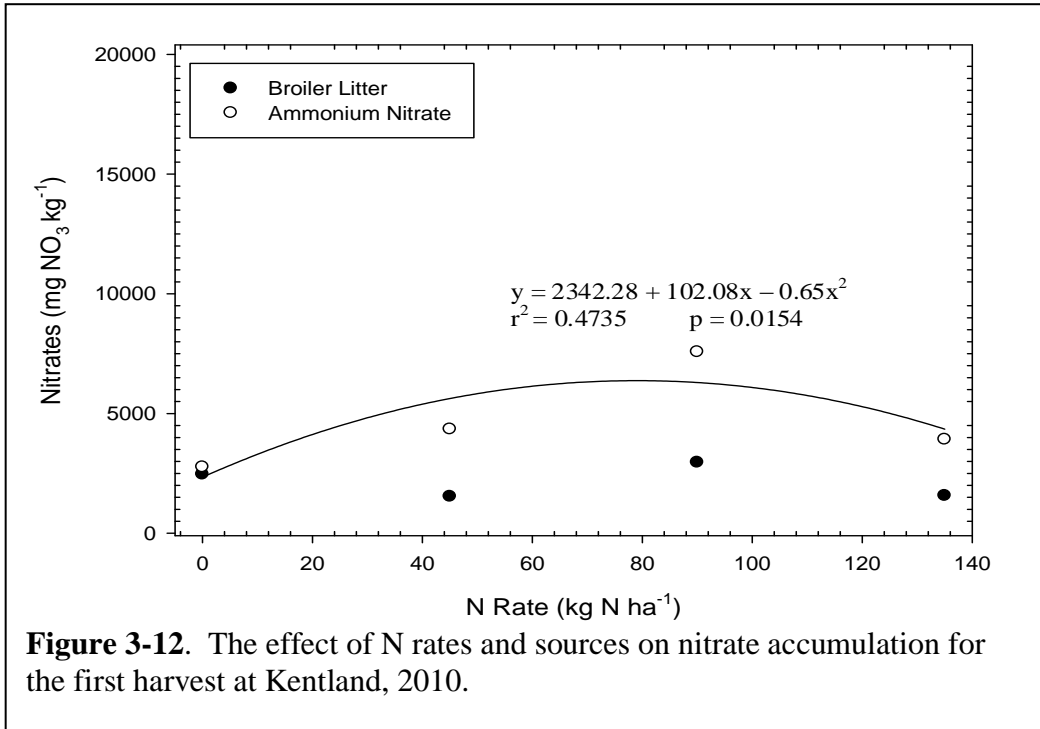
Adapted from *Southern Forages* Third Edition

Kentland

Nitrogen rate x N source interaction was significant for 2009 and 2010, therefore interaction means will be presented (Figure 3-11; 12; 13). Samples obtained from the first harvests in 2009 and 2010 showed nitrate levels above 5,000 mg kg⁻¹ NO₃⁻ (Table 3-8 and Figure 3-11, Figure 3-12). Ammonium nitrate, at application rates higher than 45 kg N ha⁻¹ from the first harvests showed nitrate accumulation at levels of both dangerous and toxic for livestock (Table 3-8 and Figure 3-11; 12). Broiler litter, at any rate, showed no dangerous or toxic levels of nitrate accumulation in teff in 2009 or 2010 (Figure 3-11;

12; 13). In 2009, ammonium nitrate showed a quadratic response where as broiler responded linearly (Figure 3-11). In 2010, nitrate levels for broiler litter showed no response to N rate and therefore means were plotted (Figure 3-12; 13). Harvest two for all rates and sources showed nitrate levels in the generally safe or below ranges.





Southern Piedmont

In 2010, significant N rate x N source interactions were present for both harvest dates (Harvest 1: $p = 0.0823$; Harvest 2: $p = 0.0035$), therefore interaction means are presented. Both N sources showed quadratic response to increasing N rates for harvest one at the Southern Piedmont in 2010 (Figure 3-14). In harvest two, however AN responded quadratically while BL responded linearly (figure 3-15). Nitrate accumulation level in teff was at a dangerous level from the first harvest for both sources of N at the at the 45 kg N ha⁻¹ rate and higher (Table 3-8; Figure 3-14). Nitrate levels in teff from second harvest at the 90 and 135 kg N ha⁻¹ rates showed nitrate accumulation levels are within the dangerous to livestock range (Table 3-8; Figure 3-15).

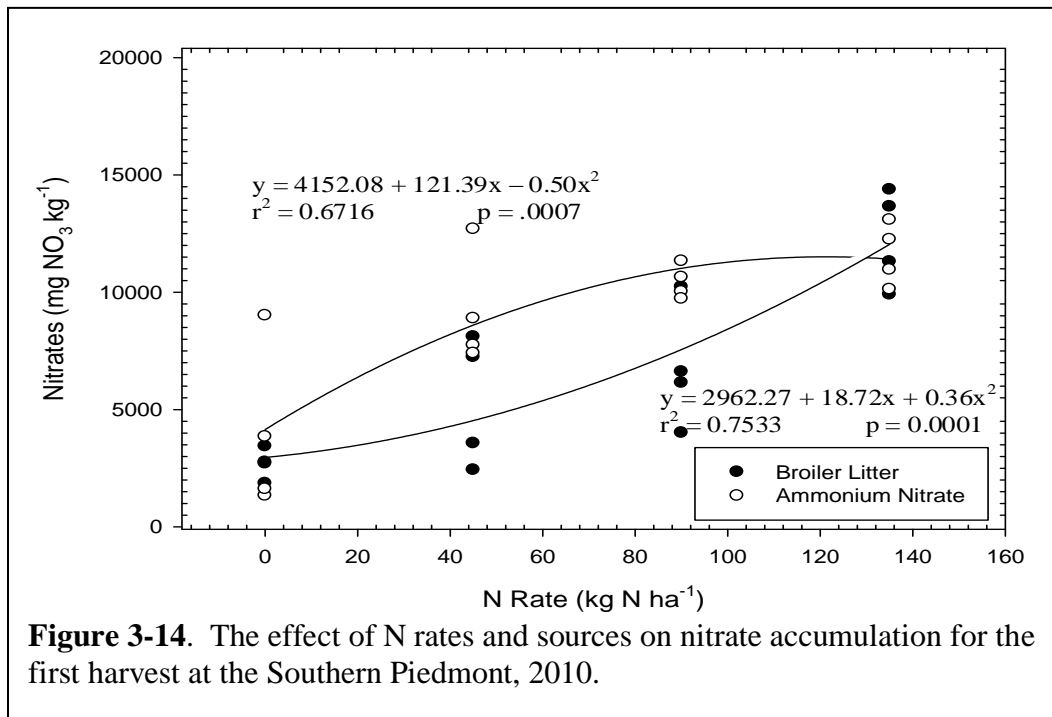
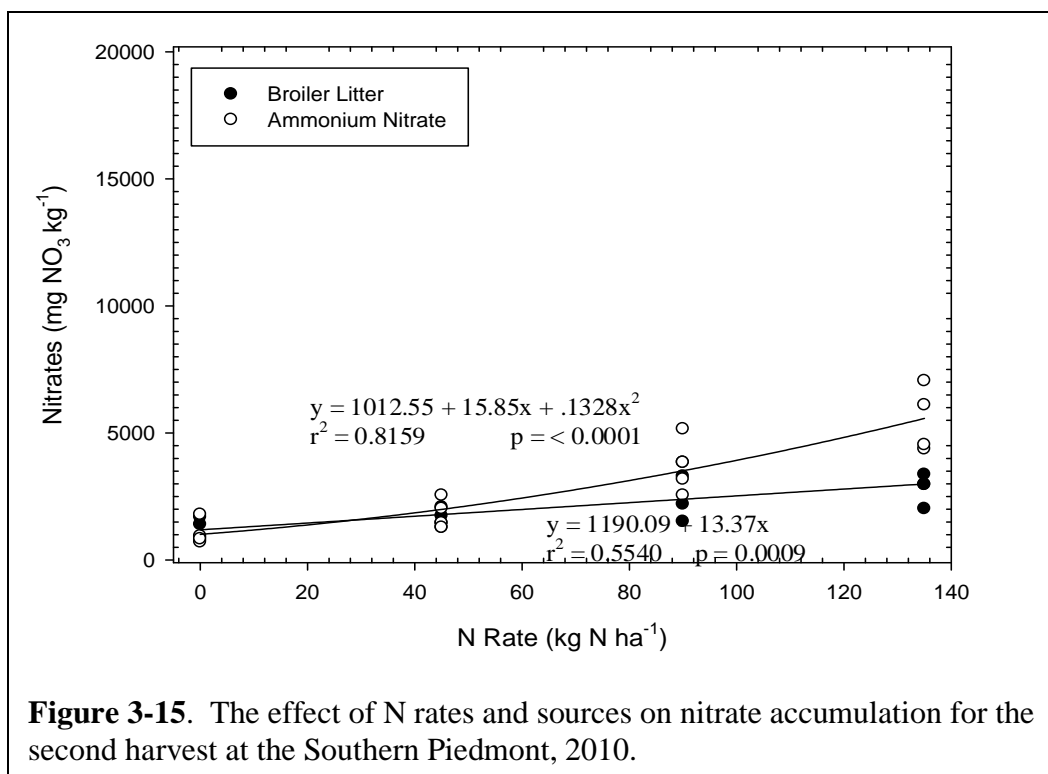


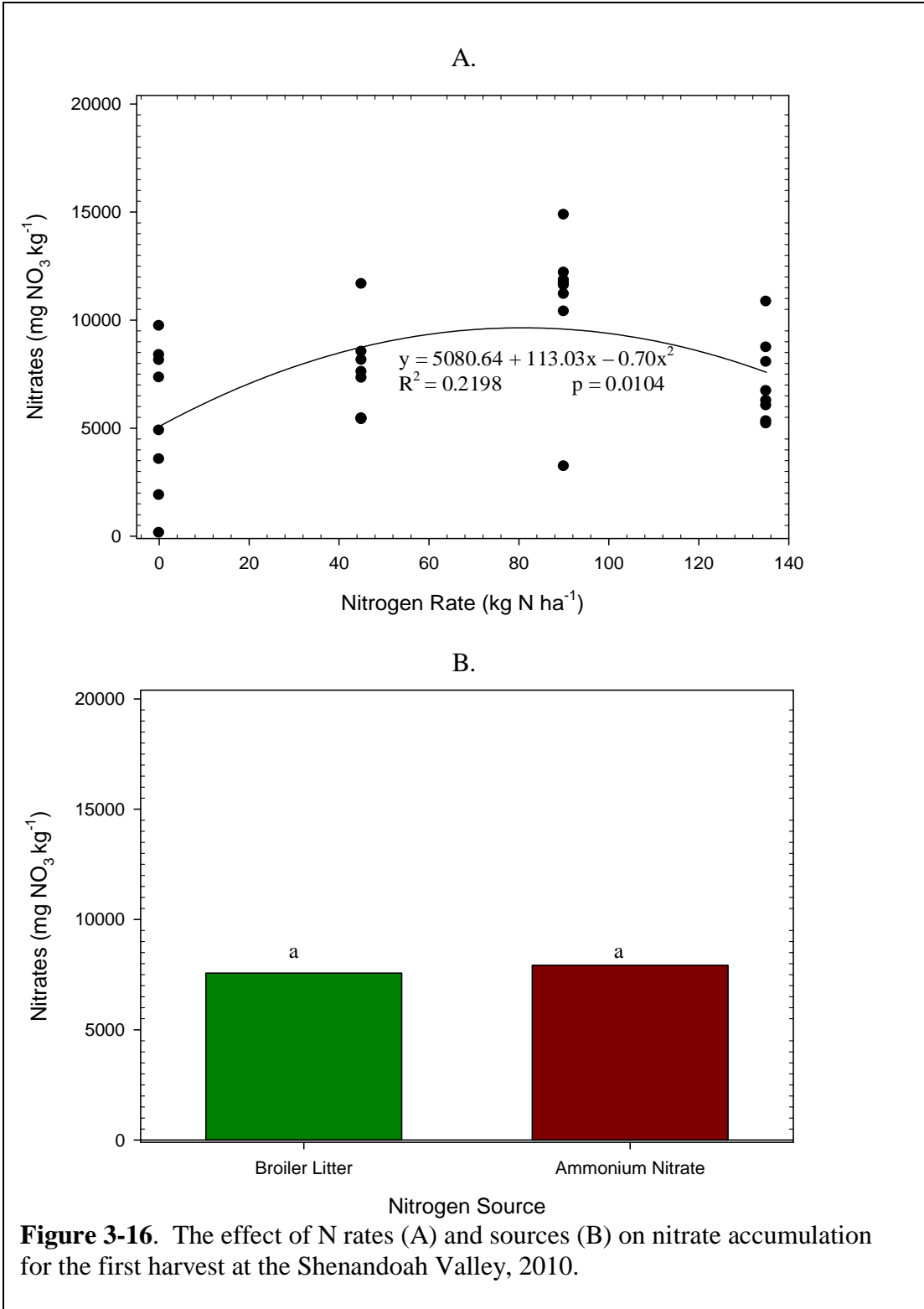
Figure 3-14. The effect of N rates and sources on nitrate accumulation for the first harvest at the Southern Piedmont, 2010.

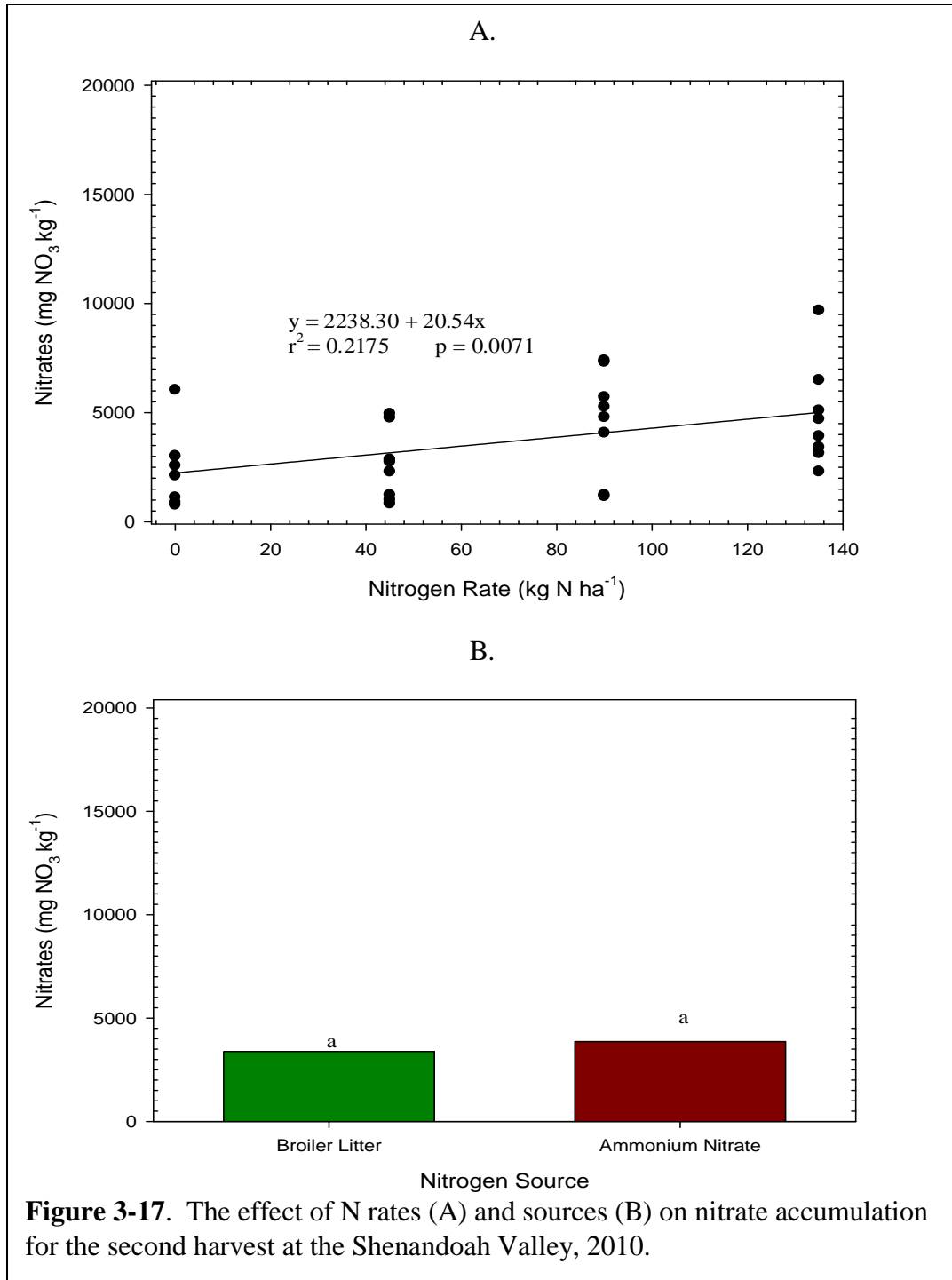


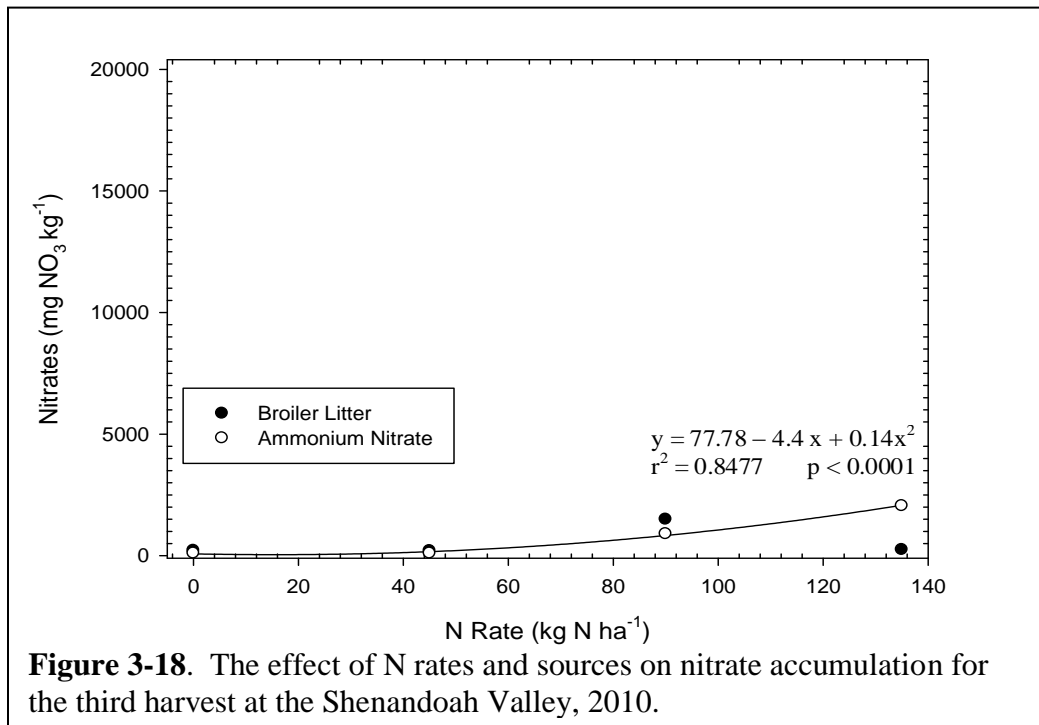
Shenandoah Valley

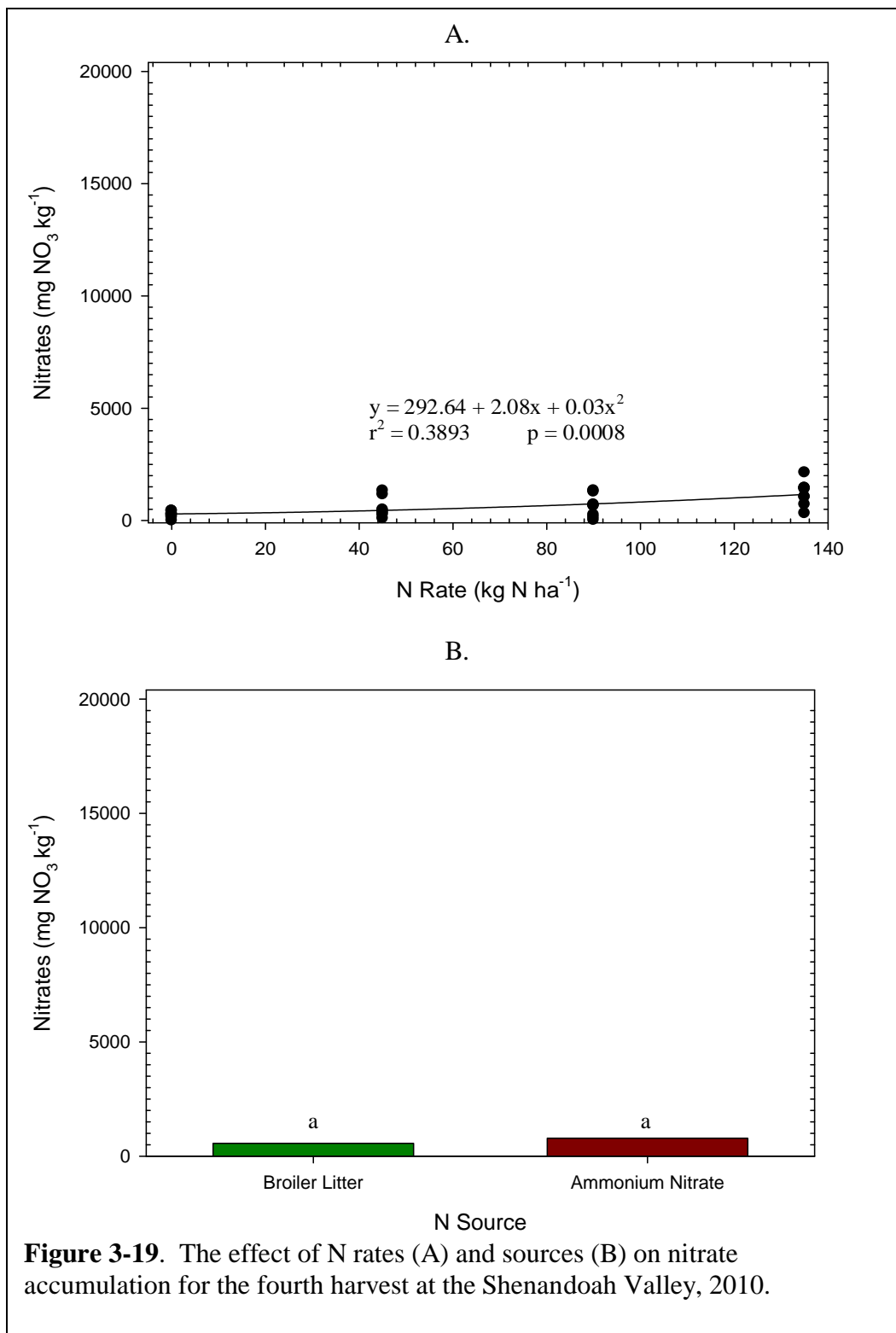
Interactions between N source and rates were not significant for the first, second, and fourth harvests at the Shenandoah Valley location, therefore results are presented by N rate (Figure 3-16-A, 3-17-A; 3-19-A) and N source (Figure 3-16-B; 3-17-B; 3-19-B). No source effect was observed for any one of the harvests in 2010. Nitrate levels for harvest one increased with increasing N rates quadratically (Figure 3-16). Nitrate levels peaked at the 90 kg N ha⁻¹ rate with nitrate accumulation reaching toxic levels. Nitrate levels were in the dangerous category for all four rates (Figure 3-16). Overall, high N rates from the first harvest led to dangerous levels of nitrates in the teff (5000 mg kg⁻¹ NO₃⁻¹+) (Table 3-8, Figure 3-16). The second harvest showed a linear response to N rate, with lower levels of nitrates overall. Generally, the dangerous level of nitrate was associated with the higher N rates, however, some high levels of nitrates were observed for the

lower N rates (Figure 3-17-A). Nitrogen rate x N source interactions were significant at harvest three at Steeles Tavern in 2010, therefore interaction means are plotted (Figure 3-18). Ammonium Nitrate showed quadratic response to increasing N rate (Figure 3-18). Broiler Litter showed no response to the increasing N rate (Figure 3-18). Response to N rate in the fourth harvest was only different at the highest N rate (135 kg N ha^{-1}). Nitrate accumulation levels in teff for the third and fourth harvest were safe for livestock consumption (Table 3-8, Figures 3-18 and 3-19).









Overall, nitrate accumulation was affected by both N rate and N source. Nitrate levels, on average, declined with each subsequent harvest. This might be due to the fact that all N was applied at planting and not split. Dangerous levels of nitrates were seen at the second harvest only at the 135 kg N ha⁻¹ rates. In general, BL produced much safer levels of nitrate accumulation than AN. This was due to the N from BL being released at slower rates, thus preventing the rapid uptake by the growing plant. In some instances, dangerous levels of nitrate accumulation were reached at both the 0 and 45 kg N ha⁻¹, but on average these rates were safe. The 90 and 135 kg N ha⁻¹ rates often resulted in high levels of nitrate in the teff, and should be heavily monitored when fed to livestock.

Summary and Conclusions

Seasonal accumulation of biomass ranged from 1478 to 8875 kg DM ha⁻¹ over all years, locations, N rates, and N sources with an average production of 4550 kg DM ha⁻¹. Average CP values over year, location, N rate and N source came in at 130 g kg⁻¹ with ADF at values of 370 g kg⁻¹ and NDF at 650 g kg⁻¹. Average TDN values reported were 590 g kg⁻¹. All of these quality factors can serve wide classes of livestock. In general, biomass production and forage quality went down per harvest. Overall, our results shows that teff can be of value as a forage crop to fill in the mid-summer forage production gap often created by the low productivity of perennial cool-season grasses. The study also showed that Teff can be adapted to a wide range of climatic zones and conditions. Teff's performance during the 2010 growing season, which was drier and hotter than the previous year and the historic average, show its potential to be used as drought tolerant species. Quality data showed no clear response to either N rate or N source. Biomass yield and nitrate accumulation show the main response to both N source and rate

treatments. Nitrate accumulation at dangerous levels was evident with ammonium nitrate single application at higher rates. In general, broiler litter produced much lower levels of nitrates than the ammonium nitrate. Generally, the N rate that resulted in the maximum biomass production and safe nitrate accumulation in teff regardless of source was the 45 kg N ha⁻¹ rate. Overall, our study shows teff to be a viable alternative for mid-summer forage production. The quick establishment and recovery after cutting prove it to be a usable emergency crop to fit into a grazing system. The lower end N requirement verifies it as low input crop compared to other summer annuals. This study also advocates teff's ability to cope with highly variable environmental conditions (temperature and rainfall), showing little variability in yield and quality data between two very different growing seasons of 2009 and 2010. Nitrate accumulation could be a potential problem, and therefore high (90+ kg N ha⁻¹) single N application rates should be avoided.

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CHAPTER IV

Summary and Conclusion

The main benefit of warm-season annual grasses is that they are most productive during hot weather and can provide badly needed forage during times of water deficit. Incorporating warm-season annual forages into a grazing system is another way producers can reduce the risk of low forage supply. Unfortunately, integrating these grasses can be challenging because of management factors such as negative quality and lack of versatility in utilization. Teff, (*Eragrostis tef* (Zucc.) Trotter), a new forage to the mid-Atlantic region could offer a possible alternative to current options of warm season annuals. Because teff is a relatively new forage crop, little is known about proper management guidelines.

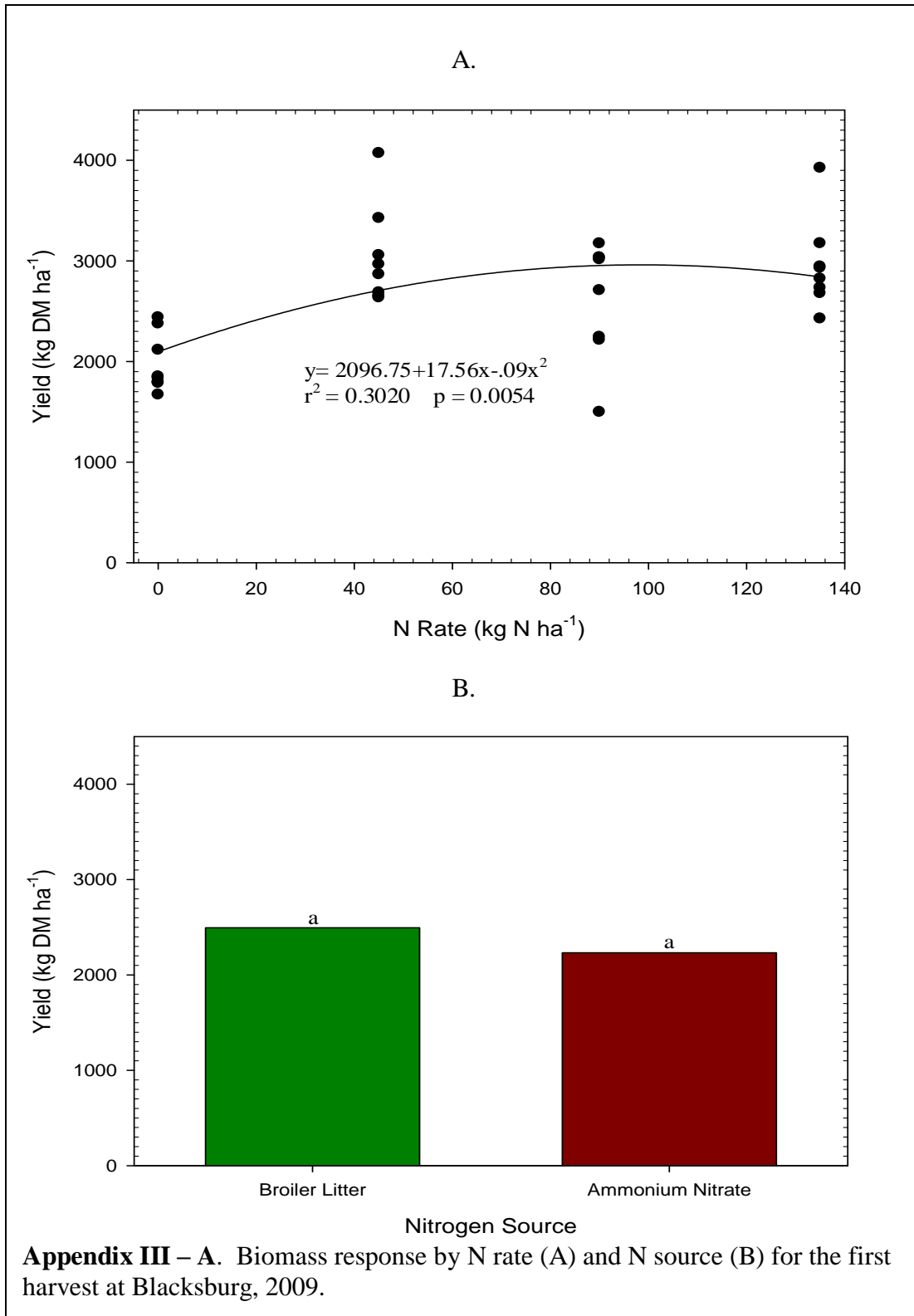
The 2010 growing season was much hotter and drier than the 2009 growing season. At the Southern Piedmont and Blacksburg locations, the average June and July rainfall was by far less than the 2009 and the historic average rainfall. Subsequently, the first harvest was delayed by 2-3 weeks compared to the Steeles Tavern location. Biomass production generally peaked around the N rate of 90 kg N ha⁻¹, but in most cases leveled off at 45 kg N ha⁻¹ rate. Teff biomass yield, in general, reduced with each subsequent harvest. Nitrogen source had minimal effect on biomass yield. Seasonal biomass yield, totaled over locations, year, N rate, and N source ranged from 1478 to 8875 kg DM ha⁻¹ with an average production level of 4550 kg DM ha⁻¹. Generally, in 2010, the potential biomass yield of teff was hindered by lack of rainfall. However, the tolerance of teff to severe drought, and its quick recovery upon minimal rainfall, makes it a valuable alternative summer annual crop where the occurrence of drought is common.

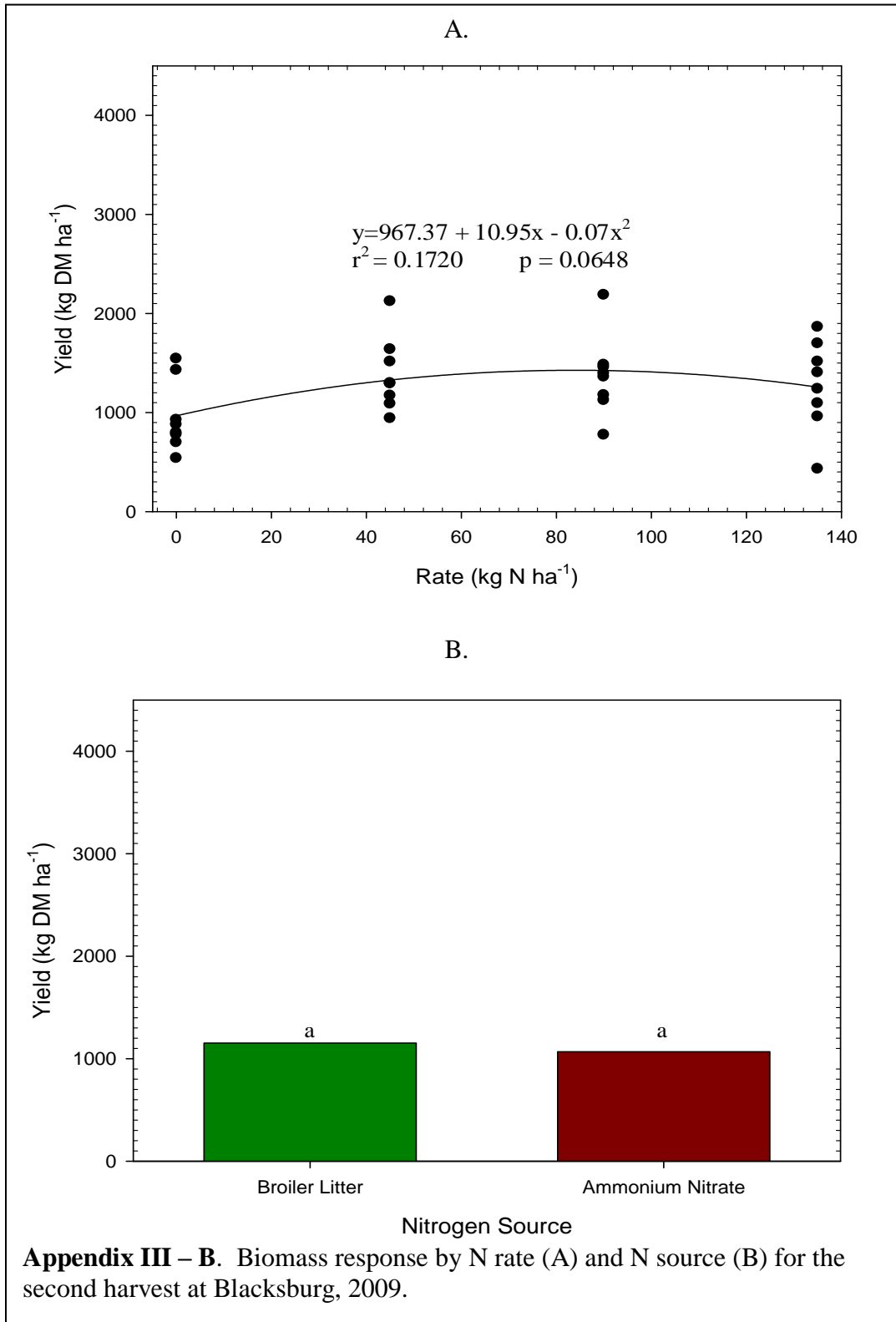
Under favorable growing conditions, a cutting interval of 28-30 days is possible. In 2010, at Steeles Tavern location, teff was ready for harvest 23 days after the first harvest.

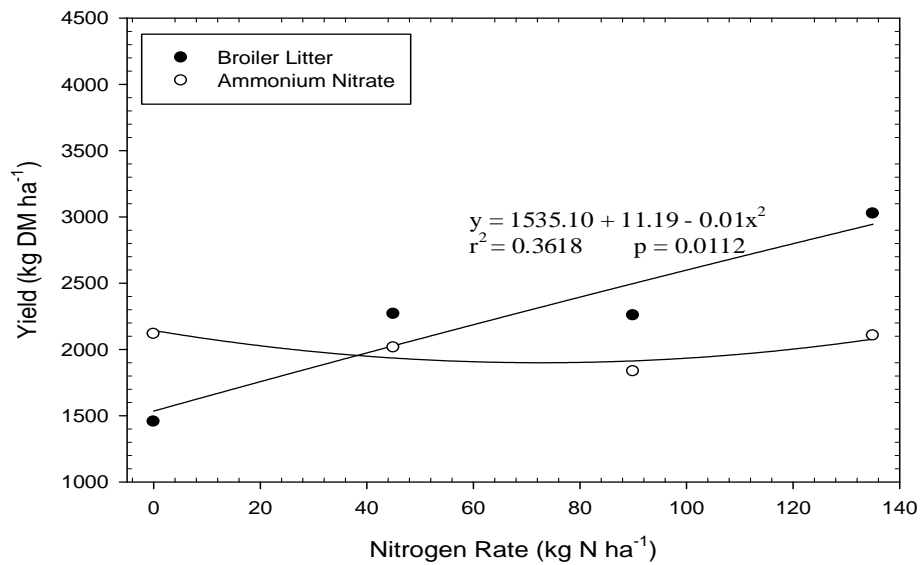
Nitrogen source had little effect on nutritive value of teff whereas N rate showed effects on CP but not on ADF, NDF, or TDN. Crude protein values ranged from 70 to 240 g kg⁻¹, with an average value of 125 g kg⁻¹ while the ADF, NDF, and TDN values ranged from 271 to 483, 507 to 758 and, 463 to 670 g kg⁻¹, respectively. Based on the nutritional requirements of various livestock classes, the nutritive values of teff in this study can be adequate to fulfill the needs of various animal classes at or above maintenance level.

In our study, nitrate accumulation in teff was reported at both dangerous and toxic levels. In general, these levels were only evident at the 90 and 135 kg N ha⁻¹ rates with ammonium nitrate at the first harvests. Where only severe drought was experienced (Blackstone, 2010), broiler litter had the same effect. That is, dangerous level of nitrate was reported at a high rate (135 kg N ha⁻¹) of broiler litter application. Based on our two year study across three geographical locations in Virginia, we can conclude that 45 kg N ha⁻¹ is the rate where the optimum biomass yield can be achieved while maintaining a safe nitrate level in teff. In terms of N source, generally no significant difference in biomass yield was observed between the two N sources. This can be beneficial to those who have access to broiler litter. In summary, the ability of teff to withstand severe droughts and recover quickly upon receiving minimum amount of rainfall, and its ability to produce optimum yield at N rates between 0-45 kg N ha⁻¹ regardless of N source, make it a viable alternative annual summer forage crop for the mid-Atlantic region.

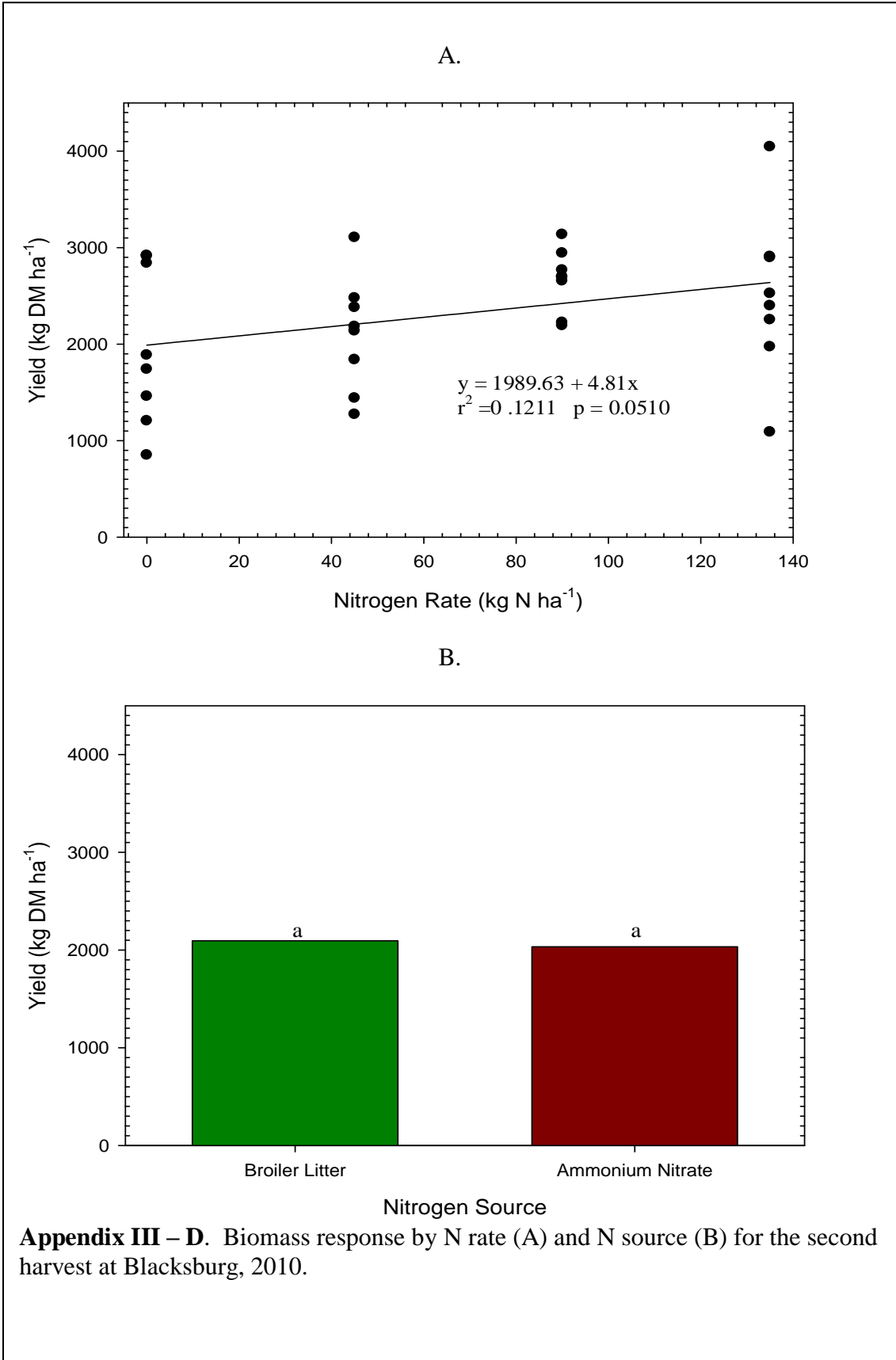
Appendix A.

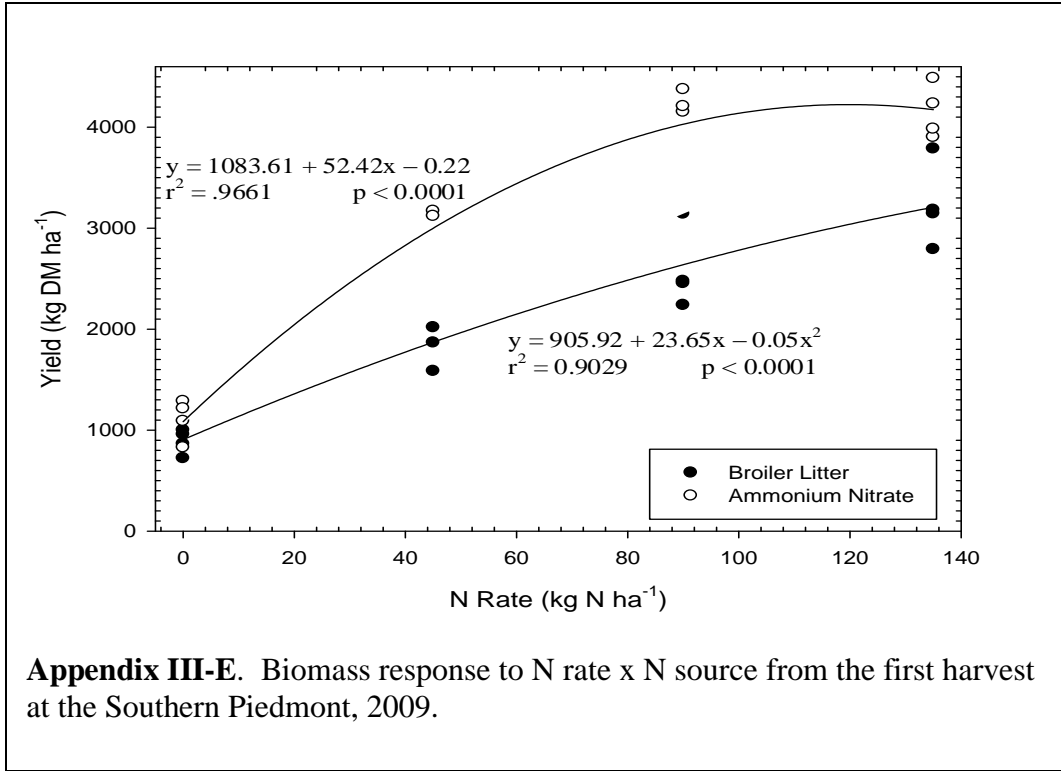


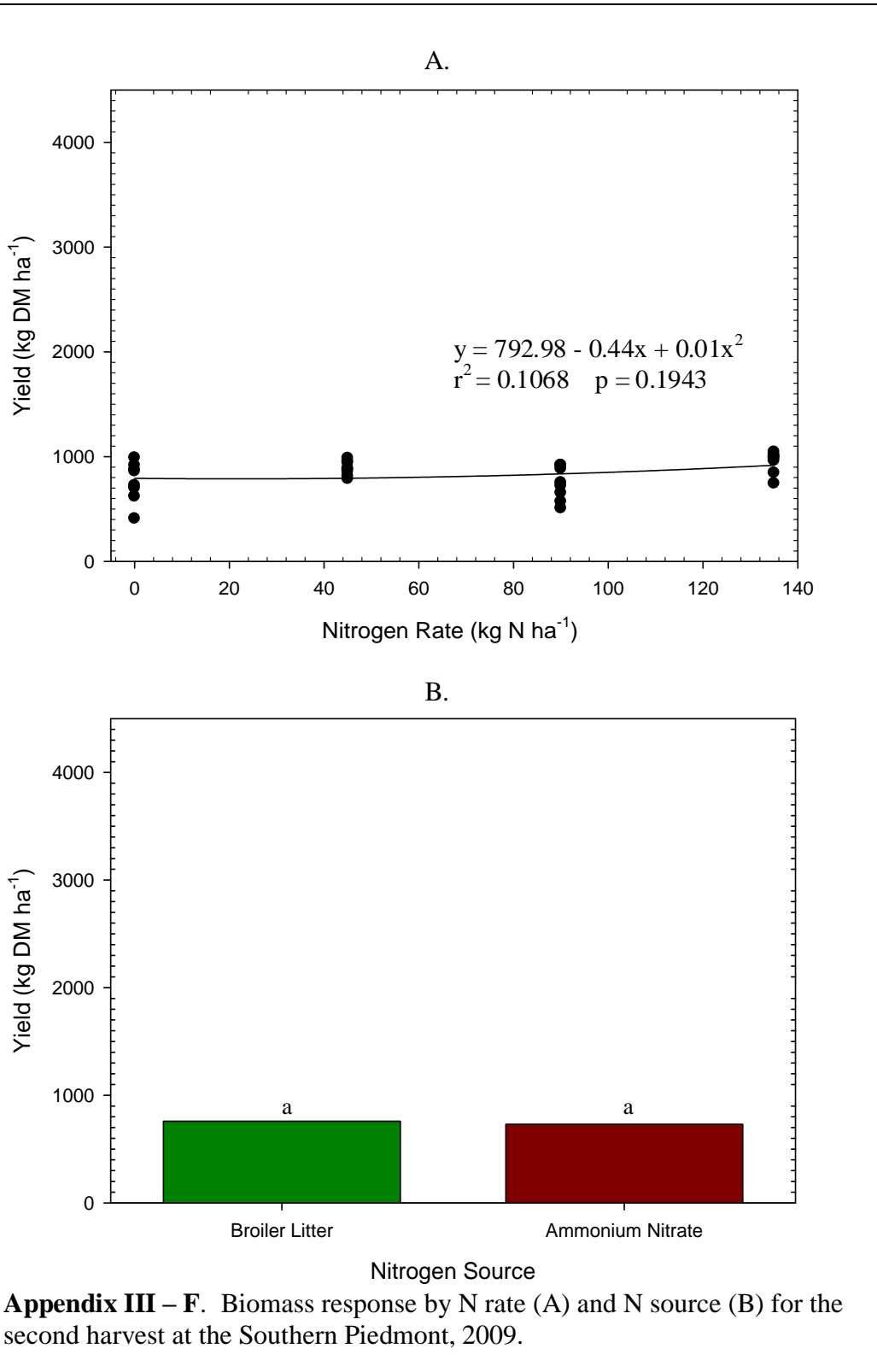


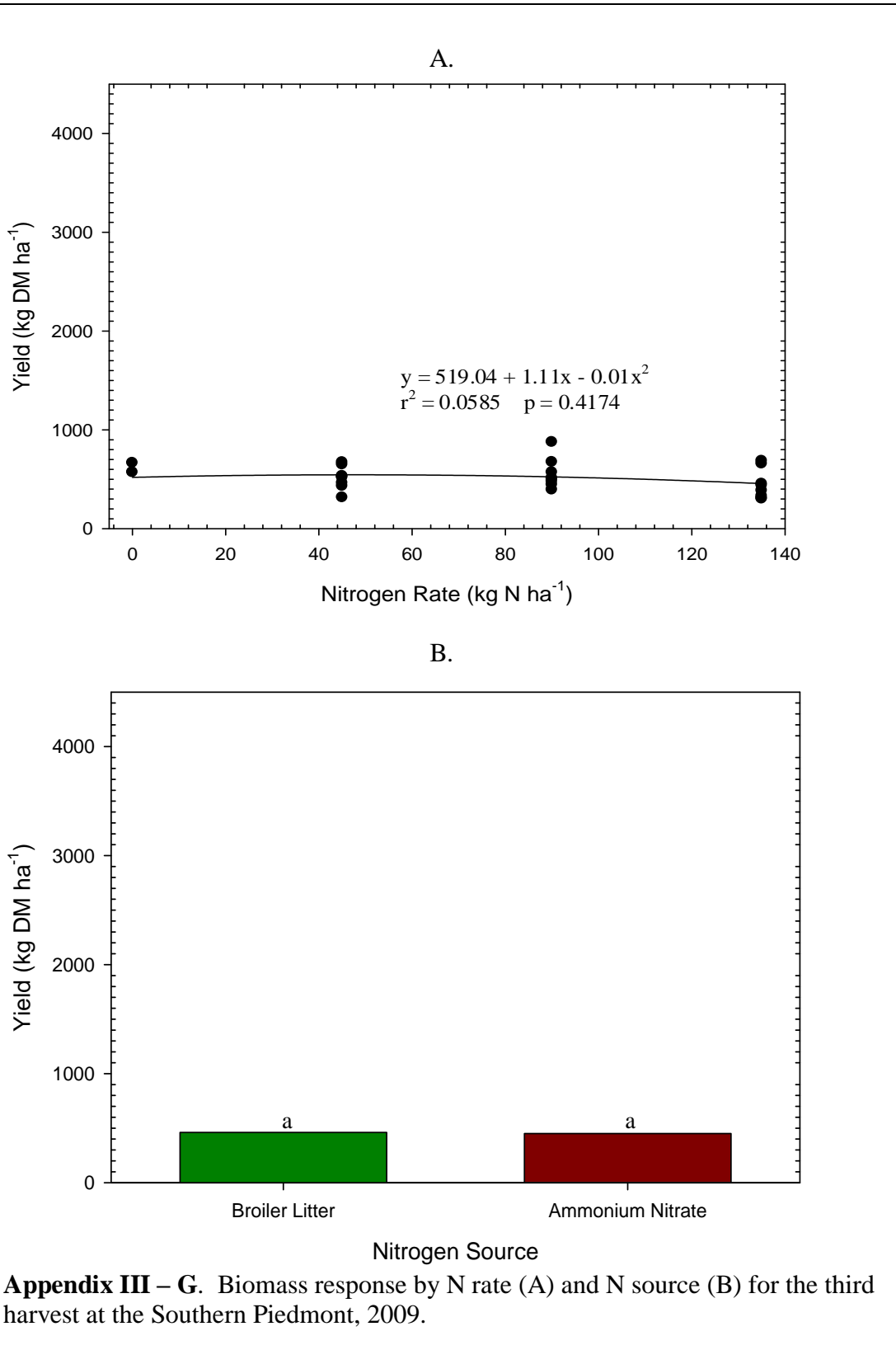


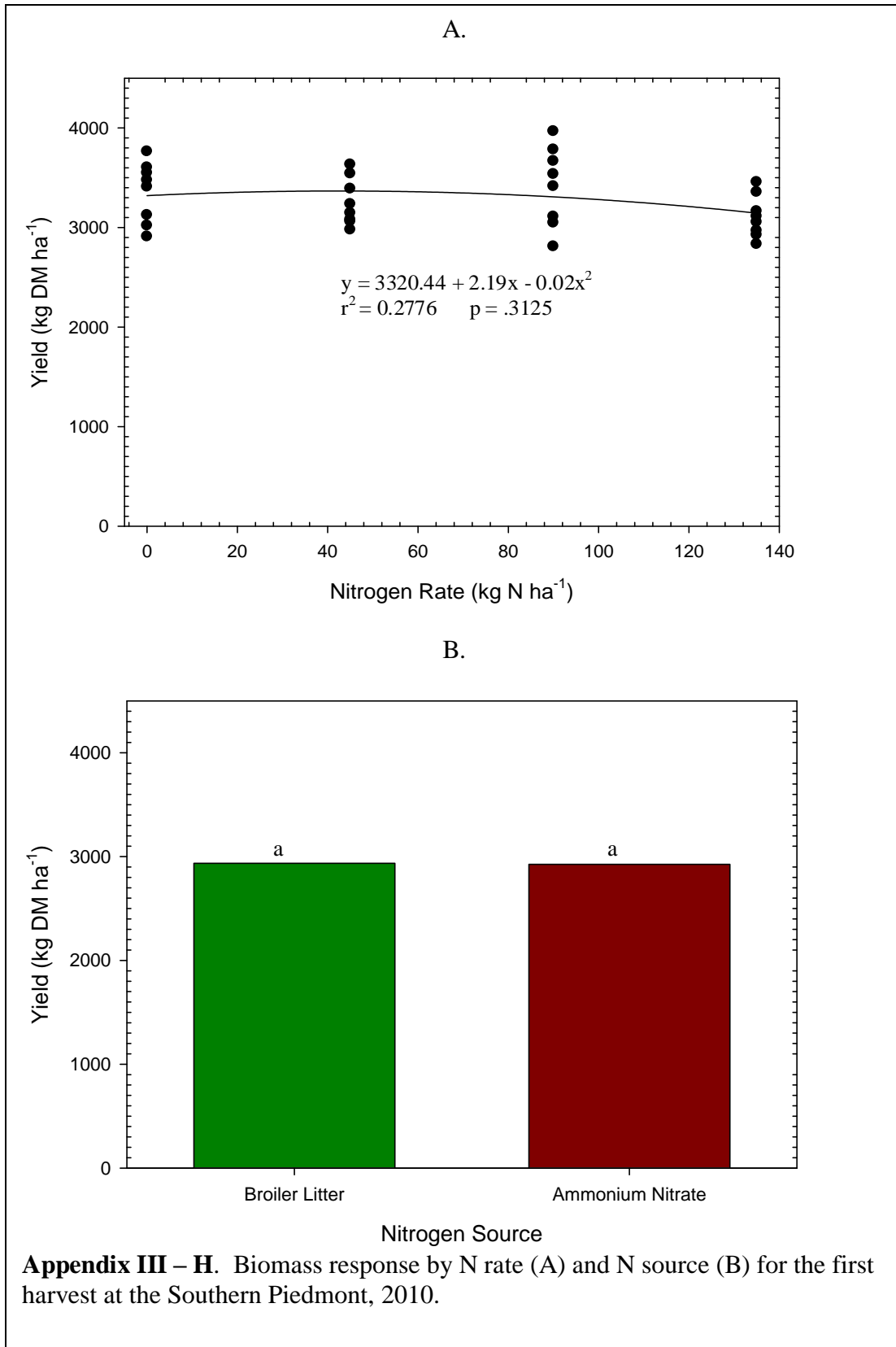
Appendix III – C. Biomass response by N rate x N source for the first harvest at Blacksburg, 2010.

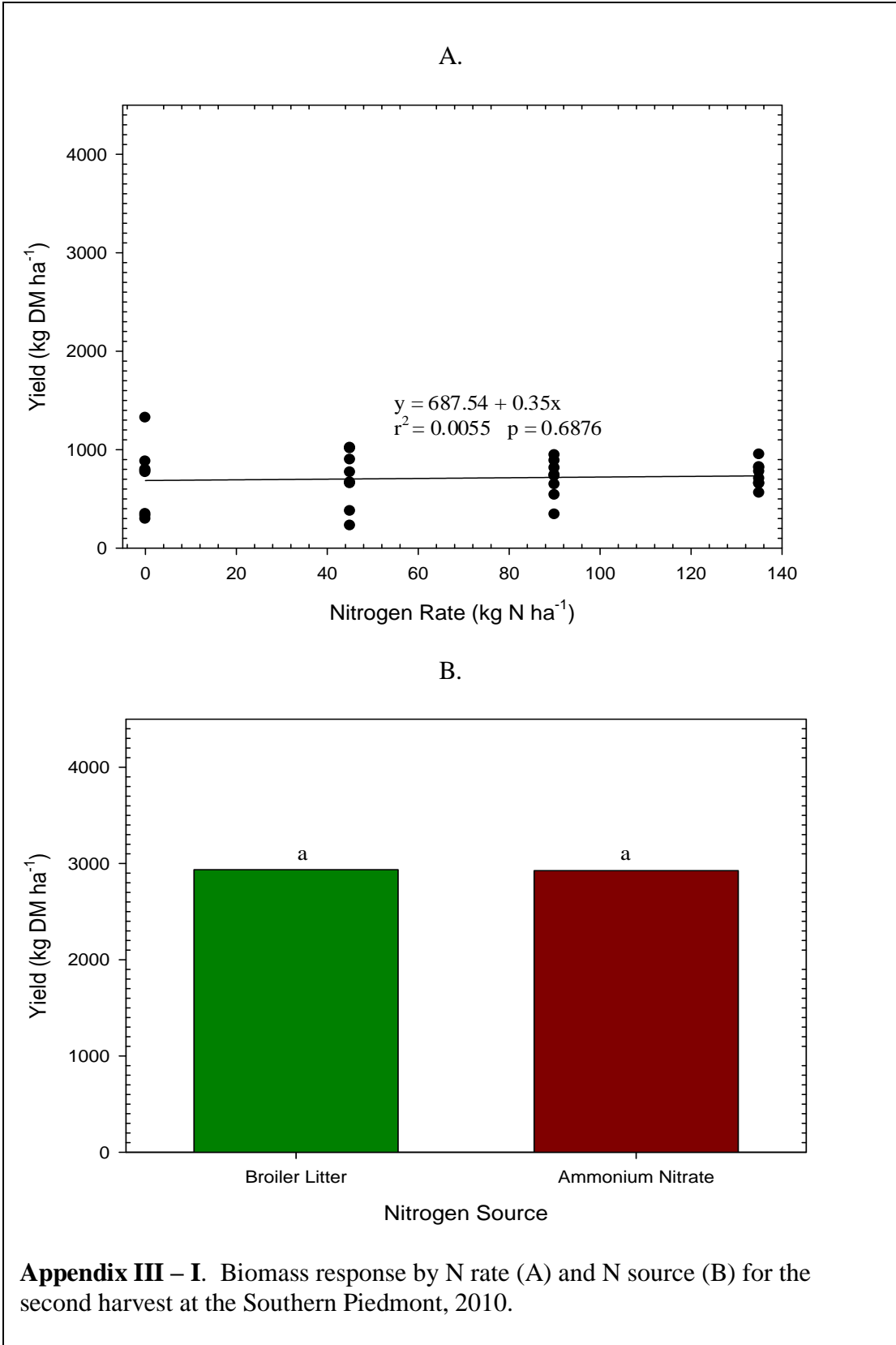


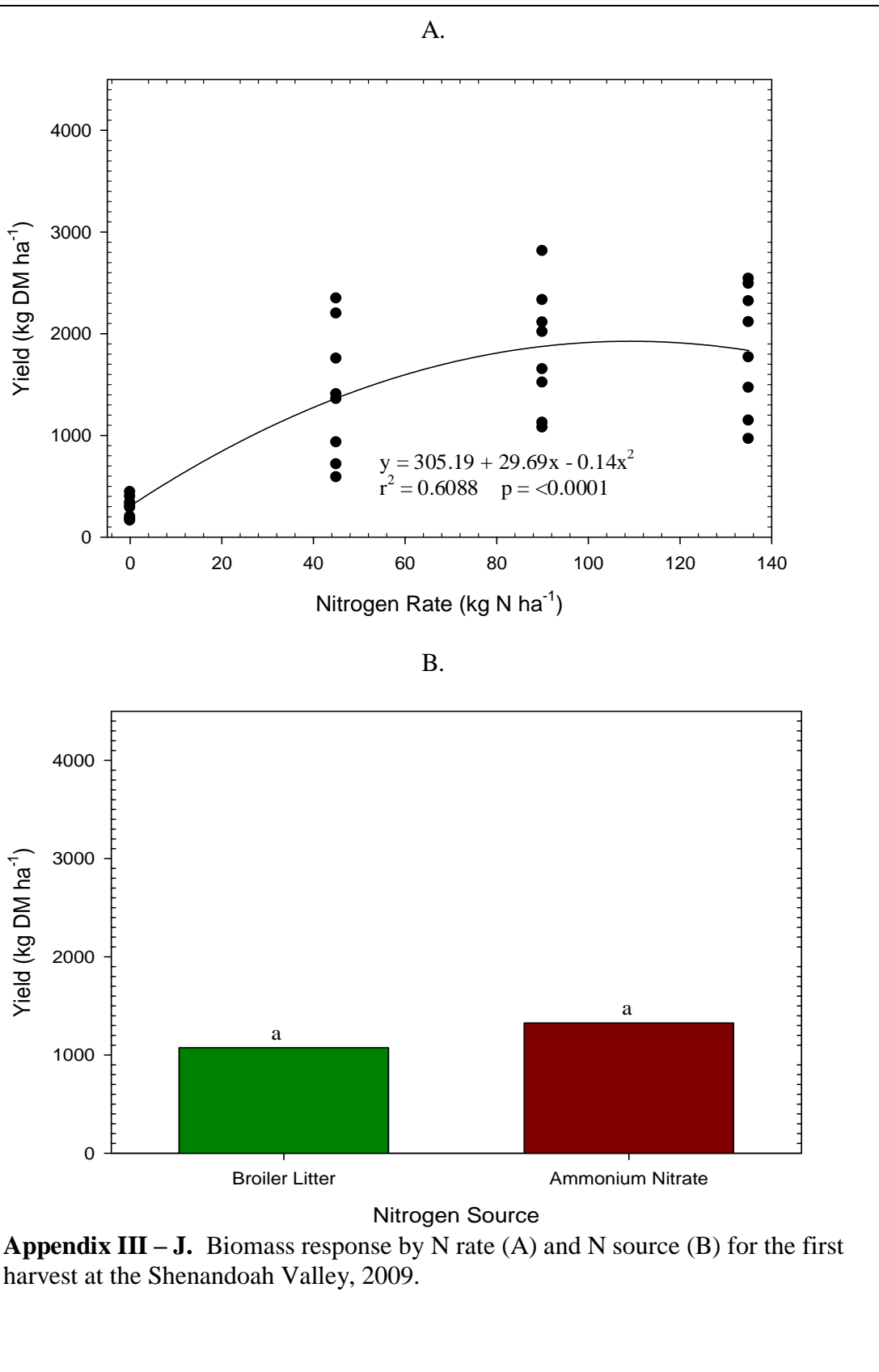


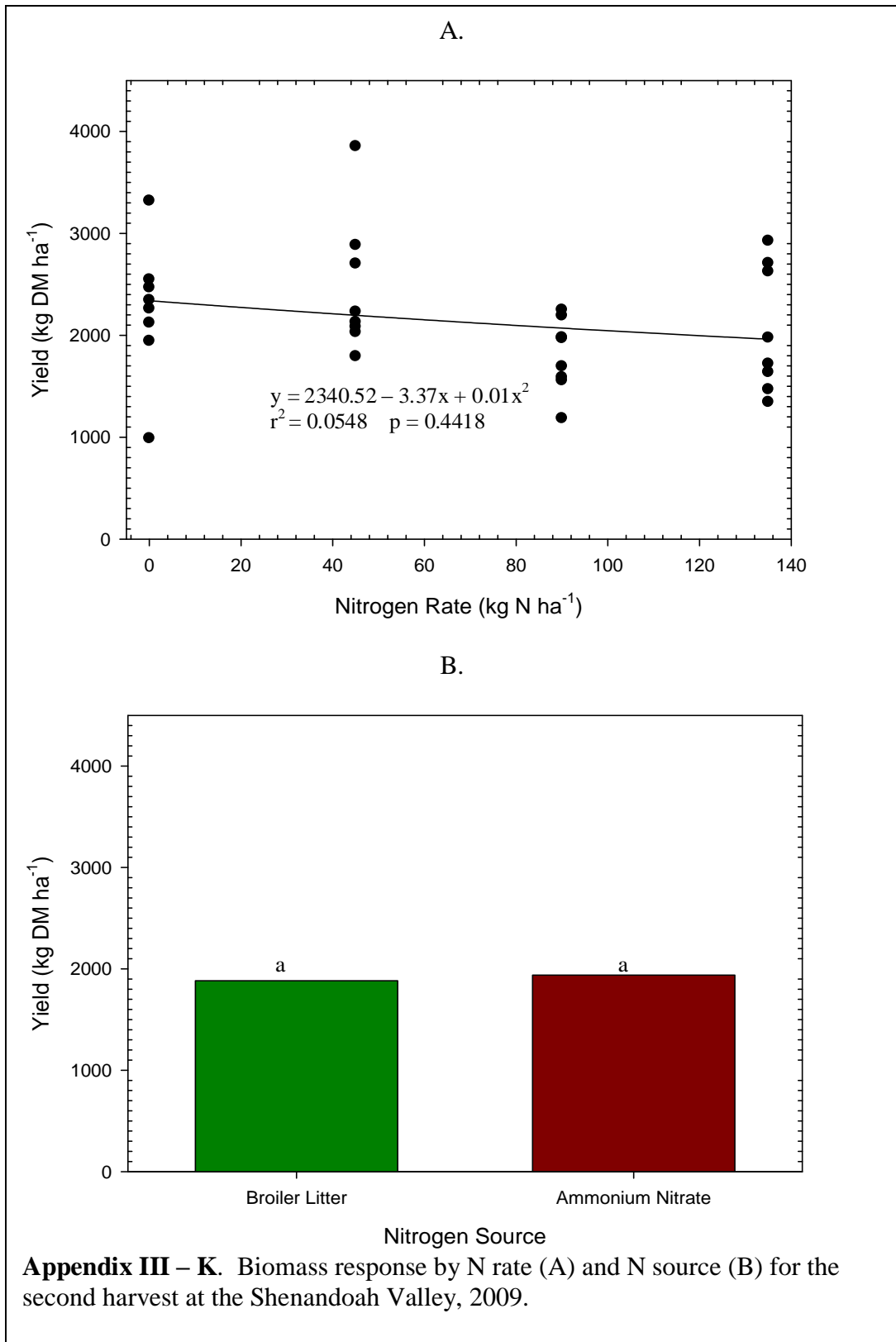


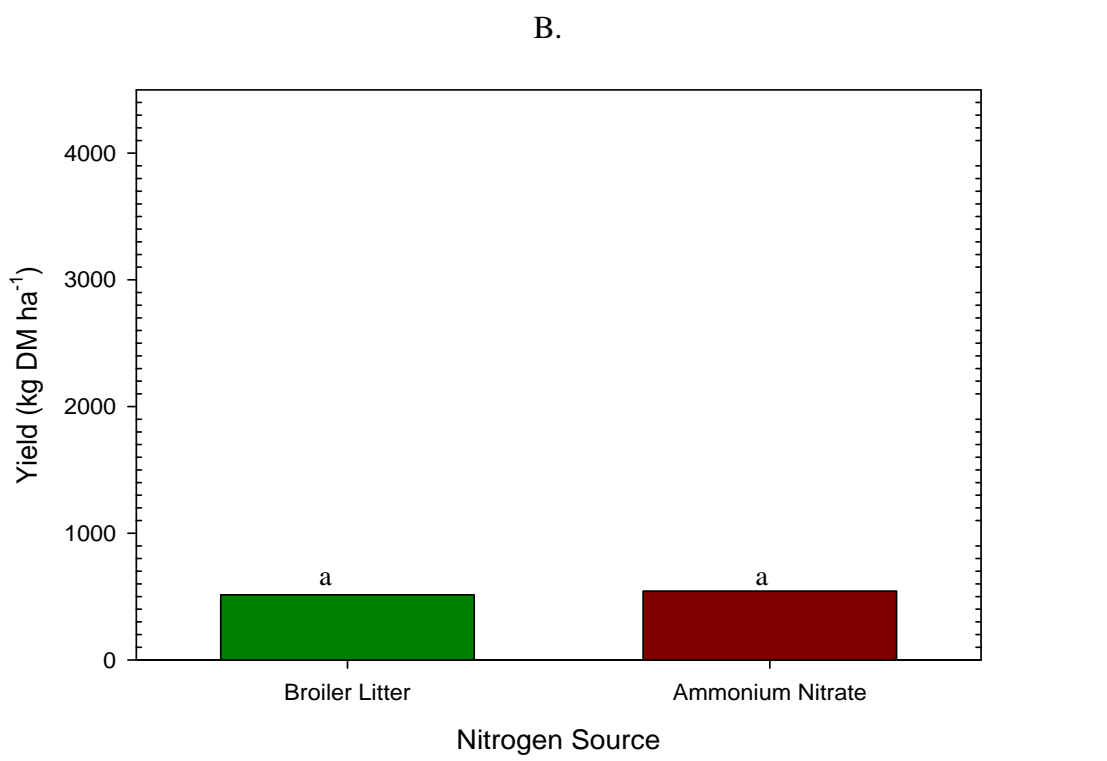
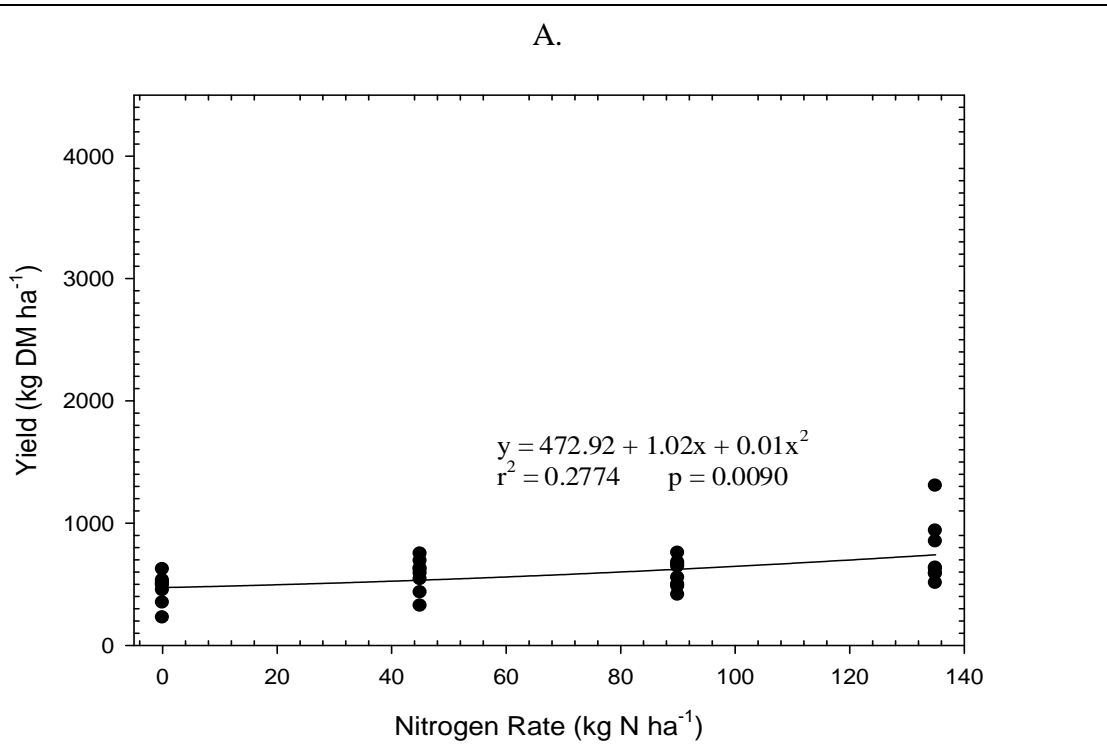












Appendix III – L. Biomass response by N rate (A) and N source (B) for the third harvest at the Shenandoah Valley, 2009.

