2014

# SWITCHGRASS YIELD AND QUALITY WITH MULTIPLE FERTILIZER APPLICATIONS AND HARVEST DATES

Thomas Clarkson Keene
*University of Kentucky*, tom.keene@uky.edu

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained needed written permission statement(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine) which will be submitted to UKnowledge as Additional File.

I hereby grant to The University of Kentucky and its agents the irrevocable, non-exclusive, and royalty-free license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless an embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's thesis including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Thomas Clarkson Keene, Student

Dr. Samuel Ray Smith, Major Professor

Dr. Mark Coyne, Director of Graduate Studies

# SWITCHGRASS YIELD AND QUALITY WITH MULTIPLE FERTILIZER APPLICATIONS AND HARVEST DATES

---

THESIS

---

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

Thomas Clarkson Keene

Lexington, Kentucky

Director: Dr. Samuel Ray Smith, Professor of Crop Science

Lexington, Kentucky

2014

ABSTRACT OF THESIS

SWITCHGRASS YIELD AND QUALITY WITH MULTIPLE FERTILIZER APPLICATIONS AND HARVEST DATES

Switchgrass (*Panicum virgatum* L.) is an important native warm-season grass for biomass and forage production in the U.S. This research determined the effect of fertilizer type (conventional, manure, and biosolids) and rate on switchgrass biomass yield and forage quality. Fertilizers were added at 0, 33, 67, 100, and 134 kg N $ha^{-1}$ on established stands of 'Kanlow' switchgrass in three northeastern Kentucky counties. Soils across sites ranged from recently cleared forestland (low pH, P, and K) to productive cropland (high pH, P and K). Stands were sampled for forage nutritive value in June, simulating a hay harvest. Nutritive value and biomass yield were sampled in November and March. Results showed a harvest date effect for mean crude protein (CP) of 8.31% in June and 1.16% November and March. There was also a harvest effect for biomass with a mean yield of all harvests of 16.6 MT $ha^{-1}$ but a N response at only one site. In conclusion, this study suggested that switchgrass may produce adequate nutritive value for dry beef cows in June and fertilizer type and rate may have a limited effect on biomass yields.



KEYWORDS: Switchgrass (*Panicum virgatum*), Yield, Quality, Biomass, Fertility



Thomas Clarkson Keene


May 5, 2014

SWITCHGRASS YIELD AND QUALITY WITH MULTIPLE FERTILIZER APPLICATIONS AND HARVEST DATES

By

Thomas Clarkson Keene

Dr. S. Ray Smith

Director of Thesis

Dr. Mark Coyne

Director of Graduate Studies

May 1, 2014

I would like to dedicate this work to my wife, Margaret (Muggs) and my children; Aubrey, Thomas$^{II}$ and Taylor.  Their support, enthusiasm and encouragement saw me through this endeavor.

ACKNOWLEDGEMENTS

Many individuals were instrumental in this research project. First, I would like to thank Dr. S. Ray Smith who was my primary advisor during this study and whose support managed to see this through to fruition. Secondly, I would like to thank Dr. Glen Aiken and his technician Mr. Tracy Hamilton whose help with lab work was invaluable. I would also like to thank Dr. Tim Phillips whose passion and zeal for plant material enabled me to appreciate this great plant that is called switchgrass (*Panicum virgatum* L.) and its potential for forage and energy. Lastly, Dr. Ben Goff was instrumental in keeping me on task and helping with my statistical work.

I would also like to thank Mr. Randy Hass, Dr. Ralph Hovermale and Mrs. Unadell Eldridge for allowing me to use their stands of 'Kanlow' switchgrass for my research. I would also like to thank a whole host of supporters who helped with everything from applying fertilizer, soil sampling, harvesting, grinding, etc.;

Dr. Greg Schwab
Krista Lea
Gabriel Roberts
Lyndsay Jones
Adam Probst
Laura Schwer
Dr. Frank Sikora
Rhonda Beasley
Troy Owens
Kristen McQuerry
Dr. John Grove
Gene Olsen
David Davis
Phillip Shine
David Davis
Kenton Sena
Diane Hunter
Julienne Wyrick
Shawn Lucas
Dr. Mark Coyne
Mr. Randy Haas (Cooperator, Campbell County)
Dr. Ralph Hovermale (Cooperator, Nicholas County)
Mrs. Unadell Eldridge (Cooperator, Rowan County)

TABLE OF CONTENTS

Acknowledgements ........ iii

List of Tables ........ vi

List of Figures ........ vii

Chapter I: Introduction ........ 1

Chapter II: Literature Review ........ 3
- 2.1 Switchgrass for Energy ........ 4
- 2.2 Switchgrass for Forage ........ 6
- 2.3 Urea as Fertility Amendment ........ 7
- 2.4 Chicken Litter as Fertility Amendment ........ 9
- 2.5 Biosolids as Fertility Amendment ........ 10
- 2.6 Objectives ........ 14

Chapter III: Materials and Methods ........ 15
- 3.1 Site and Site Preparation ........ 15
- 3.2 Fertility Applications ........ 16
- 3.3 Soil Sampling and Characteristics ........ 17
- 3.4 Data Collection ........ 23
- 3.5 Harvest Technique ........ 23
- 3.6 Statistical Analysis ........ 25

Chapter IV: Results and Discussion ........ 27
- 4.1 Weather Data ........ 27
- 4.2 Yield for Biomass ........ 29
- 4.3 Yield for Quality Forage ........ 34
- 4.4 Crude Protein (CP) Response ........ 34
- 4.5 Acid Detergent Fiber (ADF) Response ........ 38
- 4.6 Neutral Detergent Fiber (NDF) Response ........ 39

Chapter V: Conclusion ........ 41

Chapter VI: Future Work Needed ........ 43

Appendices
- Appendix A: Plot plans for each experimental site ........ 44
- Appendix B: Actual mass of fertilizers applied by treatment number ........ 45
- Appendix C: Soil sample results for each treatment replication at three experiment sites in 2010 ........ 46
- Appendix D: Soil sample results for each treatment replication at three experiment sites in 2011 ........ 48

Appendix E: Soil sample results for each treatment replication at three experiment sites in 2012 ....................50
Appendix F: Campbell County mean dry matter in DM tonnes $ha^{-1}$ ....................52
Appendix G: Nicholas County mean dry matter in DM tonnes $ha^{-1}$ ....................53
Appendix H: Rowan County mean dry matter in DM tonnes $ha^{-1}$. ....................54
Appendix I: Mean Dry Matter (tonnes $ha^{-1}$) for each treatment at three experiment sites ....................55
Appendix J: CP mean for two years ....................56
Appendix K: ADF mean for two years ....................56
Appendix L: NDF mean for two years ....................57
Appendix M: Precipitation and temperature for each county for 2010, 2011 and average. ....................57
Appendix N: Ariel photographs of each harvest site in Campbell, Nicholas and Rowan Counties ....................58
Appendix O: Map of Kentucky counties. Counties where switchgrass was harvested are marked in red. ....................58

References ....................59

Vita ....................65

LIST OF TABLES

Table 2.1. Pollutant Limits....................................................................................12

Table 2.2. Summary of Class A and Class B pathogen reduction requirements ...............13

Table 3.1. Nutrient content of Louisville Green TM biosolid and composted poultry litter on a percentage basis ....................................................................................................17

Table 3.2. Soil pH and nutrient levels from 2010 on switchgrass stands managed for biomass and forage production in Campbell, Nicholas and Rowan Counties at a 0-10 cm and 10-20 cm soil depth. ................................................................................................20

Table 3.3. Soil pH and nutrient levels from 2011 on switchgrass stands managed for biomass and forage production in Campbell, Nicholas and Rowan Counties at a 0-10 cm and 10-20 cm soil depth. ................................................................................................21

Table 3.4. Soil pH and nutrient levels from 2012 on switchgrass stands managed for biomass and forage production in Campbell, Nicholas and Rowan Counties at a 0-10 cm and 10-20 cm soil depth. ................................................................................................22

Table 3.5. Statistical data for NIRS calibration ..................................................................26

Table 4.1. Crude protein for six switchgrass harvests over two seasons (2010/11 and 2011/12) from 3 farms in separate counties in northeastern Kentucky. ............................35

Table 4.2. ADF for six switchgrass harvests over two seasons (2010/11 and 2011/12) from 3 farms in separate counties in northeastern Kentucky.............................................37

Table 4.3. NDF for six switchgrass harvests over two seasons (2010/11 and 2011/12) from 3 farms in separate counties in northeastern Kentucky.............................................39

LIST OF FIGURES

Figure 3.1. Cutting 1m2 grid of switchgrass. Grinding subsample. Ground subsample. Plots after harvest.....25

Figure 4.1. Average (1980-2010) annual temperature and average temperature for 2010 and 2011 growing seasons for all three experimental sites.....28

Figure 4.2. Average (1980-2010) annual precipitation and average precipitation for 2010 and 2011 growing seasons for all three experimental sites.....28

Figure 4.3. Campbell County switchgrass yield response (DM tonnes $ha^{-1}$) for November and March harvests in 2010/11 and 2011/12. .....29

Figure 4.4. Nicholas County switchgrass yield response (DM tonnes $ha^{-1}$) for November and March harvests in 2010/11 and 2011/12.....30

Figure 4.5. Rowan County switchgrass yield response (DM tonnes $ha^{-1}$) for November and March harvests in 2010/11 and 2011/12. .....30

Figure 4.6. Switchgrass yield response (DM tonnes $ha^{-1}$) for Campbell, Nicholas and Rowan Counties for November and March harvests in 2010/11 and 2011/12.....31

Figure 4.7. Campbell County switchgrass yield response over three fertility treatments (urea, biosolids, chicken litter) combined over November and March harvests in 2010/11 and 2011/12.....33

Figure 4.8. Campbell County switchgrass CP response over three fertility treatments (urea, biosolids, chicken litter) combined over November and March harvests in 2010/11 and 2011/12.....37

# Chapter I: Introduction

Global population (currently over 7 billion) is projected to reach 9 billion by 2050 (UN, 2009). This burgeoning global population will require increases in both the production of food and energy. Land use change from agricultural land used for food production converted into bioenergy agriculture poses a significant threat to global food security (Boddiger, 2007).

In order to fill these needs, a coordinated and systematic energy and food portfolio will need to be established and implemented. In the United States, fossil fuels account for over 81% of the energy used (Energy Information Administration, 2012) and renewable sources of energy account for only 8% of the 19% of the remaining energy consumed (i.e. water, wind, solar and biomass). Concerns over global warming and climate change will mandate the production of renewable energy crops to reduce the depletion of fossil fuels, especially in the United States.

Several crops have been proposed and analyzed for commercial renewable energy farming. Some of these crops include sorghum (*Sorghum bicolor* L.), sugarcane (*Saccharum officinarum* L.), residue crops such as corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) stover, perennial grasses and herbaceous plants as well as woody species. Switchgrass (*Panicum virgatum* L.), a native perennial grass to Kentucky, was originally found from central Canada to northern Mexico and from the Atlantic Coast to the front range of the Rocky Mountains (Casler et al., 2004). It is an important $C_4$ warm season grass that can be utilized for both energy and forage production in the U.S. Based on a series of evaluation trials, the US Department of Energy has identified switchgrass as the most promising species for development into an herbaceous biomass fuel crop (Vogel, 1996). As a multipurpose crop, it can also be used as a forage or hay crop that can be utilized by ruminant animals. The versatility of switchgrass species makes it an ideal species for growth in Kentucky. The Kentucky Agricultural Development Board commissioned the University of Kentucky Plant and Soil Science Department to conduct a "switchgrass for biomass" project in 2007 that would utilize the switchgrass to be co-fired with coal to generate electricity. The project established 2 ha plots on 20 farms in 12 northeastern Kentucky counties. The harvested material was burned with coal at the East Kentucky Power Co-op facility near Maysville, KY (Smith et al., 2008). The cooperating farms were situated within a 100 km radius of the power plant.

The wide area of adaptation for switchgrass and its ability to produce large quantities of biomass on marginal or highly productive soils makes it ideally suited for Kentucky. Data from Debolt et al. (2009) showed that utilizing Kentucky's marginal land to grow native $C_4$ grasses for cellulosic ethanol and co-firing with coal to generate electricity may account for up to 13.3% and 17.2% of the state's 2 trillion MJ of energy consumed each year.

If renewable energy crops like switchgrass are to produce enough energy to meet societal demands at low economic cost, researchers will need to develop systems that maximize yields at minimal input costs. This research was designed to determine if organic forms of fertilizer can be used to produce equal or greater yields than inorganic fertilizer such as urea (46-0-0). Urea was chosen as the source of inorganic N because the traditional form of N, ammonium nitrate (33-0-0), is no longer widely available. Urea has several advantages in comparison to ammonium nitrate including being less explosive, safer to store on farm, and easier application because it is a more concentrated form of N.

The organic forms of nitrogen that were used in this study were composted broiler chicken litter and processed biosolids (sewage sludge). Animal manure and human waste have long been used as fertility amendments throughout the course of human history. The large availability and low costs of these types of fertility amendments makes them ideal for farmers, especially when poultry houses or wastewater treatment plants are located relatively close to their own farming operations. This experiment was conducted at three sites in northeastern Kentucky on soils that ranged from marginal cleared forestland to river bottom soils utilized for corn and soybean production and slopes ranging from 2 to 12%.

# Chapter II: Literature Review

Kentucky farmers, like farmers nationwide, have always sought opportunities to find multiple income streams for their agricultural operations. While crops like tobacco (*Nicotiana tabacum* L.), corn and soybeans (*Glysine max* L.) require productive, well drained soils, Debolt et al. (2009) found that 21% of Kentucky land mass was accounted for as "marginal" land. These marginal acres are well suited for growing forages and renewable energy crops and switchgrass is ideal because it can be used for both purposes. Switchgrass is a native warm season perennial $C_4$ plant that can be grown on/in a variety of soils, slopes and climates. It can also be grown on reclaimed strip mine lands and there are many of these in eastern and western Kentucky. Xia et al. (2013) estimated that there are about 300,000 hectares of abandoned coal mine land in Kentucky. Not only can switchgrass provide benefits as a forage or energy, McLaughlin and Walsh (1998) state that switchgrass can also reduce atmospheric carbon, increase soil carbon, reduce soil erosion, improve soil and water quality and increase native wildlife habitat. Most importantly, switchgrass has the potential to produce an income stream for Kentucky farmers.

Switchgrass produces large quantities of biomass both above and below ground; root systems have been measured 3.3 meters deep (Weaver, 1968) while above ground growth has been observed over 3 meters. The inflorescence is a diffuse panicle with spikelets that contain one fertile floret and one staminate floret (Moser and Vogel, 1995). Cassida et al. (2005) stated that switchgrass cultivars can be classified morphologically as lowland (tall, coarse stems, adapted to poor drainage) and upland (short, fine stems, good drought tolerance) while physiological ecotype is determined by latitude of origin (broadly classified as northern or southern).

It is important that farmers use cultivars that originated in similar latitudes because these cultivars will be the most adapted to their local climate and conditions. The latitude of origin has a large impact on switchgrass yield potential and ability to survive extreme environments (Casler et al., 2004): lowland ecotypes from southern latitudes have higher yield potential than upland ecotypes from the north, but are not as cold tolerant (Adler et al., 2006).

Attributes of lowland ecotypes include high biomass yields, reduced dry matter concentrations, longer retention of photosynthetically active tissue, and a longer growing season. Upland ecotypes are generally associated with better cold tolerance, higher survival rates, more sustained biomass production and increased stand longevity. Fike et al. (2006a) reviewed a ten year study in western Virginia comparing upland ecotypes Cave-In-Rock and Shelter to lowland ecotypes Alamo and Kanlow. His results showed that Kanlow was the most robust across the mid-south region under low input management schemes. Results from field trials in Kentucky have shown that Kanlow has equivalent yields to Alamo (Fike et al., 2006a), but Alamo occasionally suffers winterkill in the state (Olson et al., 2009).

2.1 Switchgrass for Energy

Fike et al. (2006b) said "Switchgrass has an enormous potential for renewable herbaceous biomass in North America". Sanderson and Adler (2008) found that second generation biomass crops such as switchgrass are considered to be the future of a national bioenergy industry. Some of the most important parameters that make switchgrass ideal for energy production include low input and production cost and adaptation to a wide range of growing conditions (Sanderson and Adler, 2008). Vogel et al. (2002) reported that 168 kg N $ha^{-1}$ produced optimum yields for Alamo switchgrass. Work done by Casler et al. (2004) showed that lowland switchgrass cultivars and ecotypes managed for biomass produced 15.0, 9.8, and 19.2 Mg $ha^{-1}$ when fertilized with 112 kg N $ha^{-1}$ in Oklahoma, Kansas, and Nebraska, respectively. Other statewide and regional studies show varying results with nitrogen applications in terms of yield. Lemus et al. (2008) found that there was no significant harvest difference with first year treatment of nitrogen. McLaughlin and Walsh (1998) suggested that there would be many environmental benefits with increased utilization of switchgrass as a renewable energy crop. The three most significant benefits that they reported were improved soil conservation, improved energy gain and decreased emissions of carbon dioxide.

Combustion of biomass with coal referred to as co-firing is technically feasible but the economics remain challenging as biomass feedstock as they are more costly than coal to generate electricity (Moore et al., 2008). Renewable energy crops such as switchgrass can be utilized as combustible biomass or it can be processed into liquid transportation fuels such ethanol or butanol. This study is only concerned with the combustible aspect of the biomass but the economics are currently the same for the biofuels component.

Tillman (2000) describes there being three general techniques that comprise cofiring technology; blending the biomass and the coal prior to entering the boiler, preparing the biomass separately and injecting into the boiler without affecting the coal delivery, and gasifying the biomass with subsequent combustion. The material in this study was blended with the coal prior to entering one of the two fluidized bed boilers at the East Kentucky Power Plant near Maysville, KY.

In the final report by Solow et al. (2005) of the Chariton Valley Biomass Project they showed that by substituting 90,720 MT tons of coal with btu equivalent amount of switchgrass, $NO_x$ would be increased by 9.25 MT per year but $SO_x$ would be decreased by 406.43 MT per year and $CO_2$ reduced by 246,917 MT per year.

Fales et al. (2007) reported that current biofuel production in the United States relies primarily on corn grain conversion to ethanol but future systems are expected to depend more extensively on plant biomass as a feedstock. The report also stated that a new energy strategy must include maximizing the capture and use of light and $CO_2$ available on every unit of arable land. This confirms that energy production is not only possible but needed as we move to replace the consumption of fossil fuels.

Biomass, defined by Perlack et al. (2005) includes all plant and plant derived materials including animal manure, not just starch, sugar, oil crops already used for food and energy. Production of large scale biomass crops will be complicated. Wood products and materials such as annual crop residues will all contribute to the renewable energy portfolio but perennial herbaceous crops such as switchgrass can contribute as much or more to the whole renewable energy picture.

Establishment, production, harvesting and storage will all be concerns for farmers if switchgrass becomes a major biomass crop. Moisture of the plant material at harvest will be a major concern. Lewandowski and Kicherer (1997) showed that biomass should be delivered to a combustion power plant at 23% moisture or below. Moisture above

23% affects the combustion process and the stability during storage. This moisture level is very attainable to Kentucky farmers who want to harvest biomass either in the late fall or spring. Research harvests in Kentucky have shown that these moisture levels can be manageable in the fall (Nov.) harvest field drying similar to hay production and spring (March) harvests can be baled immediately upon cutting as long as there is no snow or ice in the material and it is standing dry in the field.

While grasses such as switchgrass are acceptable in the biomass market, grass biofuels contain three to five times more ash than wood (42-66 vs. 11-25 g kg-1), respectively, (Burvall, 1997, Obernberger et al., 1997, Olanders and Steenari, 1995). Ash contains the elements potassium (K), chlorine (Cl) and nitrogen (N) which can have a corrosive effect on combustion boilers.

## 2.2 Switchgrass for Forage

Most of Kentucky's pasture and hay production is based on tall fescue (*Schedonorus arundinacus* (Schreb. Dumort.)) and other cool season grasses such as orchardgrass (*Dactylis glomerata* L.) and Kentucky bluegrass (*Poa pratensis* L.). This is extremely important because Kentucky is the largest cattle producing state east of the Mississippi River. The cheapest way to raise cattle is on pasture and locally produced hay. While this cool season forage system works well in the spring, fall and early winter, it is not usually productive during the hot summer months or during the winter months. During the summer months of late June, July, August and sometimes early September, tall fescue and other cool season grasses slow down forage production and occasionally become completely dormant. Farmers sometimes refer to this as the "summer slump" period. During this time period, it is often necessary to supplement cattle and other livestock with hay or other feedstuffs (Ball et al., 2007). Switchgrass (and other warm season grasses) have the capability to fill in the "summer slump" period and supplement or mitigate the loss in forage production.

Research conducted at the University of Tennessee (Keyser et al., 2012a), showed that 272 kg stockers maintained a 1.00 kg average daily gain (ADG) when grazing switchgrass in a 30 day trial. The same study showed that when the grazing period was extended to 74 to 95 days, the animals performed at 0.75 kg ADG. Even though the longer grazing period showed reduced animal production, the ADG was still higher than typical infected tall fescue pasture during the summer months. Hoveland et al. (1983) reported stocker ADG in Alabama on infected tall fescue pastures to be 0.454 kg day $^{-1}$. In a three year study, work conducted by Burns et al. (1984) saw ADG on switchgrass to be 0.96 kg day $^{-1}$on yearling steers.

Switchgrass is an excellent grazing forage but it can also be harvested for hay to feed cattle or other livestock. However, it takes a different management scheme than cool season grass species. Tall fescue and other cool season grasses can be cut at low heights (5-10 cm) and regrow quickly. Switchgrass should be cut at a height of 16 -20 cm (Fike et al., 2006a) for adequate regrowth and stand survival, but can be cut at 7- 10 cm at end of season harvests such as November or March.

Keyser et al. (2012b) at the University of Tennessee showed that when harvested for hay using a two cut system Alamo switchgrass yielded 8.74 MT ha$^{-1}$ with the addition of 54kg of N ha$^{-1}$ (split application, 27 kg at green up and 27 kg following the first cutting). Without a nitrogen application, the yield was 6.72 MT ha$^{-1}$. Crude protein levels for the first cutting were 7.5% and 9.1% (0 kg N ha$^{-1}$ & 134 kg N ha$^{-1}$) and 7.3% and 9.1 % (0 kg N ha$^{-1}$ & 134 kg N ha$^{-1}$) for the second cutting. These protein levels were sufficient for feeding a mature beef cow in her first or second trimester of pregnancy (NRC, 2000)

The University of Kentucky variety trial from 2003 to 2009 in Lexington, KY showed annual yields of Alamo switchgrass ranged from 4.5 to 26 MT ha$^{-1}$ with an average of 11.9 MT ha$^{-1}$ (Olson et al., 2009). In this trial 67 kg ha$^{-1}$ of N was applied at initial green up each spring and P, K and pH were maintained soil test recommendations.

## 2.3 Urea as Fertility Amendment

The addition of inorganic nitrogen (N) fertilizers such as urea (46-0-0) has long been known to increase yields of most herbaceous and grain crops and higher yields can mean lower per unit input costs, thus increasing profitability. This increase in production has led to the ever increasing use and utilization of commercial nitrogen sources.

Inorganic N, especially in the form of urea and anhydrous ammonia and ammonium nitrate became more readily available to farmers with the development of the Haber – Bosh process in the early 1900's. Inorganic N is readily taken up by plant roots and is available as soon as it moves into the soil profile. However, inorganic N does not remain in the soil for very long and it is mobile. Large rainfall events that may occur soon after an N application will cause leaching through the root zone into the water table or applied N can move laterally from the soil surface into streams and rivers and eventually into the Gulf of Mexico. Gobler et al. (2002) reported that this excess N provides favorable conditions for excessive growth of algae that utilize the water's oxygen supply for respiration and when decomposing deplete oxygen levels for fish and other aquatic wildlife.

Urea as a N fertilizer or soil amendment has some distinct advantages over other N sources. It is less explosive than ammonium nitrate (although urea mixed with nitric acid can be explosive) and its storage is considered much safer. Urea can be utilized as a solid or liquid and is more cost effective for transportation purposes. Ease of application of the granular form makes it convenient for producers. Because of its high nitrogen content, it is usually cheaper on a per unit N basis, thus lowering input costs. When producing switchgrass for a renewable energy crop, urea would typically be added when the plant begins to produce new vegetation in the spring following winter dormancy, typically during early April in Kentucky. For producers interested in a two cut hay production system nitrogen should be applied in a split application. The second application should occur after the first harvest typically during late June (Keyser et al., 2012b). Topdressing in late June can sometimes lead to volatilization. Schwab and Murdock (2010) reported that there were three types of products being marketed to improve nitrogen efficiency: nitrification inhibitors, urease inhibitors (to minimize volatilization of the ammonia in the urea) and controlled release fertilizers (such as products that are sulfur coated). These products are designed to conserve nitrogen and should be targeted for individual situations.

## 2.4 Chicken Litter as Fertility Amendment

Poultry litter is a common byproduct in many areas of the eastern and central United States. Poultry species include but are not limited to chickens, turkeys, ducks, geese, etc. The most commonly available poultry litter is chicken litter and the material used in this research was composted chicken litter. In chicken production, the two types of animals produced are broilers (those used in meat production) and layers (those animals used to produce the eggs for the broilers). In the United States, between 1982 and 1992 broiler production increased 59% with a corresponding increase in manure and other residual materials (NRCS, 1995). The large amount of chicken litter produced in the USA each year could become a major source of nutrients for energy crops such as switchgrass. In 2011, the state of Kentucky produced 310 million broilers (USDA, 2012) with a value of 794 million dollars.

Poultry litter is a combination of the manure produced by the animals and the bedding material used in the housing process. The nutrient concentration of the litter will vary depending on what type of bedding is used and the feeding regiment for the broilers. The different types of bedding materials include but are not limited to rice hulls, sawdust, wood shavings, shredded paper, etc. (Espinoza et al., 2005). Before applying chicken litter to fields, famers should always submit a sample for testing to determine the fertility value of the material.

Poultry litter also contains all 13 of the essential plant nutrients that are used by plants. These include (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chlorine (Cl), boron (B), iron (Fe) and molybdenum (Mo) (Chastain et al., 2003).

Eghball et al. (2002) showed that with decomposed chicken litter 55% of the N is typically available to plants in the first year of application and that 45% of the N is available in subsequent years. To maximize yield when using chicken litter as a fertilizer source, timing of application should be coordinated with the growth pattern of the desired species. Espinoza et al. (2005) reported that mineralization of organic component of N occurs quickly, usually within the first two to four weeks of application.

Best management practices (BMP'S) suggest that chicken litter should be mechanically incorporated as soon after application as possible. In this study, the material was surface applied by hand and not incorporated. In work done by Rasnake (1996) in Kentucky, the addition of 22.4 MT $ha^{-1}$ of broiler litter produced up to 20.2 MT $ha^{-1}$ of hay equivalent yield from Bermudagrass (*Cynodon dactylon* L.). The litter was applied in May and the grass was cut 3 times during the summer. Rasnake (1996) concluded that broiler litter is best used with crops such as corn and grass that can utilize N efficiently.

## 2.5 Biosolids as Fertility Amendment

With the increased cost of commercially produced fossil fuel derived fertilizers, it is imperative that other sources of fertilizers are developed for renewable energy crops. Crops such as corn and soybeans rely heavily on these fossil fuel types of fertilizers and can justify their use by a significant increase in production from their use. Renewable energy crops such as switchgrass will need to use cheaper, alternative sources of fertilizer to increase their yields. Processed biosolids (sewage sludge) provide another opportunity to explore as alternative fertilizer source for switchgrass. Land applied biosolids takes place in 50 states. Kresse and Naylor (1987) have reported that biosolid treated plots produced corn yields equivalent to those to which commercial fertilizer was applied.

Municipal biosolids originate from waste water treatment facilities located in metropolitan areas around the country. They treat the wastewater to a point that allows the water to re-enter the surface or ground water while removing the dissolved and suspended solids. These dissolved or suspended solids are now referred to as biosolids (formerly sludge or sewage sludge). Raw biosolids are 2-3% solids and 97 to 98% water. This "solid" material must then be treated further before it can be applied on any type of crop. Before being applied the material must be classified as "A" or "B" according to pathogen reduction (Table 2.2). Federal regulations mandate that the material be disposed of by three methods; placed in a regulated landfill, incinerated or recycled through the application to soil.

Louisville Green™ is a heat dried biosolid produced and bagged in Louisville, KY. The product is pelleted for convenience and transport. It complies with all regulations contained in the EPA Part 503 Rule (Walker et al., 1994) regarding levels of heavy metals and bacteria content. EPA Guide to Part 503 Rule states that biosolids applied to the land must meet risk based pollutant limits specified in Part 503. All biosolids applied to the land must meet the ceiling concentrations for pollutants listed in table 2.1.

Table 2.1. Pollutant Limits

| Pollutant | Ceiling Concentration Limits for All Biosolids Applied to Land (milligrams per kilogram)[a] | Pollutant Concentration Limits for EQ and PC Biosolids (milligrams per kilogram)[a] | Cumulative Pollutant Loading Rate Limits for CPLR Biosolids (kilograms per hectare) | Annual Pollutant Loading Rate Limits for APLR Biosolids (kilograms per hectare per 365-day period) |
|---|---|---|---|---|
| Arsenic | 75 | 41 | 41 | 2 |
| Cadmium | 85 | 39 | 39 | 1.9 |
| Chromium | 3,000 | 1,200 | 3,000 | 150 |
| Copper | 4,300 | 1,500 | 1,500 | 75 |
| Lead | 840 | 300 | 300 | 15 |
| Mercury | 57 | 17 | 17 | 0.85 |
| Molybdenum[b] | 75 | ---- | ---- | --- |
| Nickel | 420 | 420 | 420 | 21 |
| Selenium | 100 | 36 | 100 | 5 |
| Zinc | 7,500 | 2,800 | 2,800 | 140 |
| Applies to: | All biosolids that are land applied | Bulk biosolids and bagged biosolids[c] | Bulk biosolids | Bagged biosolids[c] |
| From Part 503 | Table 1, Section 503.13 | Table 3, Section 503.13 | Table 2, Section 503.13 | Table 4, Section 503.13 |

[a] Dry-weight basis.

[b] As a result of the February 25, 1994, Amendment to the rule, the limits for molybdenum were deleted from the part 503 rule pending EPA reconsideration.

[c] Bagged biosolids are sold or given away in a bag or other container.

All biosolids applied to the land must fall into two categories; Class A or Class B pathogen requirement. That determination is summarized in Table 2.2.

Table 2.2. Summary of Class A and Class B pathogen reduction requirements.

| | |
|---|---|
| **CLASS A**<br>In addition to meeting the requirements in one of the six alternatives listed below, fecal coliform or Salmonella sp. Bacteria levels must meet specific density requirements at the time of biosolids use or disposal or when prepared for sale or give away (see Chapter Five of this guidance)<br><br>***Alternative 1: Thermally Treated Biosolids***<br>Use one of four time-temperature regimens<br><br>***Alternative 2: Biosolids Treated as a High pH-High Temperature Process***<br>Specifies pH, temperature, and air-drying requirements<br><br>***Alternative 3: For Biosolids Treated in Other Processes***<br>Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration.<br><br>***Alternative 4: Biosolids Treated in Unknown Processes***<br>Demonstration of the process is unnecessary. Instead, test for pathogens-Salmonella sp. Or fecal coliform bacteria, enteric viruses, and viable helminth ova-at the time the biosolids are used or disposed of or are prepared for sale or give away | ***Alternative 5: Use of PFRP*** Biosolids are treated in one of the Processes to Further Reduce Pathogens (PFRP) (see Table 5-4)<br><br>***Alternative 6: Use of a Process Equivalent to PFRP***<br>Biosolids are treated in a process equivalent to one of the PFRP's as determined by the permitting authority<br><br>**CLASS B**<br>The requirements in one of the three alternatives below must be met<br><br>***Alternative 1: Monitoring of Indicator Organisms***<br>Test for fecal coliform density as an indicator for all pathogens at the time of biosolids use or disposal<br><br>***Alternative 2: Use of PSRP***<br>Biosolids are treated in one of the Processes to Significantly Reduce Pathogens (PSRP) (see table 5-7)<br><br>***Alternative 3: Use of Processes Equivalent to PSRP***<br>Biosolids are treated in a process equivalent to one of the PSRP's, as determined by the permitting authority |

Biosolids have been used for centuries to fertilize. Present day regulations guide end users as to what class of biosolids they can use on their particular farming operation. Using this product rather than depositing in a landfill or incineration allows farmers to return these nutrients and organic matter to the soil. Concerns that heavy metals may accumulate during prolonged applications of biosolids (> 6 YR) was dispelled by Gaskin et al. (2003) whose study indicated that toxic levels of metals have not accumulated in the soil.

Through centuries of production agriculture, farmers have come to realize the value of organic sources of N including biosolids. Biosolids can help to increase yield and organic matter which improves soil productivity. It is important to understand that municipal biosolids today have been treated to reduce or eliminate disease pathogens and organisms and are safe to use in renewable energy crops such as switchgrass.

## 2.6 Objectives

The objective of this study was to determine the effect of N fertilizer type (urea, broiler chicken litter, processed biosolids) and rate on switchgrass biomass yield and nutritive value.

# Chapter III: Materials and Methods

## 3.1 Site and Site Preparation

This trial was conducted on three separate cooperator farms in Campbell, Nicholas and Rowan Counties in east Central Kentucky. An on-farm study was chosen, so that results obtained would better simulate farmers' actual results as the market for renewable energy crops develops in the future. On each of these farms, 2 hectares of Kanlow switchgrass had been established in 2008. In each field, a uniform area of the stand was located and an experimental plot of 27.43 by 18.28 meters was initiated. This experiment had 15 treatments with four replications organized in a randomized complete block design (RCBD). Each individual treatment plot size was 1.83 by 3.65 meters. Plots were split in half to allow for the fall harvest and spring harvest with subplots of 1.83 by 1.83 meters. Harvests were made in a split block rotation.

3.2 Fertility Applications

The fertility treatments were applied on 6 May 2010 in Rowan County and on 7 May 2010 in Campbell and Nicholas counties. The following year the fertility treatments were applied on 10 May 2011 in Campbell County and 11 May 2011 in Nicholas and Rowan counties. At the time of the first fertility treatment in both years of the study, the plant material was approximately 30 to 45 cm tall. The individual treatments are listed below:

1) Check Plot – No fertility or amendments applied
2) 33 kg N $ha^{-1}$ applied as urea fertilizer (46-0-0)
3) 67 kg N $ha^{-1}$ applied as urea fertilizer (46-0-0)
4) 100 kg N $ha^{-1}$ applied as urea fertilizer (46-0-0)
5) 134 kg N $ha^{-1}$ applied as urea fertilizer (46-0-0)
6) 33 kg N $ha^{-1}$ (on per weight basis) applied as composted chicken litter
7) 67 kg N $ha^{-1}$ (on per weight basis) applied as composted chicken litter
8) 100 kg N $ha^{-1}$ (on per weight basis) applied as composted chicken litter
9) 134 kg N $ha^{-1}$ (on per weight basis) applied as composted chicken litter
10) 134 kg N $ha^{-1}$ (on per weight basis) applied as composted chicken litter (only applied in initial year)
11) 33 kg N $ha^{-1}$ (on per weight basis) applied as biosolids (Louisville Green)
12) 67 kg N $ha^{-1}$ (on per weight basis) applied as biosolids (Louisville Green)
13) 100 kg N $ha^{-1}$ (on per weight basis) applied as biosolids (Louisville Green)
14) 134 kg N $ha^{-1}$ (on per weight basis) applied as biosolids (Louisville Green)
15) 134 kg N $ha^{-1}$ (on per weight basis) applied as biosolids (Louisville Green) (only applied in initial year)

Three different forms of nitrogen fertility amendments were used for the treatments included in this research; chemical urea fertilizer (46-0-0), composted broiler chicken litter and a processed, pelleted biosolid, Louisville Green™. Samples of both the biosolids and the chicken litter were sent to the University of Kentucky Regulatory Services laboratory each year of the study for analyses. Calculations for nitrogen treatments were formulated using the "total nitrogen" component generated by the UK laboratory. While nitrogen was the primary nutrient that the study considered, other macro and micro nutrients were included in the Louisville Green and the chicken litter as described below in table 3.1.

Table 3.1. Nutrient content of Louisville Green biosolid and composted poultry litter on a percentage basis.

| | Louisville Green | | Poultry Litter | |
|---|---|---|---|---|
| | 2010 | 2011 | 2010 | 2011 |
| Nutrient | --------------------------------------% DM | -------------------------------- | | |
| Total Nitrogen | 6.57 | 6.48 | 2.85 | 3.02 |
| Available Phosphate | 2.9 | 3.16 | 1.96 | 2.7 |
| Soluble Potash | 0.54 | 0.37 | 3.03 | 3.6 |
| Water Insoluble Nitrogen | 5.33 | 5.67 | 1.27 | 1.63 |
| Calcium | 2.66 | 2.35 | 1.89 | 2.09 |
| Magnesium | 0.47 | 0.4 | 0.61 | 0.74 |
| Copper | 0.02 | 0.02 | 0.03 | 0.04 |
| Iron | 0.76 | 0.69 | 0.2 | 0.21 |
| Manganese | 0.02 | 0.02 | 0.05 | 0.06 |
| Molybdenum | 0.0008 | 0.0009 | 0.0004 | 0.0004 |
| Zinc | 0.04 | 0.04 | 0.05 | 0.06 |

## 3.3 Soil Sampling and Characteristics

Soil samples were collected from each replication at each of the three sites prior to the application of treatments; Campbell County and Nicholas County on 5 May 2010 and Rowan County on 6 May 2010.

The Campbell County site was a previous tall fescue pasture/ hay field which had been cut annually for hay for more than five years prior to establishing the switchgrass plots in 2008. The soil was a Faywood silt loam, with a six to twelve percent slope. The Faywood series is characterized by moderately deep, well-drained soil formed in residuum of limestone interbedded with thin layers of shale. Permeability is moderately slow to slow. Slopes range from 2 to 60 percent. Average annual precipitation is about 112 cm. The average annual temperature is 12.3$^{o}$C. (USA.com, 2014). The elevation at that site is 250 meters above sea level.

The Nicholas County site was previously wooded with scrub trees such as black locust (*Robinia pseudoacacia* L.), hackberry (*Celtis occidentalis* L.) and box elder (*Acer negundo* L.). It consisted of an Eden flaggy silty clay with six to twenty percent slope (severely eroded). The Eden series consists of moderately deep, well drained, slowly permeable soils that formed in residuum from interbedded calcareous shale, siltstone, and limestone. These soils are on hillsides and narrow ridgetops with slopes ranging from 2 to 70 percent. Mean annual temperature is about 12.6$^{o}$C and mean annual precipitation is 110 cm (USA.com, 2014). The tree species were removed via bulldozer operation in 2007 and the switchgrass plots were established the next year. The elevation at that site is 280 meters above sea level.

The Rowan County site was a river bottom that had been in corn production for several years prior to the switchgrass establishment. It consisted of Whitley silt loam, terrace with two to six percent slope. The Whitley series is characterized by very deep, well drained, moderately permeable soils on stream terraces, foot slopes and alluvial fans. They formed in mixed alluvium weathered from siltstone, shale and sandstone. Slopes range from 0 to 12 percent. The annual mean temperature is 12.2$^{o}$C with the annual mean precipitation being 117 cm (see Figures 5.1 and 5.2). The elevation at that site is 238 meters above sea level.

Switchgrass had previously been established at each of these sites in 2008. ‘Kanlow’ seed was drilled into existing sod with a Truax drill. Prior to planting plots had been sprayed with Roundup$^{TM}$ at least twice. Seeding rate was 11.2 kg ha$^{-1}$ of pure live seed.

In May 2010, prior to the first treatment application, one core was taken from each plot at a depth of 0 to 10 cm. These fifteen cores in each replication were mixed together in a plastic pail and submitted to the University of Kentucky Regulatory Services Laboratory for analysis. Correspondingly, another core was taken from each plot at a depth of 10 to 20 cm in the exact same site within the plot. These cores within the corresponding depths were then mixed together in a plastic pail and then submitted to the same laboratory for analysis. Soil samples were collected again in March 2011 (between the first and second season of this experiment) using the same collection procedure. Campbell County samples were collected on 3 March 2011, Nicholas County samples were collected on 2 March 2011 and Rowan County samples were collected on 18 March 2011. The final soil samples were collected in March of 2012 (at the conclusion of the experiment after final harvests had been completed). The Campbell County samples were collected on 6 March 2012, the Nicholas County samples were collected on 8 March 2012 and the Rowan County samples were collected on 7 March 2012. The results of these soil tests are shown in Tables 3.2, 3.3 and 3.4 and the mean of the soil samples from all four replications.

Table 3.2 Soil pH and nutrient levels from 2010 on switchgrass stands managed for biomass and forage production in Campbell, Nicholas and Rowan Counties at a 0-10 cm and 10-20 cm soil depth.

| Sampling Depth | County | KCL pH | Water pH | Buffer pH | Phosphorous (lbs) | Potassium (lbs) | Calcium (lbs) | Magnesium (lbs) | Zinc (lbs) | Soil Organic Matter (%) | Total Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 cm | Campbell | 5.66 | 6.49 | 6.99 | 35.25 | 212.50 | 8013.00 | 377.25 | 2.65 | 3.58 | 0.17 |
| | Nicholas | 3.82 | 4.82 | 6.05 | 19.50 | 245.50 | 2923.50 | 292.75 | 2.00 | 3.29 | 0.15 |
| | Rowan | 4.32 | 5.27 | 6.65 | 214.50 | 364.75 | 1098.50 | 97.75 | 1.48 | 1.75 | 0.08 |
| 10-20 cm | Campbell | 5.11 | 5.99 | 6.80 | 15.25 | 164.00 | 9030.25 | 456.00 | 0.95 | 1.21 | 0.05 |
| | Nicholas | 3.65 | 4.66 | 5.74 | 16.00 | 176.75 | 2864.75 | 214.25 | 1.23 | 1.77 | 0.09 |
| | Rowan | 4.30 | 5.25 | 6.65 | 180.50 | 272.00 | 1138.00 | 81.50 | 0.95 | 1.43 | 0.07 |

Table 3.3 Soil pH and nutrient levels from 2011 on switchgrass stands managed for biomass and forage production in Campbell, Nicholas and Rowan Counties at a 0-10 cm and 10-20 cm soil depth.

| Sampling Depth | County | KCL pH | Water pH | Buffer pH | Phosphorous (lbs) | Potassium (lbs) | Calcium (lbs) | Magnesium (lbs) | Zinc (lbs) | Soil Organic Matter (%) | Total Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 cm | Campbell | 5.69 | 6.52 | 7.09 | 42.00 | 231.00 | 7099.00 | 351.00 | 3.50 | 4.08 | 0.23 |
| | Nicholas | 3.91 | 4.90 | 6.20 | 33.00 | 256.00 | 2613.00 | 279.00 | 3.00 | 3.67 | 0.20 |
| | Rowan | 4.48 | 5.41 | 6.73 | 230.00 | 429.00 | 1165.00 | 118.00 | 2.10 | 1.92 | 0.10 |
| 10-20 cm | Campbell | 5.32 | 6.18 | 6.96 | 25.00 | 205.00 | 7531.00 | 397.00 | 1.40 | 1.64 | 0.09 |
| | Nicholas | 3.60 | 4.61 | 5.88 | 17.00 | 199.00 | 2275.00 | 221.00 | 1.40 | 2.00 | 0.12 |
| | Rowan | 4.27 | 5.23 | 6.67 | 203.00 | 283.00 | 1113.00 | 80.00 | 1.00 | 1.52 | 0.08 |

Table 3.4 Soil pH and nutrient levels from 2012 on switchgrass stands managed for biomass and forage production in Campbell, Nicholas and Rowan Counties at a 0-10 cm and 10-20 cm soil depth.

| Sampling Depth | County | KCL pH | Water pH | Buffer pH | Phosphorous (lbs) | Potassium (lbs) | Calcium (lbs) | Magnesium (lbs) | Zinc (lbs) | Soil Organic Matter (%) | Total Nitrogen (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 cm | Campbell | 5.61 | 6.45 | -- | 38.00 | 215.00 | 7626.00 | 385.00 | 3.10 | 3.68 | 0.19 |
| | Nicholas | 3.93 | 4.92 | 6.19 | 23.00 | 254.00 | 2651.00 | 283.00 | 3.10 | 3.07 | 0.17 |
| | Rowan | 4.56 | 5.49 | 6.82 | 188.00 | 362.00 | 1095.00 | 121.00 | 3.00 | 1.91 | 0.10 |
| 10-20 cm | Campbell | 5.24 | 6.11 | 6.87 | 20.00 | 198.00 | 7960.00 | 440.00 | 1.50 | 1.56 | 0.09 |
| | Nicholas | 3.66 | 4.67 | 5.84 | 13.00 | 168.00 | 2088.00 | 205.00 | 1.90 | 1.74 | 0.11 |
| | Rowan | 4.30 | 5.25 | 6.69 | 186.00 | 246.00 | 1055.00 | 85.00 | 1.30 | 1.43 | 0.08 |

3.4 Data Collection

Six harvests were made at all three experimental sites. The dates for the initial nutritive value harvest were as follows: 11 June 2010 for Rowan and Nicholas County and 14 June 2010 for Campbell County. The following year the harvest dates were 14 June 2011 for Nicholas and Rowan County sites and 16 June 2011 for Campbell County plot. The harvests were analyzed for the forage nutritive value parameters such as crude protein (CP), acid detergent fiber (ADF) and neutral detergent fiber (NDF). These estimates were also used to determine relative feed value (RFV).

The first biomass harvests were taken in November and March of each year and yield and forage nutritive value were measured. The first harvests started 9 November 2010 in Campbell County, 11 November 2010 in Nicholas County and 17 November 2010 in Rowan County. The dates for the second harvest were 2 March 2011 in Nicholas County, 3 March 2011 in Campbell County and 18 March 2011 in Rowan County. The dates for the third harvest were 17 November 2011 in Campbell and Nicholas counties and 18 November 2011 in Rowan County. The fourth and final harvests for yield and nutritive value were 6 March 2012 in Campbell County and 7 March 2012 in Nicholas and Rowan counties.

3.5 Harvest Technique

The June harvests (2010 and 2011) were collected solely for the purpose of evaluating forage nutritive value. No yield measurements were taken at that time because nutritive value for beef cattle was the only parameter considered for a summer harvest. In the middle of each sub-plot, a grab sample of approximately 500 g of fresh material was harvested at a height of 15 cm with a rice knife. Material collected was approximately 150 to 180 cm in height and included green leafy material. The material was dried in a forced air dryer at $60^{o}$C for a period of 72 hours. Once the plots had been harvested at all three sites and dried, samples were ground in a Thomas Wiley Mill (Thomas Scientific, Swedesboro, NJ ) grinder to pass a 4 mm screen and then reground through a UDY Cyclone Sample Mill (UDY Corporation, Fort Collins, CO) to pass a

1mm screen. Each sample was placed in quartz rings and reflectance spectra scanned using a Foss 6500 Near Infrared Reflectance Spectroscopy (NIRS) autosampler (Foss, Inc., Hillderod, Denmark) and ISIscan software (Infrasoft International, L.L.C., State College, PA).

For the November and March harvests, a three sided one $m^2$ grid, constructed of 2.5 cm PVC pipe with 10 cm legs at each corner, was placed inside the center of each subplot. The plant material was then gathered into a shock type bundle by one individual while another individual used a Stihl HS 45 (Stihl, Inc. Virginia Beach, VA) gas powered hedge trimmer to cut the material 10 cm above the soil surface. The material was then carried to an on-site staging area where a total wet weight was recorded. A representative grab sample of material weighing approximately 1 kg was shredded into a brown paper bag with a Del Morino G107d (Del MorinoS.r.l., CapreseMichalangelo, Italy) power unit with a CARAVAGGI (CARAVAGGI S.r.l., Pontoglio, Italy) shredder attachment. Paper bags of the shredded material were placed inside a forced air dryer at $60^oC$ for a period of 72 hours. After drying the grab samples, they were placed into a plastic five gallon pail and mixed thoroughly. A subsample of approximately 50 g was ground through a Thomas Wiley grinder with a four mm screen and then reground through a Udy Cyclone Mill Grinder with a one mm screen. The samples were placed in quartz rings and analyzed with a Foss 6500 Near Infrared Spectroscopy autosampler.

The March harvests differed from the November harvests because some of the switchgrass had lodged over the winter. There was a higher percentage of lodging in March 2012 likely due to record rainfall amounts the previous year and added snow cover. This made harvest more difficult as gathering the material required a great deal of effort. The hand harvesting technique allowed for total collection of all plant material even with the significant lodging. Lodging would create a major production issue for producers because commercial hay harvesting equipment is not designed for severely lodged stands.

Figure 3.1. Cutting 1 $m^2$ grid of switchgrass (top left). Grinding subsample (top right). Ground subsample (bottom left). Plots after harvest (bottom right).

3.6 Statistical Analysis

This study was conducted at three individual sites in northeastern Kentucky (Campbell, Nicholas and Rowan Counties). The experimental layout was a split-plot design. The whole plot was a randomized complete block design with a four by four factorial. Analysis on yield was investigated using the PROC GLM procedure of SAS 9.3 (Cary, NC). Four harvests at each site were explored. The harvests included two November harvests (2010 and 2011) and two March harvests (2011 and 2012).

Nutritive value parameters (CP, ADF and NDF) were also investigated using the PROC GLM procedure of SAS 9.3. Six harvests at each site were explored. These harvests included two in June (2010 and 2011) two in November (2010 and 2011) and two in March (2011 and 2012).

The single year application of chicken litter and biosolids created an unbalanced statistical design, therefore the yield and nutritive value results from these treatments were not included in the analysis.

Main and simple effects and any interactions were considered significant at $P < 0.05$. When the effect or interaction was significant, means were separated by LSMEANS (a=0.05). The variability of this trial across several sites with different soil types and different previous management schemes required analysis within individual sites.

Project samples were ground through a UDY Cyclone grinder to a 1 mm grind size. Samples were then analyzed with as Foss 6500 Near Infra-red Spectrometer utilizing an existing switchgrass equation that was calibrated for local conditions with switchgrass samples collected over several years. Subsequently, a subset of samples (216 of the 1080 total samples) was analyzed for NDF and ADF with an ANKOM F200 Fiber Analyzer (Macedon, NY). ADF and NDF were determined using the filter bag method described in (Vogel et al., 1999). These samples were also analyzed for nitrogen concentration using a LECO FP-528 nitrogen analyzer (St. Joseph, MI). Once these procedures were completed the equation was entered into the NIRS which then validated NIRS calibration and predict the values in other the other samples.

Table 3.5. Statistical data for NIRS calibration

| | CP | ADF | NDF |
|---|---|---|---|
| $r^2$ | 0.968 | 0.973 | 0.948 |
| SEP | 0.673 | 1.301 | 1.327 |
| SED | 0.863 | 1.3 | 1.3 |
| Global H | 1.326 | 1.323 | 1.323 |

# Chapter IV: Results and Discussion

This experiment was conducted as an "on-farm trial" to achieve results that farmers could expect when growing switchgrass as a forage or biomass crop. In the initiation process, three farms (with distinct soil types) were selected in separate counties where 'Kanlow' switchgrass had been previously planted in 2008. At each site, a uniform area within the switchgrass field was identified for the purpose of this study. Stand populations within the experimental area were uniform with occasional small areas that did not have complete "cover".

## 4.1 Weather Data

The weather during 2010 was typical of central Kentucky with temperatures within $1^{o}C$ of the long term average at all sites. Precipitation was near average with the exception of Nicholas County where annual precipitation was 40 cm below normal. Drought conditions from mid-August to mid-November were the main reason for the below average annual precipitation in 2010 in Nicholas County. This lower fall precipitation had minimal effect on switchgrass yield because the plants had already reached maximum growth and full panicle elongation prior to the onset of the drought. The limited fall growth in this research was similar to another study in Kentucky with 'Alamo' and 'Cave-In-Rock' switchgrass (Sena et al., 2011). Environmental conditions in 2011 were characterized by much higher than average precipitation and a higher than average temperature at all sites (Figures 4.1 and 4.2).

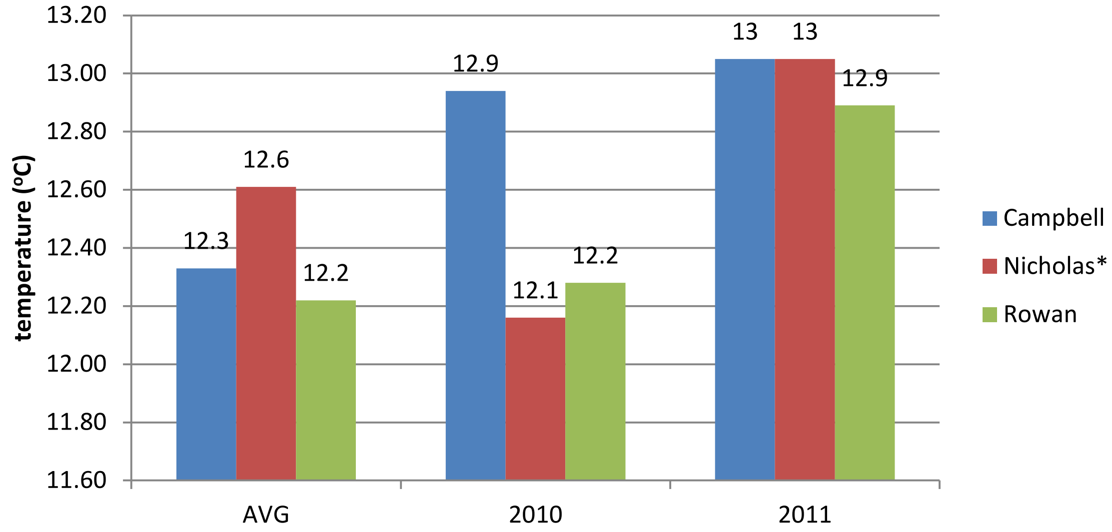



Figure 4.1. Average (1980-2010) annual temperature and average temperature for 2010 and 2011 growing seasons for all three experimental sites.
*Data is composite of Nicholas County and Harrison County data due to missing data in Nicholas County

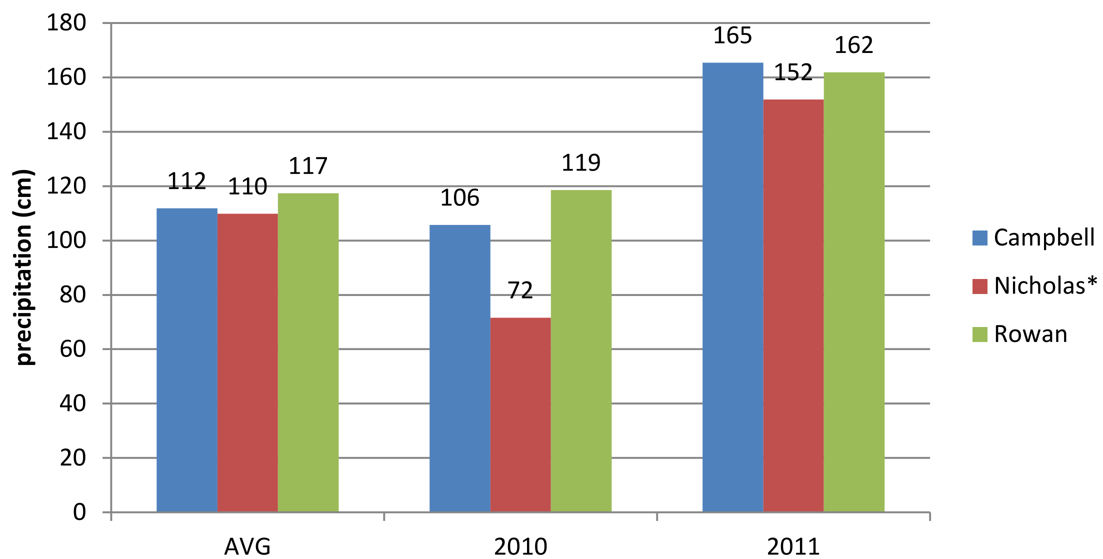



Figure 4.2. Average (1980-2010) annual precipitation and average precipitation for 2010 and 2011 growing seasons for all three experimental sites.
*Data is composite of Nicholas County and Harrison County data due to missing data in Nicholas County

4.2 Yield for Biomass

Analysis for yield showed a site by harvest interaction, therefore results were separated by sites (Figures 4.3, 4.4 and 4.5). Across all sites there was a significant harvest response. Biomass yield in November of 2010 was higher than the overwintered spring harvest of 2011 at the Campbell and Rowan sites but not at the Nicholas site. There was no fertility treatment response for biomass yield at the Nicholas and Rowan sites but there was a significant treatment response in Campbell County (Figure 4.7).

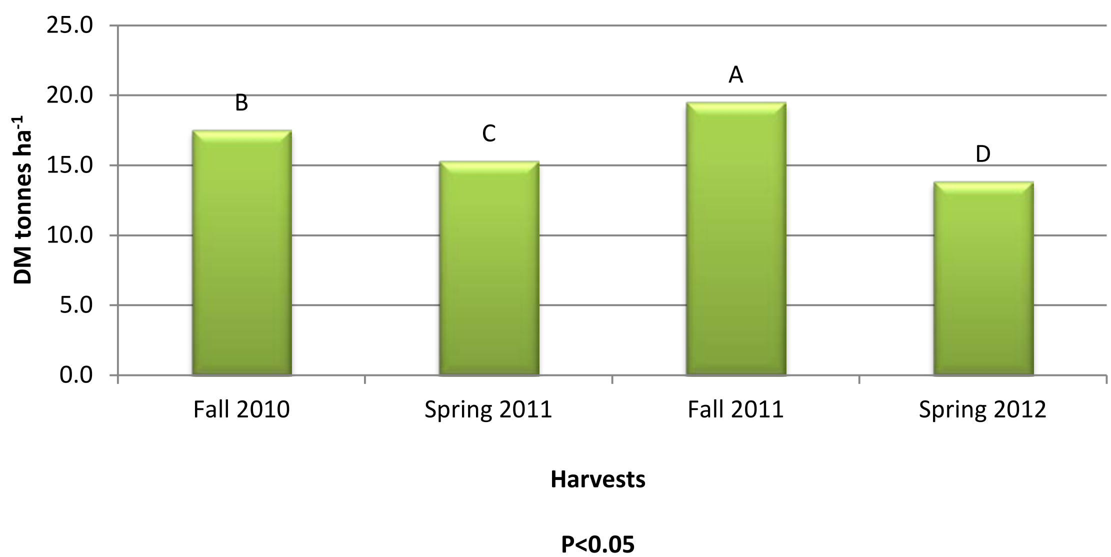



Figure 4.3. Campbell County switchgrass yield response (DM tonnes $ha^{-1}$) for November and March harvests in 2010/11 and 2011/12

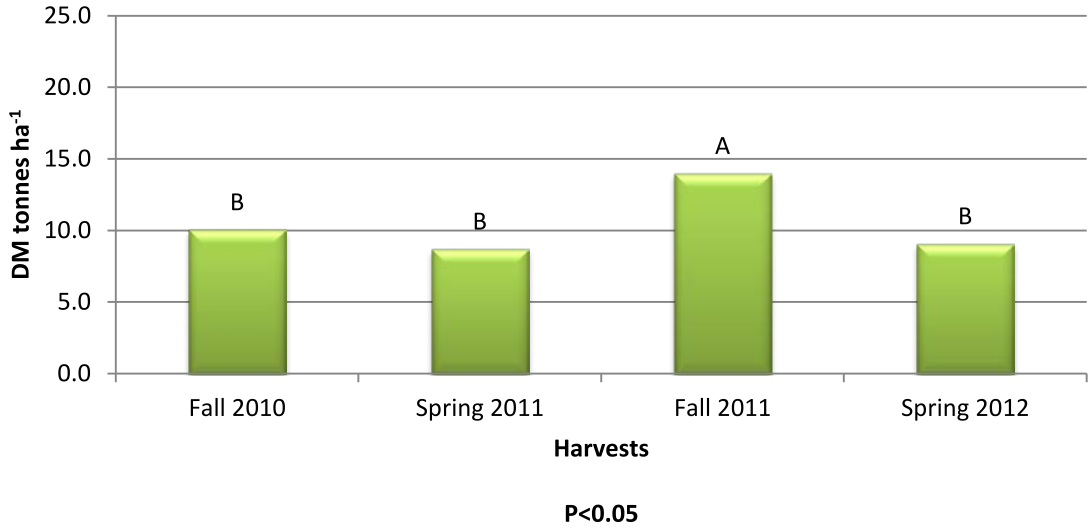



Figure 4.4. Nicholas County switchgrass yield response (DM tonnes $ha^{-1}$) for November and March harvests in 2010/11 and 2011/12

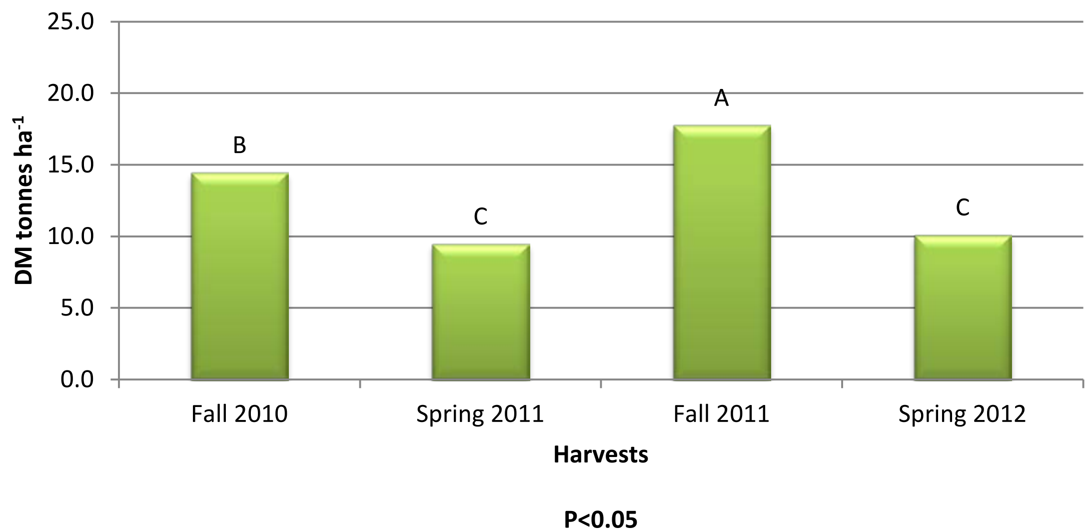



Figure 4.5. Rowan County switchgrass yield response (DM tonnes $ha^{-1}$) for November and March harvests in 2010/11 and 2011/12

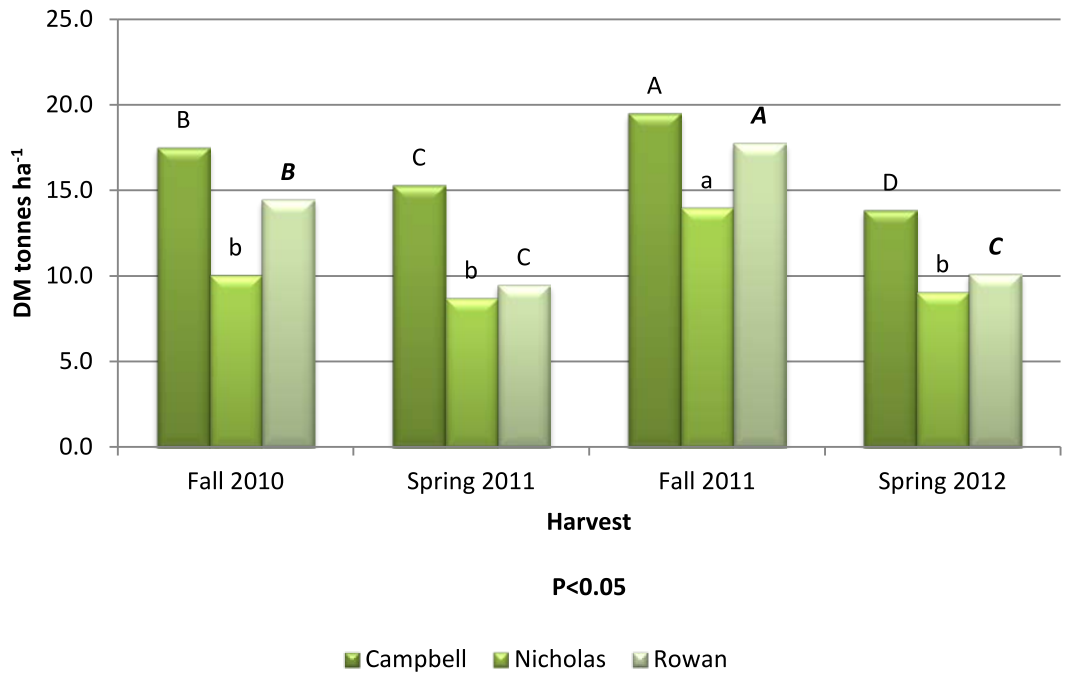


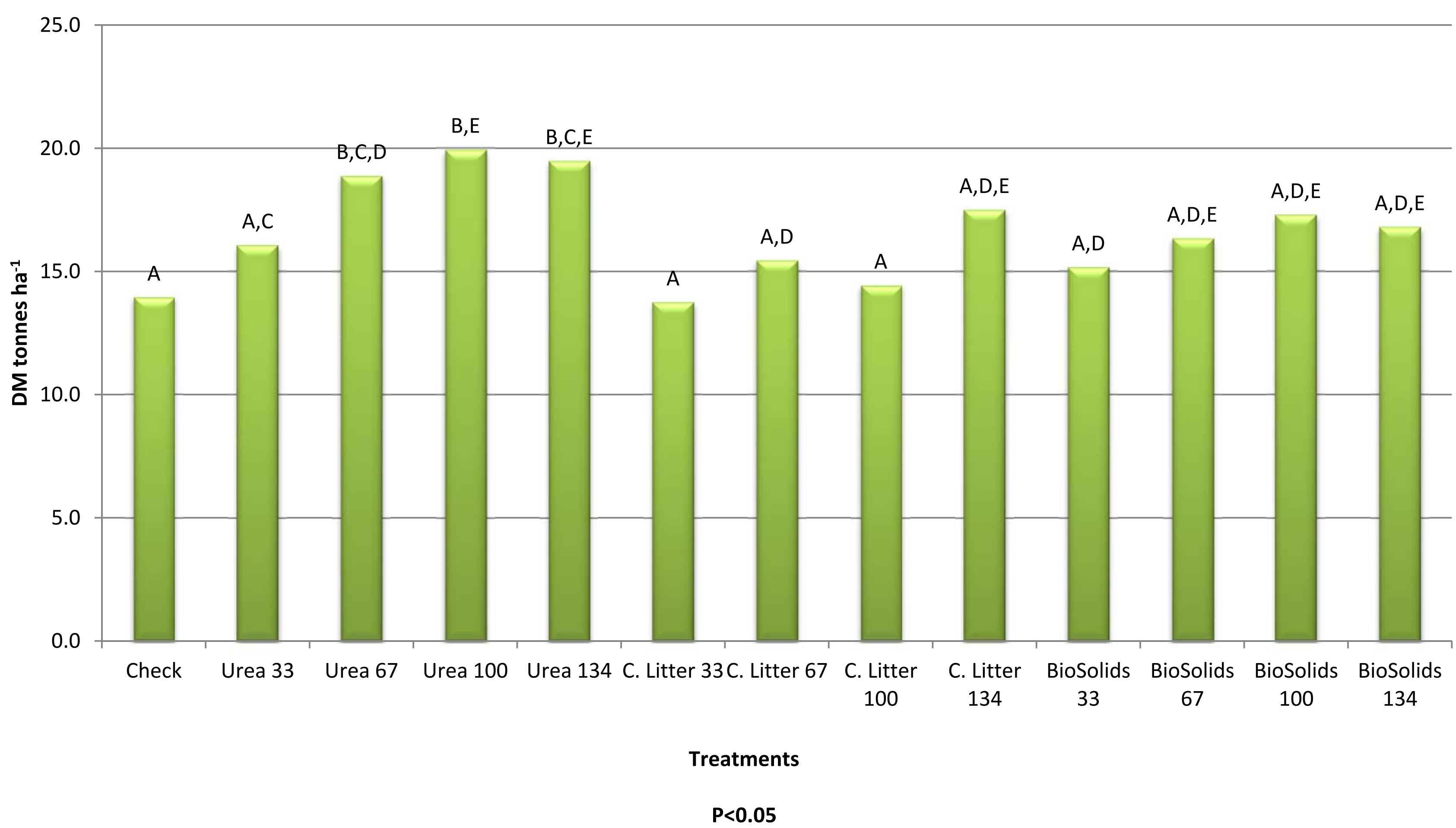

Figure 4.6. Switchgrass yield response (DM tonnes $ha^{-1}$) for Campbell, Nicholas and Rowan Counties for November and March harvests in 2010/11 and 2011/12.

In November of 2011, biomass yield was higher at all sites in comparison to spring of 2012 at 19.5, 17.8 and 14.0 DM tonnes $ha^{-1}$ at the Campbell, Rowan and Nicholas County sites respectively. The high November 2011 yields can be attributed to several factors including above average rainfall that season, it was the second year of the study and there may have been potential carryover on the organic nitrogen from the composted chicken litter and biosolids treatments. Overall, fall biomass yield was higher than the spring yield within a growing season with the exception of Nicholas County in 2010. The decreased biomass yields for the spring harvests were expected because of the impact of overwintering, especially the loss of leaf material. Adler et al. (2006) observed decreased spring harvest mass due to decreased standing tiller weight. The generally lower biomass yield in Nicholas County can be attributed to poorer soil conditions at that site. The land was cleared of timber immediately prior to the initial switchgrass planting and the water pH remained below 5.0 during the entire study (Table 4.2, 4.3 and 4.4).

The differences in biomass yield between the fall and spring harvests shown from this study has significant implications for Kentucky producers. The reduction in yield by waiting to harvest in the spring versus the fall could mean the difference between profit and loss for some farmers. For example, biomass decreased by 7.7 MT $ha^{-1}$ in Rowan County between the fall harvest of 2011 and the final spring harvest in 2012. An advantage of spring harvest was shown by the significant decrease in the concentration of elements such as potassium and chlorine from fall to spring (Robuck and Smith, 2014) These elements are known to be corrosive to boilers and their concentration is a major concern to power plants that seek to co-fire the switchgrass with coal (Zheng et al., 2007). Harvesting in the spring would have an added benefit for soil nutrient status. Leaching of essential macronutrients such as potassium from the switchgrass plant material into the soil profile will likely reduce fertilizer recommendations. For example, (Robuck and Smith, 2014) showed that potassium concentrations in the plant declined from 0.4 to <0.1% from fall to spring harvests. This results in a potassium fertilizer savings of 20 kg K $ha^{-1}$.

Farmers will need to take into account many factors before deciding whether to harvest switchgrass in the fall or spring. For example, if the crop is valued at $66/MT (Halich and Smith, 2010), then a fall harvest could mean an additional $508 $ha^{-1}$ to the farmer in comparison to a spring harvest. If the power plant prefers the biomass harvested in the spring because of the reduction in Cl and K, then some type of premium will probably need to be paid to the farmer to offset the loss in yield. Other considerations for timing of switchgrass harvests include the farm workload between fall and spring and soil moisture conditions. In Kentucky, fall conditions are usually drier which would facilitate harvest, especially for fields with significant topography challenges.

Figure 4.7. Campbell County switchgrass yield response over three fertility treatments (urea, biosolids, chicken litter) combined over November and March harvests in 2010/11 and 2011/12.



The positive treatment response in Campbell County indicated the benefit of increased N applications for increased biomass yield but only urea showed a significant difference between rates. Interestingly, these results show that there was no benefit of urea rates higher than 67 kg N $ha^{-1}$. Lemus et al. (2008) also observed no response to increasing nitrogen applications in a first year study looking at nitrogen use dynamics. There was no significant treatment response of the chicken litter or biosolids at the $P > 0.05$.

The significant urea response was likely due to its availability for plant uptake while the organic forms of N require time to breakdown and move into the soil profile for plant uptake. The N rate used for the chicken litter and the biosolids was based on total N and did not take into consideration organically bound N.

## 4.3 Yield for Quality Forage

Harvests were conducted in both June of 2010 and 2011 to assess the nutritive value of the switchgrass if it were to be harvested by grazing or cutting for hay. These quality assessments also provide a useful indicator of important parameters of biomass quality. Dry matter yield was not recorded during these harvests to avoid stand damage that would have impaired the more important biomass yield measurements in the fall and the spring.

Analyses for CP, ADF and NDF showed a site by harvest interaction. Therefore all results are shown on an individual site basis. The only significant treatment effect was for CP at the Campbell County site.

## 4.4 Crude Protein (CP) Response

The CP for June 2010 and 2011 harvests ranged from 8.0 to 8.9% indicating that the switchgrass growing in these fields would have provided an adequate maintenance ration as hay or pastures for dry beef (NRC, 2000) (Table 5.1). Since CP is calculated as 6.25 times the N content this plant material ranged from 1.28 to 1.42 %N. If this material was harvested as biomass fuel for renewable energy production, nitrous oxide emissions may be above allowable EPA levels. In work with miscanthus (*Miscanthus X giganteus*), Lewandowski and Kicherer (1997) stated that the N contained in the biomass is mainly responsible for the $NO_x$- emissions of the combustion system. They also reported that different combustion technologies such as stage combustion and steam gas recirculation can reduce the $NO_x$ emissions significantly.

Harvests in November showed higher CP levels than in March for Rowan County in 2010 and Campbell and Nicholas in 2011 likely due to overwintering and the resultant leaf loss that occurred (Table 4.1). Soluble CP would have leached from the stems and remaining leaves during this 4 month overwintering period. It was surprising that there were not greater differences in CP over winter. Regardless, the low CP levels across all sites both years (ranging from 0.7 to 1.5%) shows that season long switchgrass biomass production does not produce forage with adequate CP for any class of livestock.

The decreased CP levels from the fall to spring harvest would be advantageous to the power plants because any reduction in N is beneficial both in the combustion process and the release of $NO_x$. Although there are multiple advantages and disadvantages of a late fall versus spring switch grass harvest, these results suggest that CP is not as important a consideration.

Table 4.1. Crude protein for six switchgrass harvests over two seasons (2010/11 and 2011/12) from 3 farms in separate counties in northeastern Kentucky.

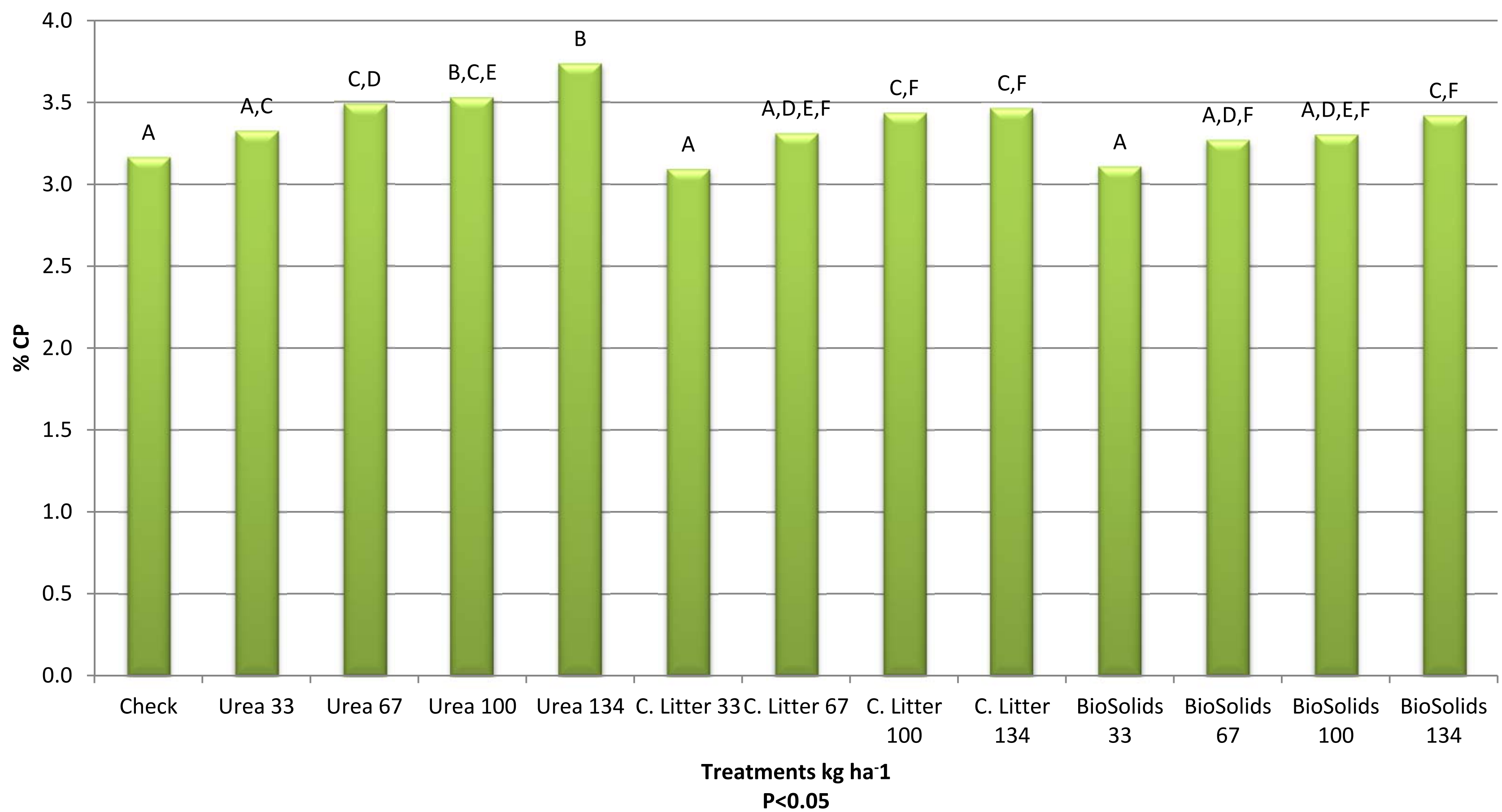
| Harvests | Campbell | Nicholas | Rowan |
|---|---|---|---|
| | --------% DM-------- | | |
| Jun-10 | $8.1^{B}$ | $8.1^{B}$ | $8.0^{A}$ |
| Nov-10 | $0.8^{C,D}$ | $1.0^{D}$ | $1.4^{C}$ |
| Mar-11 | $0.9^{C}$ | $1.0^{D}$ | $1.2^{D}$ |
| Jun-11 | $8.7^{A\dagger}$ | $8.9^{A}$ | $8.0^{A}$ |
| Nov-11 | $0.9^{C}$ | $1.5^{C}$ | $1.7^{B}$ |
| Mar-12 | $0.7^{D}$ | $1.0^{D}$ | $1.7^{B}$ |

† Numbers within a column followed by matching letters do not differ at $P<0.05$

There was a treatment effect for CP at the Campbell County site across both years and harvests but not at the other two sites. Using urea as the N source, application rates of 67, 100 and 134 kg N $ha^{-1}$ all produced higher CP levels than the control (Figure 4.8).

There was also a response for chicken litter at the 100 and 134 kg $ha^{-1}$ equivalent rates but only at the 134 kg N $ha^{-1}$ equivalent rate for biosolids. The highest CP levels were at the 134 kg N $ha^{-1}$ as urea, higher than all treatments with the exception of urea at the 100 kg N $ha^{-1}$. These results suggest that CP is higher when urea applications exceed 67 kg N $ha^{-1}$ but that of organic derived N source require applications above 100 kg N $ha^{-1}$ before there is a crude protein response. The results for CP are similar to the results for biomass yield at increasing rates of N as area except that biomass yield plateaued at 67 kg N $ha^{-1}$.

Figure 4.8. Campbell County switchgrass CP response over three fertility treatments (urea, biosolids, chicken litter) combined over November and March harvests in 2010/11 and 2011/12).



4.5 Acid Detergent Fiber (ADF) Response.

There was a harvest by site interaction, therefore ADF values are shown separately by site (Table 4.2).

Table 4.2 ADF for six switchgrass harvests over two seasons (2010/11 and 2011/12) from 3 farms in separate counties in northeastern Kentucky.

| | Campbell | Nicholas | Rowan |
|---|---|---|---|
| Harvests | ----------------------------------- | -% ADF- | ----------------------------------- |
| Jun-10 | $35.9^{B}$ | $33.6^{B}$ | $36.0^{B}$ |
| Nov-10 | $49.6^{D}$ | $48.8^{C}$ | $48.6^{C}$ |
| Mar-11 | $50.0^{D}$ | $49.0^{C}$ | $50.0^{E}$ |
| Jun-11 | $33.0^{A\dagger}$ | $33.0^{A}$ | $33.7^{A}$ |
| Nov-11 | $47.6^{C}$ | $49.1^{C}$ | $49.0^{D}$ |
| Mar-12 | $49.9^{D}$ | $50.9^{D}$ | $51.1^{F}$ |

† - Values within a column followed by the same letter are not different at P<0.05

Acid detergent fiber (ADF) is the residue remaining after incubating a forage sample in an acid detergent solution. The fiber fraction contains cellulose, lignin, and silica but not hemicellulose. This forage quality component provides a good predictor of forage digestibility in livestock. Lower ADF levels indicate higher forage digestibility because there is less fiber to be broken down by the rumen microbes.

This research study showed that ADF was much lower for the June harvest in comparison to the November and March harvests (averages 12 to 16% lower) at all sites and both years. ADF levels increased with each successive harvest (June to November to March) at all sites and both years with the exception of the November to March harvest at Campbell County and Rowan County over the 2010/2011 harvest season. Although the increase in ADF between November and March was small (averaged less than 2%) it was still significant at the P <0.05 level.

These results have important implications for nutritive value and biomass yield. The ADF levels in June (ranging from 33 to 36%) suggest that switchgrass harvested at this stage of maturity may provide an adequate complete feed source for dry beef cows and for stockers (NRC, 2000). For stockers, some protein will be required for maximum production but these ADF levels show adequate energy levels for most classes of ruminant livestock. Ball et al. (2007) report that cool season grass species such as tall fescue, orchardgrass and timothy cut at an early stage have ADF levels ranging from 31 to 35% which are approximate to June harvest of switchgrass.

Not surprisingly, ADF levels were much higher for switchgrass biomass at a late stage of maturity. These ADF levels in November and March were not adequate for any class of ruminant livestock unless processed in a tub grinder and used a fiber source in a total mixed ration (TMR).

Vogel et al. (2011) attempted to correlate ethanol yields using NIRS and measured ADF along with many other parameters in the work. ADF may provide a measurement or predictor of energy value for ethanol or other liquid fuels since the breakdown of cellulose and other sugars provides the substrate for alcohol fermentation. Further research to determine the relationship between ADF and alcohol production is needed and also work on the amount of lignification that will influence cellulose availability.

## 4.6 Neutral Detergent Fiber (NDF) Response.

There was a harvest by site interaction therefore NDF values are shown separately by site (Table 4.3).

Table 4.3 NDF for six switchgrass harvests over two seasons (2010/11 and 2011/12) from 3 farms in separate counties in northeastern Kentucky

| | Campbell | Nicholas | Rowan |
|---|---|---|---|
| Harvests | ------------------------------------ | % NDF | ------------------------------ |
| Jun-10 | $66.7^{B}$ | $64.5^{B}$ | $65.4^{B}$ |
| Nov-10 | $74.0^{C}$ | $74.0^{C}$ | $74.6^{C}$ |
| Mar-11 | $76.1^{E}$ | $75.5^{D}$ | $77.0^{E}$ |
| Jun-11 | $64.2^{A\dagger}$ | $63.9^{A}$ | $64.3^{A}$ |
| Nov-11 | $74.9^{D}$ | $75.6^{D}$ | $76.2^{D}$ |
| Mar-12 | $77.0^{F}$ | $77.9^{E}$ | $78.6^{F}$ |

† - Values within a column followed by the same letter are not different at P<0.05

Neutral detergent fiber (NDF) is the residue remaining after boiling a forage sample in a neutral detergent solution. The fiber fraction of the residue represents the indigestible and slowly digestible components of the cell wall containing cellulose, hemicellulose lignin and ash. The forage nutritive value component can be a predictor of forage intake in ruminant livestock. The lower the NDF levels the higher the potential for forage intake because there is a lower fiber fraction to be broken down by the rumen fluid. On the other hand, higher NDF levels indicate a lower intake capacity because the material takes longer to be broken down and that does not allow for passage of the material through the complex ruminant stomach.

This experiment showed that NDF was much lower for the June harvests in comparison to the November and March harvests (averages 10 to 14% lower) at all sites and both years. NDF levels increased with each successive harvest (June to November to March) at all sites and both years. Although the increase in NDF between the November and March harvests was small (averaging less than 2%), it was still significant at the $P<0.05$ level.

These results can have profound implications for forage nutritive value and biomass yield. The NDF levels in June (ranging from 63.9 to 66.7%) suggest that switchgrass harvested at this stage of maturity can provide an adequate feed source for dry beef cows or for stocker animals (NRC, 2000). Stockers would need the addition of some protein in their diet for maximum production but these levels of NDF show adequate energy levels for most classes of ruminant livestock.

Similarly with ADF, NDF levels were much higher for switchgrass biomass at a late stage of maturity. These levels in November and March were not sufficient for any class of ruminant livestock unless processed in a tub grinder and used primarily as a fiber source in a total mixed ration (NRC, 2000).

Some research is attempting to correlate NDF levels and biomass energy levels for combustion but the results are still very limited. Lewandowski and Kicherer (1997) stated that the higher the lignin content of a biomass the better its heating value.

## Chapter V: Conclusion

The results of this experiment confirmed that farmers need to be steadfast in the management of warm season native grasses, such as switchgrass, if they want to produce yields large enough to generate a profit as a renewable energy crop or if they want to manage the crop as a forage crop for pasture or hay. The results of this study were not as conclusive as expected since there was no treatment effect on yield or CP (other than in Campbell County). The results did suggest that further research should be conducted on the potential benefit of organic or inorganic forms of N for switchgrass biomass production. If the trial were to be repeated, it would be good to include a check for each type of N source and it would be good to eliminate the single treatment of 134 kg N $ha^{-1}$ as opposed to the treatment in both growing seasons.

Increased fertility levels from 0 to 134 kg N $ha^{-1}$ yielded more biomass at the Campbell County site, but only for the urea rates above 67 kg N $ha^{-1}$. The yield for the November 2011 harvest was higher than the other biomass harvests at all three sites. Contributing factors for this higher yield were increased rainfall for the 2011 growing season and it was the second year of the study with the fertility treatments applied on the same plots both years. The organic sources of nitrogen would have provided carryover nitrogen from 2010 to 2011. Zhang et al. (2013) calculates that 25 to 50% of surface N is available in the year of application. Based on these yield results, farmers would be better off to harvest in the fall of the year versus the next spring. The exception would be if power plants offset reduced yield with a premium for a reduction in N, K, and Cl content of the material.

Crude protein levels were at the highest levels with the June harvests (CP levels ranged from 8.0 to 8.9%). Levels were sufficient for dry beef cows either as a grazing crop or as a hay crop. ADF and NDF levels were at their lowest levels with the June harvests. These numbers support the use of this material as feed for dry beef cows. The November and March lower CP and higher ADF and NDF show that end of the season switchgrass harvests are only suitable for biomass (e.g. liquid fuels or co-firing).

While results did not show significant differences in yield and nutritive value when using composted chicken litter and processed biosolids, they remain a viable option for famers to use as fertility treatments when growing switchgrass for biomass or as forage. According to the (American Meat Institute, 2009) chicken consumption rose from 18.23 kg per person in 1970 to 39.23 kg per person in 2007. That coupled with the ever increasing world population and its corresponding increase in sewage sludge (biosolids) ensures that those types of fertility amendments will be available to farmers (depending on transportation and processing, etc.).

A final conclusion is that switchgrass managed correctly is a very versatile and multi-use crop. Farmers that wish to plant and use switchgrass have multiple options when it comes to utilizing and marketing this plant including forage and biomass. Other potential uses for harvested switchgrass material include use as a potential bedding material for dairy animals, as green chop source of fiber for dairy animals, as a hydro seeding mulch or as a floral adornment in bouquets.

# Chapter VI: Future Work Needed

This study confirmed that increased N levels can increase yield. However, the overall lack of treatment effects suggest that other factors such as lower than recommended pH levels at both Campbell and Rowan Counties and very low calcium levels in Rowan County may have contributed to the lack of treatment interaction for both yield and nutritive value in those two counties. The review of literature for this study found limited research on these growth parameters and switchgrass growth.

Another possibility for the lack of treatment effects might be that switchgrass has the ability to either store N in its root system, the ability to mineralize nitrogen from the soil and soil organic matter, or facilitate N fixation through free living soil bacteria. Another possibility could be the enormous and deep root system of switchgrass. These results support the continuation of Debolt et al. (2009) research on the effect of bacteria residing within the rhizosphere which correspondingly improved mineralization rates.

Continued research also needs to be conducted on switchgrass' ability to build organic matter in the soil (SOM). During the study SOM trended higher from the initial sampling in the spring of 2010 and the spring of 2011. Interestingly, SOM samples in the spring of 2012 were slightly lower than 2011. The fact that these numbers do not trend in one direction suggest that more work should be done in this area.

While this study showed higher yields in the fall when compared to spring, it also showed that levels of antiquality factors such as Cl and K were lower in the spring harvest (Robuck and Smith, 2014). In the future it will be important to survey power plants to determine what premiums, if any, they would be willing to pay for switchgrass with lower levels of antiquality components.

**Appendices**

Appendix A: Plot plans for each experimental site

Campbell County plot plan

| Block | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Treatment #* | 13 | 13 | 3 | 12 |
| | 6 | 9 | 5 | 11 |
| | 4 | 7 | 2 | 9 |
| | 12 | 2 | 12 | 8 |
| | 15 | 5 | 14 | 5 |
| | 3 | 3 | 1 | 7 |
| | 7 | 8 | 13 | 10 |
| | 5 | 14 | 8 | 14 |
| | 2 | 6 | 9 | 2 |
| | 1 | 10 | 7 | 6 |
| | 10 | 15 | 15 | 1 |
| | 14 | 11 | 10 | 13 |
| | 8 | 12 | 6 | 3 |
| | 11 | 4 | 11 | 15 |
| | 9 | 1 | 4 | 4 |

Nicholas County plot plan

| Block | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Treatment #* | 2 | 4 | 1 | 9 |
| | 15 | 3 | 8 | 3 |
| | 11 | 5 | 3 | 1 |
| | 3 | 15 | 5 | 12 |
| | 12 | 9 | 14 | 14 |
| | 14 | 11 | 9 | 11 |
| | 6 | 8 | 2 | 15 |
| | 13 | 13 | 7 | 10 |
| | 10 | 12 | 11 | 7 |
| | 5 | 7 | 15 | 2 |
| | 9 | 10 | 10 | 6 |
| | 7 | 1 | 12 | 8 |
| | 8 | 6 | 6 | 13 |
| | 1 | 2 | 4 | 5 |
| | 4 | 14 | 13 | 4 |

Rowan County plot plan

| Block | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Treatment #* | 15 | 12 | 3 | 2 |
| | 11 | 5 | 13 | 15 |
| | 14 | 10 | 1 | 9 |
| | 2 | 7 | 12 | 6 |
| | 12 | 3 | 8 | 13 |
| | 8 | 9 | 5 | 10 |
| | 7 | 13 | 14 | 11 |
| | 5 | 1 | 9 | 7 |
| | 3 | 15 | 6 | 12 |
| | 10 | 2 | 10 | 4 |
| | 13 | 4 | 4 | 1 |
| | 1 | 11 | 11 | 14 |
| | 6 | 14 | 7 | 3 |
| | 4 | 8 | 2 | 8 |
| | 9 | 6 | 15 | 5 |

* treatment numbers correspond to list of treatments in Appendix B

Appendix B. Actual mass of fertilizers applied by treatment number.

| Treatment # | N-source | Phosphorous | Potassium |
|---|---|---|---|
| | ----------------------g (fertilizer form)------------------- | | |
| 1 | - | - | - |
| 2 | 49.03 (46-0-0) | 5.45 (0-44-0) | 10.90 (0-0-60) |
| 3 | 98.06 (46-0-0) | 10.90 (0-44-0) | 21.80 (0-0-60) |
| 4 | 147.1 (46-0-0) | 16.43 (0-44-0) | 32.69 (0-0-60) |
| 5 | 196.12 (46-0-0) | 21.8 (0-44-0) | 43.60 (0-0-60) |
| 6 | 1,043 (poultry litter) | - | - |
| 7 | 2,086 (poultry litter) | - | - |
| 8 | 3,129 (poultry litter) | - | - |
| 9 | 5,987 (poultry litter) | - | - |
| 10 | 5,987 (poultry litter) | - | - |
| 11 | 340.5 (Louisville Green) | 18.16 (0-44-0) | 10.9 (0-0-60) |
| 12 | 681 (Louisville Green) | 36.32 (0-44-0) | 21.8 (0-0-60) |
| 13 | 1021.5 (Louisville Green) | 54.48 (0-44-0) | 32.86 (0-0-60) |
| 14 | 1362 (Louisville Green) | 72.64 (0-44-0) | 43.58 (0-0-60) |
| 15 | 1362 (Louisville Green) | 72.64 (0-44-0) | 43.58 (0-0-60) |

Appendix C: Soil sample results for each treatment replication at three experiment sites in 2010

| | Sample ID | KCL pH | Water pH | Buffer pH | P | K | CA | MG | ZN | SOM | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 cm sample depth | CCRI | 5.42 | 6.27 | 6.92 | 33 | 250 | 7203 | 389 | 2.8 | 3.59 | 0.172 |
| | CCR2 | 5.54 | 6.38 | 6.99 | 31 | 184 | 7338 | 348 | 2.4 | 3.3 | 0.159 |
| | CCR3 | 5.79 | 6.61 | 7.03 | 36 | 191 | 7787 | 348 | 2.7 | 3.66 | 0.173 |
| | CCR4 | 5.87 | 6.68 | 7.03 | 41 | 225 | 9724 | 424 | 2.7 | 3.77 | 0.172 |
| | Average | 5.66 | 6.49 | 6.99 | 35 | 213 | 8013 | 377.25 | 2.7 | 3.58 | 0.17 |
| | NCR1 | 4.07 | 5.04 | 6.13 | 20 | 274 | 3600 | 347 | 2 | 3.72 | 0.159 |
| | NCR2 | 3.83 | 4.83 | 6.16 | 22 | 246 | 3089 | 320 | 2 | 3.35 | 0.161 |
| | NCR3 | 3.89 | 4.88 | 6.08 | 22 | 259 | 2961 | 304 | 2.3 | 3.66 | 0.169 |
| | NCR4 | 3.49 | 4.52 | 5.82 | 14 | 203 | 2044 | 200 | 1.7 | 2.43 | 0.116 |
| | Average | 3.82 | 4.82 | 6.05 | 19.5 | 246 | 2923.5 | 292.75 | 2 | 3.29 | 0.15 |
| | RCR1 | 4.32 | 5.27 | 6.68 | 176 | 309 | 1081 | 102 | 1.6 | 1.75 | 0.076 |
| | RCR2 | 4.27 | 5.23 | 6.66 | 261 | 336 | 1132 | 98 | 1.5 | 1.62 | 0.075 |
| | RCR3 | 4.38 | 5.33 | 6.59 | 227 | 369 | 1128 | 100 | 1.5 | 1.89 | 0.08 |
| | RCR4 | 4.29 | 5.24 | 6.66 | 194 | 445 | 1053 | 91 | 1.3 | 1.74 | 0.078 |
| | Average | 4.32 | 5.27 | 6.65 | 214.5 | 365 | 1098.5 | 97.75 | 1.5 | 1.75 | 0.08 |

Appendix C continued

| | Sample ID | KCL pH | Water pH | Buffer pH | P | K | CA | MG | ZN | SOM | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-20 cm sample depth | CCR1 | 4.49 | 5.43 | 6.65 | 13 | 167 | 7772 | 477 | 0.9 | 1.14 | 0.047 |
| | CCR2 | 5.02 | 5.91 | 6.77 | 13 | 175 | 8343 | 480 | 0.9 | 1.15 | 0.055 |
| | CCR3 | 5.36 | 6.22 | 6.93 | 16 | 155 | 8157 | 412 | 1 | 1.34 | 0.056 |
| | CCR4 | 5.58 | 6.42 | 6.83 | 19 | 159 | 11849 | 455 | 1 | 1.19 | 0.051 |
| | Average | 5.11 | 5.99 | 6.8 | 15.25 | 164 | 9030.25 | 456 | 1.0 | 1.21 | 0.05 |
| | NCR1 | 3.96 | 4.94 | 6.15 | 12 | 175 | 4836 | 254 | 0.9 | 1.79 | 0.085 |
| | NCR2 | 3.65 | 4.66 | 5.8 | 14 | 169 | 2251 | 214 | 1.2 | 1.81 | 0.099 |
| | NCR3 | 3.55 | 4.57 | 5.71 | 22 | 192 | 2177 | 214 | 1.9 | 2.32 | 0.124 |
| | NCR4 | 3.44 | 4.47 | 5.28 | 16 | 171 | 2195 | 175 | 0.9 | 1.17 | 0.062 |
| | Average | 3.65 | 4.66 | 5.74 | 16 | 177 | 2864.75 | 214.25 | 1.2 | 1.77 | 0.09 |
| | RCR1 | 4.22 | 5.18 | 6.68 | 141 | 264 | 1094 | 82 | 0.9 | 1.29 | 0.064 |
| | RCR2 | 4.34 | 5.29 | 6.67 | 224 | 293 | 1118 | 89 | 1.1 | 1.39 | 0.067 |
| | RCR3 | 4.33 | 5.28 | 6.7 | 144 | 246 | 1264 | 83 | 0.8 | 1.46 | 0.067 |
| | RCR4 | 4.31 | 5.26 | 6.56 | 213 | 285 | 1076 | 72 | 1 | 1.57 | 0.076 |
| | Average | 4.3 | 5.25 | 6.65 | 180.5 | 272 | 1138 | 81.5 | 1.0 | 1.43 | 0.07 |

Appendix D: Soil sample results for each treatment replication at three experiment sites in 2011

| | Sample ID | KCL pH | Water pH | Buffer pH | P | K | CA | MG | ZN | SOM | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 cm sample depth | CCR1 | 5.55 | 6.39 | 7.02 | 41 | 236 | 6183 | 351 | 4.2 | 4.33 | 0.238 |
| | CCR2 | 5.59 | 6.43 | 7.11 | 40 | 235 | 6972 | 350 | 2.7 | 3.73 | 0.204 |
| | CCR3 | 5.84 | 6.65 | 7.08 | 50 | 230 | 7254 | 338 | 4.4 | 4.49 | 0.251 |
| | CCR4 | 5.77 | 6.59 | 7.14 | 38 | 224 | 7987 | 363 | 2.8 | 3.78 | 0.209 |
| | Average | 5.69 | 6.52 | 7.09 | 42.25 | 231.25 | 7099 | 350.5 | 3.53 | 4.08 | 0.23 |
| | NCR1 | 4.17 | 5.13 | 6.4 | 33 | 263 | 3249 | 332 | 3.1 | 4.42 | 0.214 |
| | NCR2 | 3.89 | 4.88 | 6.23 | 34 | 259 | 2703 | 293 | 3.4 | 3.54 | 0.202 |
| | NCR3 | 4.01 | 4.99 | 6.24 | 40 | 269 | 2716 | 295 | 3.2 | 4.23 | 0.221 |
| | NCR4 | 3.58 | 4.6 | 5.91 | 24 | 231 | 1782 | 194 | 2.2 | 2.48 | 0.142 |
| | Average | 3.91 | 4.9 | 6.2 | 32.75 | 255.5 | 2612.5 | 278.5 | 2.98 | 3.67 | 0.19 |
| | RCR1 | 4.47 | 5.41 | 6.74 | 179 | 405 | 1115 | 119 | 2.1 | 1.93 | 0.1 |
| | RCR2 | 4.52 | 5.45 | 6.76 | 297 | 489 | 1214 | 128 | 2.3 | 1.96 | 0.103 |
| | RCR3 | 4.51 | 5.44 | 6.74 | 230 | 376 | 1199 | 110 | 1.9 | 1.94 | 0.105 |
| | RCR4 | 4.4 | 5.34 | 6.69 | 215 | 447 | 1130 | 116 | 2 | 1.86 | 0.098 |
| | Average | 4.48 | 5.41 | 6.73 | 230.25 | 429.25 | 1164.5 | 118.25 | 2.08 | 1.92 | 0.1 |

Appendix D continued

| | Sample ID | KCL pH | Water pH | Buffer pH | P | K | CA | MG | ZN | SOM | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-20 cm sample depth | CCR1 | 5.11 | 5.99 | 6.9 | 24 | 221 | 7055 | 420 | 1.7 | 1.7 | 0.102 |
| | CCR2 | 5.11 | 5.99 | 6.92 | 23 | 209 | 7332 | 419 | 1.2 | 1.46 | 0.077 |
| | CCR3 | 5.44 | 6.29 | 6.96 | 24 | 204 | 7729 | 395 | 1.4 | 1.48 | 0.079 |
| | CCR4 | 5.6 | 6.44 | 7.07 | 27 | 187 | 8008 | 352 | 1.3 | 1.93 | 0.102 |
| | Average | 5.32 | 6.18 | 6.96 | 24.5 | 205.25 | 7531 | 396.5 | 1.4 | 1.64 | 0.09 |
| | NCR1 | 3.71 | 4.72 | 5.98 | 14 | 204 | 2710 | 247 | 1.2 | 1.86 | 0.114 |
| | NCR2 | 3.61 | 4.63 | 5.95 | 15 | 192 | 2306 | 236 | 1.3 | 2.08 | 0.129 |
| | NCR3 | 3.64 | 4.65 | 5.91 | 18 | 223 | 2281 | 241 | 1.6 | 2.44 | 0.136 |
| | NCR4 | 3.42 | 4.45 | 5.68 | 20 | 175 | 1802 | 160 | 1.5 | 1.63 | 0.096 |
| | Average | 3.6 | 4.61 | 5.88 | 16.75 | 198.5 | 2274.75 | 221 | 1.4 | 2 | 0.12 |
| | RCR1 | 4.17 | 5.13 | 6.64 | 188 | 262 | 1014 | 78 | 0.9 | 1.46 | 0.076 |
| | RCR2 | 4.27 | 5.23 | 6.67 | 240 | 322 | 1136 | 89 | 1.2 | 1.43 | 0.079 |
| | RCR3 | 4.41 | 5.35 | 6.74 | 179 | 252 | 1245 | 77 | 0.8 | 1.55 | 0.091 |
| | RCR4 | 4.23 | 5.19 | 6.62 | 203 | 295 | 1056 | 75 | 0.9 | 1.63 | 0.088 |
| | Average | 4.27 | 5.23 | 6.67 | 202.5 | 282.75 | 1112.75 | 79.75 | 0.95 | 1.52 | 0.08 |

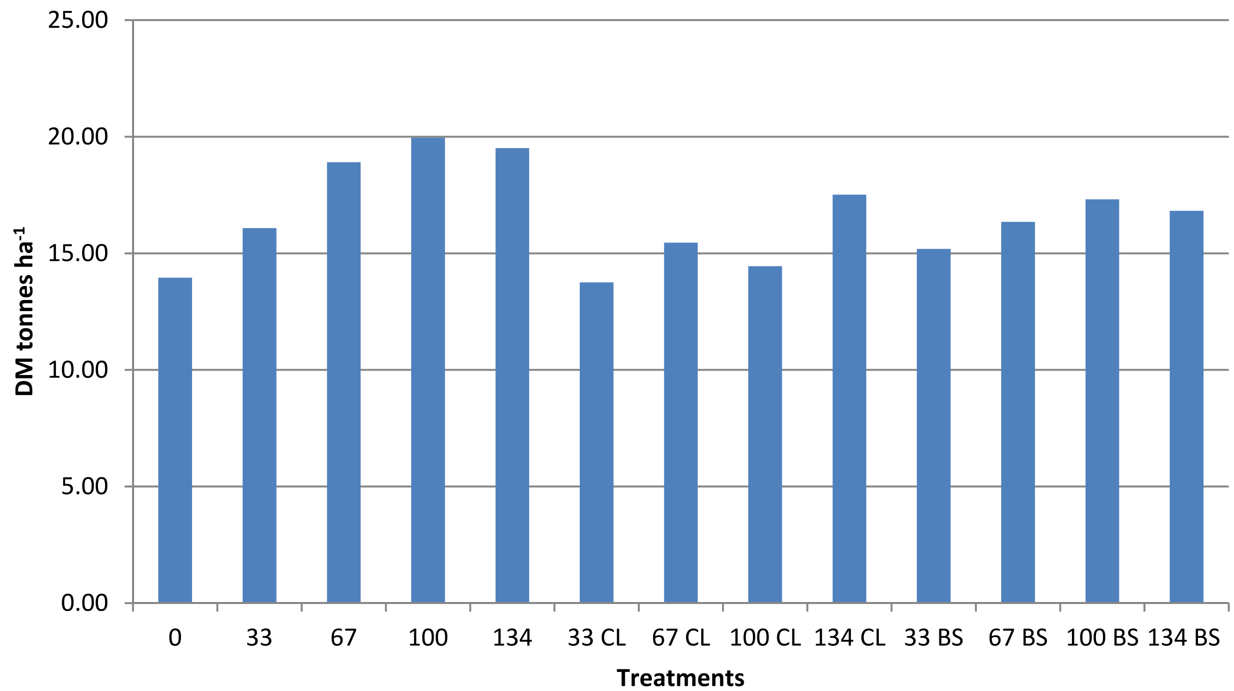
Appendix E: Soil sample results for each treatment replication at three experiment sites in 2012

| | Sample ID | KCL pH | Water pH | Buffer pH | P | K | CA | MG | ZN | SOM | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 cm sample depth | CCR1 | 5.49 | 6.34 | 6.96 | 34 | 228 | 6856 | 371 | 3 | 3.51 | 0.19 |
| | CCR2 | 5.58 | 6.42 | -9 | 41 | 221 | 7104 | 384 | 3.5 | 4.22 | 0.22 |
| | CCR3 | 5.73 | 6.55 | -9 | 41 | 208 | 7333 | 353 | 3.3 | 3.96 | 0.2 |
| | CCR4 | 5.64 | 6.47 | -9 | 34 | 203 | 9212 | 432 | 2.5 | 3.04 | 0.15 |
| | Average | 5.61 | 6.45 | -5.01 | 37.5 | 215 | 7626.25 | 385 | 3.08 | 3.68 | 0.19 |
| | NCR1 | 4.03 | 5.01 | 6.28 | 19 | 262 | 3353 | 336 | 2.5 | 3.22 | 0.17 |
| | NCR2 | 4.04 | 5.02 | 6.28 | 25 | 266 | 3021 | 320 | 3.3 | 3.43 | 0.18 |
| | NCR3 | 3.92 | 4.91 | 6.3 | 31 | 270 | 2578 | 283 | 4 | 3.33 | 0.18 |
| | NCR4 | 3.73 | 4.73 | 5.9 | 18 | 216 | 1653 | 191 | 2.4 | 2.28 | 0.13 |
| | Average | 3.93 | 4.92 | 6.19 | 23.25 | 253.5 | 2651.25 | 282.5 | 3.05 | 3.06 | 0.17 |
| | RCR1 | 4.47 | 5.41 | 6.85 | 141 | 301 | 1034 | 117 | 2.9 | 1.87 | 0.1 |
| | RCR2 | 4.51 | 5.44 | 6.78 | 251 | 388 | 1096 | 116 | 2.6 | 1.74 | 0.09 |
| | RCR3 | 4.73 | 5.64 | 6.89 | 186 | 385 | 1202 | 131 | 2.9 | 2.1 | 0.1 |
| | RCR4 | 4.54 | 5.47 | 6.77 | 172 | 374 | 1049 | 119 | 3.4 | 1.92 | 0.1 |
| | Average | 4.56 | 5.49 | 6.82 | 187.5 | 362 | 1095.25 | 120.75 | 2.95 | 1.91 | 0.1 |

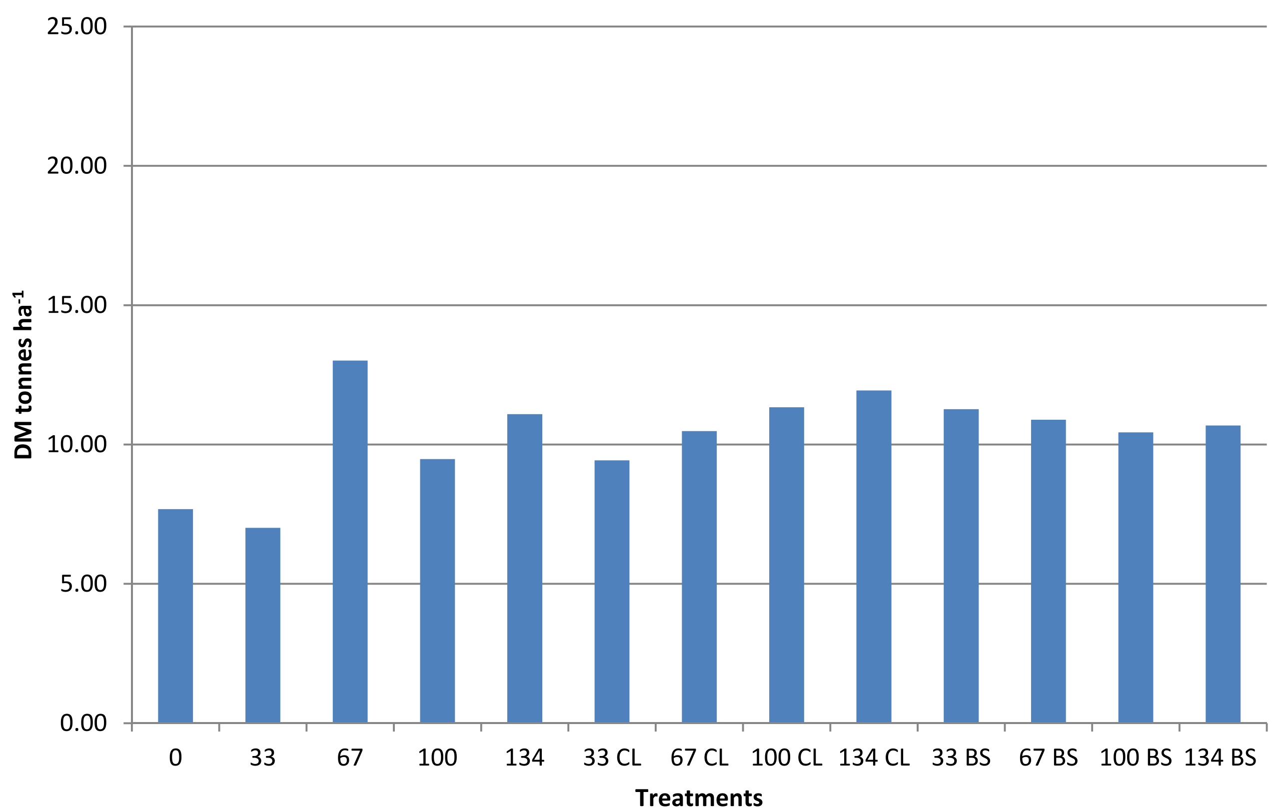
Appendix E continued

| | Sample ID | KCL pH | Water pH | Buffer pH | P | K | CA | MG | ZN | SOM | TN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-20 cm sample depth | CCR1 | 4.98 | 5.87 | 6.79 | 15 | 197 | 7670 | 457 | 1.4 | 1.49 | 0.09 |
| | CCR2 | 4.99 | 5.88 | 6.87 | 20 | 193 | 7168 | 401 | 1.4 | 1.6 | 0.08 |
| | CCR3 | 5.6 | 6.44 | -9 | 22 | 197 | 7888 | 414 | 1.7 | 1.49 | 0.09 |
| | CCR4 | 5.4 | 6.25 | 6.97 | 22 | 206 | 9115 | 489 | 1.3 | 1.65 | 0.1 |
| | Average | 5.24 | 6.11 | 2.91 | 19.75 | 198.25 | 7960.25 | 440.25 | 1.45 | 1.56 | 0.09 |
| | NCR1 | 3.75 | 4.75 | 6.01 | 10 | 180 | 2631 | 241 | 1.5 | 1.82 | 0.11 |
| | NCR2 | 3.67 | 4.68 | 5.95 | 12 | 165 | 2107 | 215 | 1.4 | 1.91 | 0.12 |
| | NCR3 | 3.74 | 4.74 | 5.95 | 17 | 176 | 1862 | 193 | 2.8 | 2.08 | 0.13 |
| | NCR4 | 3.48 | 4.51 | 5.44 | 11 | 152 | 1751 | 170 | 2 | 1.15 | 0.08 |
| | Average | 3.66 | 4.67 | 5.84 | 12.5 | 168.25 | 2087.75 | 204.75 | 1.93 | 1.74 | 0.11 |
| | RCR1 | 4.35 | 5.3 | 6.73 | 121 | 221 | 1057 | 90 | 1.3 | 1.23 | 0.07 |
| | RCR2 | 4.29 | 5.24 | 6.73 | 228 | 268 | 1081 | 88 | 1.7 | 1.37 | 0.08 |
| | RCR3 | 4.34 | 5.29 | 6.66 | 203 | 241 | 1101 | 83 | 1.1 | 1.66 | 0.1 |
| | RCR4 | 4.21 | 5.17 | 6.65 | 190 | 255 | 980 | 78 | 1.1 | 1.47 | 0.08 |
| | Average | 4.3 | 5.25 | 6.69 | 185.5 | 246.25 | 1054.75 | 84.75 | 1.3 | 1.43 | 0.08 |

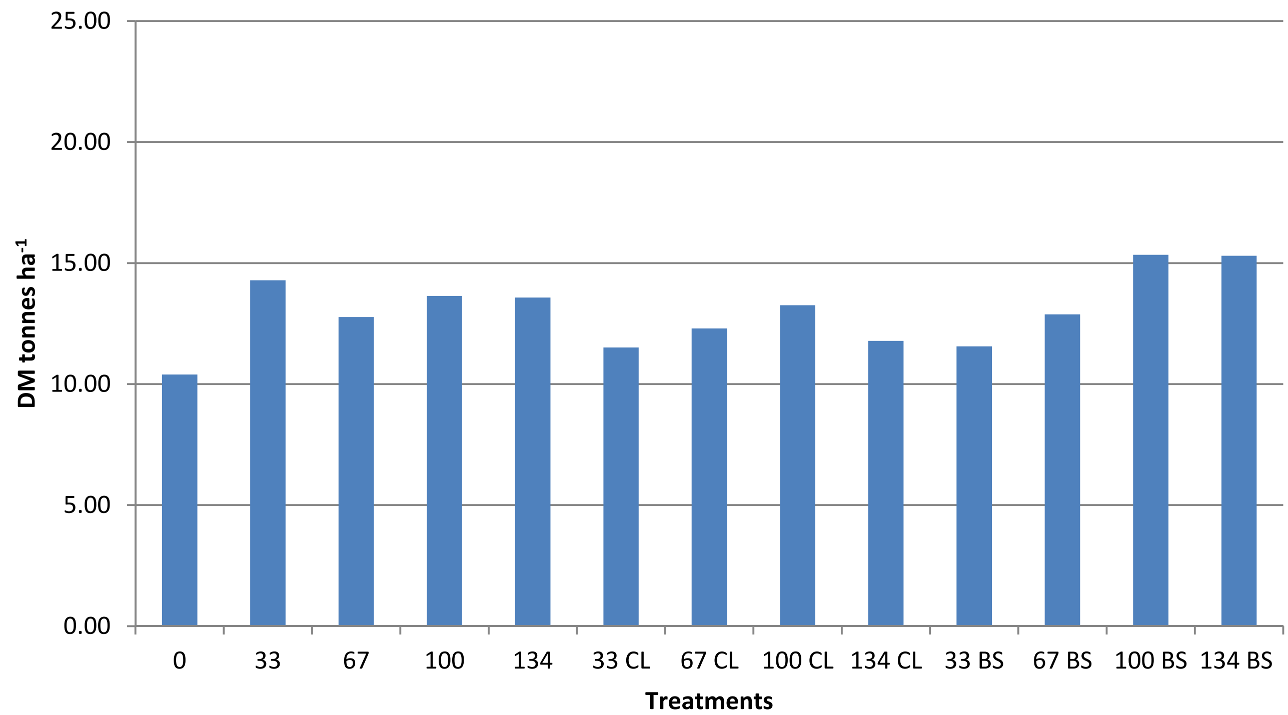
Appendix F: Campbell County mean dry matter in DM tonnes $ha^{-1}$.



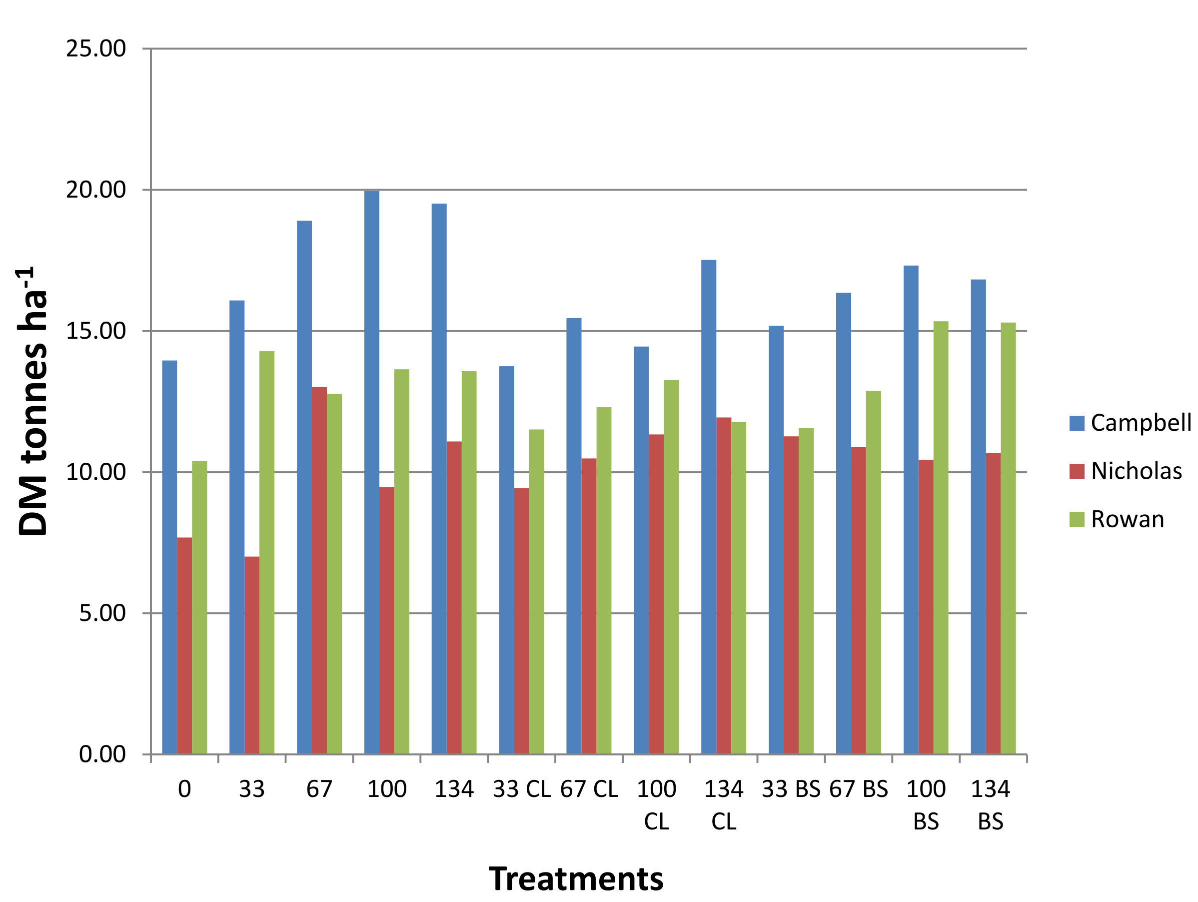
Appendix G: Nicholas County mean dry matter in DM tonnes $ha^{-1}$.

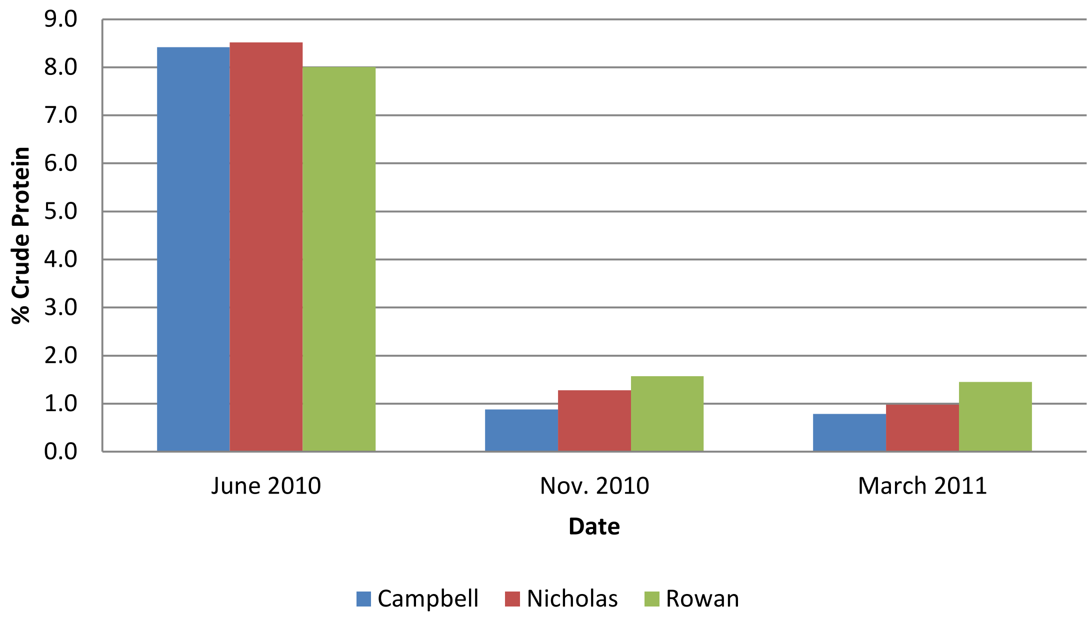


Appendix H: Rowan County mean dry matter in DM tonnes $ha^{-1}$.

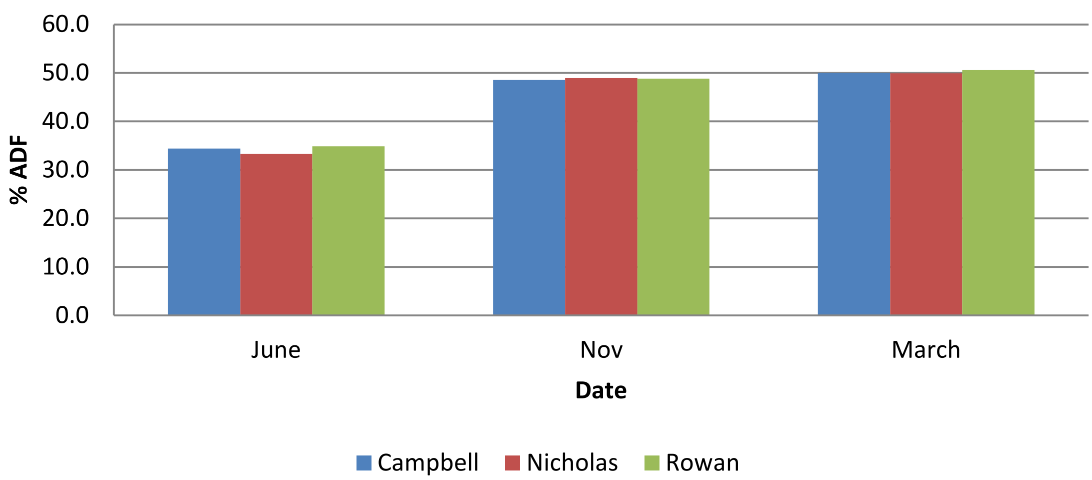


Appendix I: Mean Dry Matter (tonnes/$ha^{-1}$) for each treatment at three experiment sites

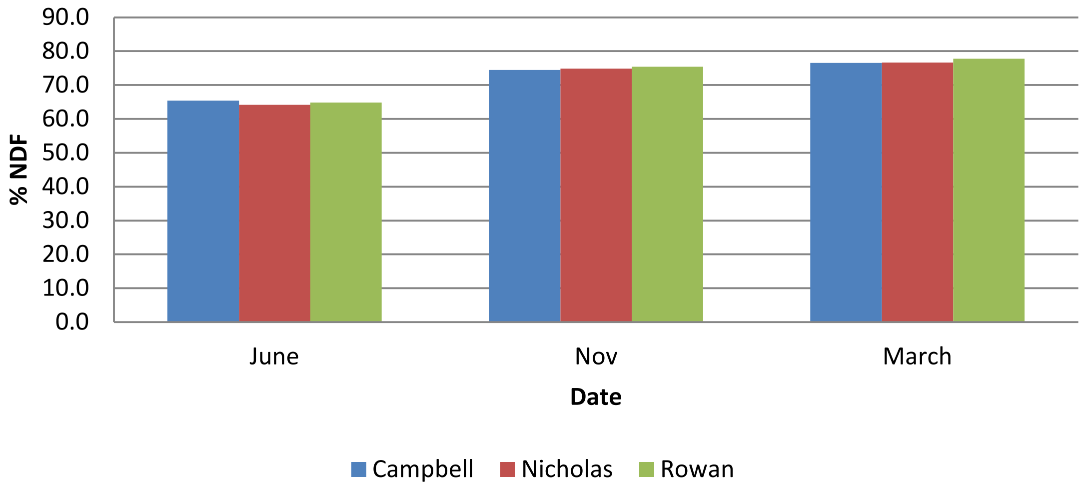





Appendix J: CP mean for two years




Appendix K: ADF mean for two years



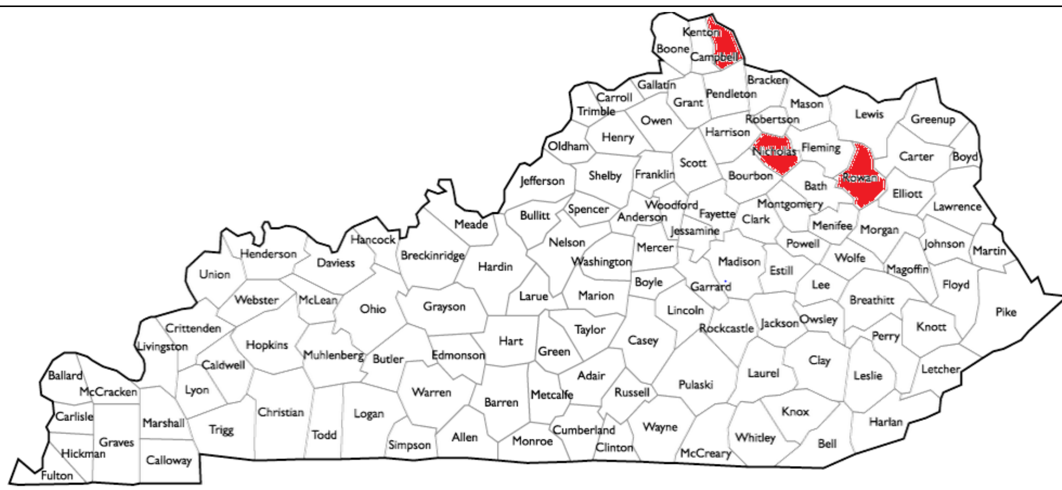

Appendix L: NDF mean for two years

Appendix M: Precipitation and temperature for each county for 2010, 2011 and average.

| | Precipitation | | | Temperature | | |
|---|---|---|---|---|---|---|
| | Average | 2010 | 2011 | Average | 2010 | 2011 |
| | ------------(cm)------------ | | | -------------$^{o}$C------------ | | |
| Campbell | 111.78 | 105.7 | 165.38 | 12.33 | 12.94 | 13.05 |
| Nicholas* | 109.83 | 71.63 | 151.81 | 12.61 | 12.16 | 13.05 |
| Rowan | 117.35 | 118.52 | 161.82 | 12.22 | 12.28 | 12.89 |

* Contains data from Nicholas and Harrison County due to missing data

Appendix N: Ariel photographs of each harvest site in Campbell (upper left), Nicholas (upper right) and Rowan (lower) Counties.




Appendix O: Map of Kentucky Counties. Counties where switchgrass was harvested are marked in red.

## References


Adler, P.R., M.A. Sanderson, A.A. Boateng, P.J. Weimer and H.-J.G. Jung. 2006. Biomass yield and biofuel quality of switchgrass harvested in fall or spring. Agron. J. 98: 1518-1525. doi:10.2134/agronj2005.0351.

American Meat Institute. 2009. U.S. meat and poultry production and consumption: An overview. Fact Sheet. Washington, D.C. www.meatAMI.com.

Ball, D.M., C.S. Hoveland and G.D. Lacefield. 2007. Southern Forages, Fourth Edition International Plant Nutrition Institure (IPNI), Norcross, Georgia.

Boddiger, D. 2007. Boosting biofuel crops could threaten food security. The Lancet 370: 923-924.

Burns, J.C., R.D. Mochrie and D.H. Timothy. 1984. Steer performance from two perennial pennisetum species, switchgrass, and a fescue—'coastal' bermudagrass system. Agron. J. 76: 795-800. doi:10.2134/agronj1984.00021962007600050020x.

Burvall, J. 1997. Influence of harvest time and soil type on fuel quality in reed canary grass (*Phalaris arundinacea* L.). Biomass and Bioenergy 12: 149-154. doi:http://dx.doi.org/10.1016/S0961-9534(96)00064-5.

Casler, M.D., K.P. Vogel, C.M. Taliaferro and R.L. Wynia. 2004. Latitudinal adaptation of switchgrass populations. Crop Sci. 44: 293-303. doi:10.2135/cropsci2004.2930.

Cassida, K.A., J.P. Muir, M.A. Hussey, J.C. Read, B.C. Venuto and W.R. Ocumpaugh. 2005. Biofuel component concentrations and yields of switchgrass in south central U.S. environments Crop Sci. 45: 682-692. doi:10.2135/cropsci2005.0682.

Chastain, J.P., J.J. Camberato and P. Skewes. 2003. Poultry manure production and nutrient content. Confined Animal Manure Managers Certification Program Manual B. Poultry Version. Clemson University Cooperative Extension Service. p. 3-b-1-3-b-17.

Debolt, S., J.E. Campbell, S.R. Smith, M. Montross and J. Stork. 2009. Life cycle assessment of native plants and marginal lands for bioenergy agriculture in Kentucky as a model for south-eastern USA. GCB Bioenergy 1: 308-316. doi:10.1111/j.1757-1707.2009.01023.x.

Eghball, B., B.J. Wienhold, J.E. Gilley and R.A. Eigenberg. 2002. Mineralization of manure nutrients. Journal of Soil and Water Conservation 57: 470-473.

Energy Information Administration. 2012. Trends in renewable energy consumption and electricity 2010. http://www.eia.gov/renewable/annual/trends/.

Espinoza, L., N. Slaton, M. Mozaffari and M. Daniels. 2005. The use of poultry litter in row crops. University of Arizona Cooperative Extension Service. FSA2147-2M-4-05N.

Fales, S., J. Hess and W. Wilhelm. 2007. Convergence of agriculture and energy: Poducing cellulosic biomass for biofuels. Council for Agricultural Science and Technology (CAST). CAST Commentary QTA2007-2. CAST, Ames, Iowa 15: 10-11.

Fike, J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green Jr, M. Rasnake and J.H. Reynolds. 2006a. Long-term yield potential of switchgrass-for-biofuel systems. Biomass and Bioenergy 30: 198-206. doi:http://dx.doi.org/10.1016/j.biombioe.2005.10.006.

Fike, J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green Jr, M. Rasnake and J.H. Reynolds. 2006b. Switchgrass production for the upper southeastern USA: Influence of cultivar and cutting frequency on biomass yields. Biomass and Bioenergy 30: 207-213. doi:http://dx.doi.org/10.1016/j.biombioe.2005.10.008.

Gaskin, J.W., R.B. Brobst, W.P. Miller and E.W. Tollner. 2003. Long-term biosolids application effects on metal concentrations in soil and bermudagrass forage. J. Environ. Qual. 32: 146-152. doi:10.2134/jeq2003.1460.

Gobler, C.J., M.J. Renaghan and N.J. Buck. 2002. Impacts of nutrients and grazing mortality on the abundance of *Aureococcus anophagefferens* during a New York brown tide bloom. Limnology and Oceanography 47: 129-141.

Halich, G. and S.R. Smith. 2010. Profitability of switchgrass compared to hay. UK Agric. Exper. Station Publication, http://www.uky.edu/Ag/Forage/Forage%20Decision%20Aids.htm.

Hoveland, C.S., S.P. Schmidt, C.C. King, J.W. Odom, E.M. Clark, J.A. McGuire, L.A. Smith, H.W. Grimes and J.L. Holliman. 1983. Steer performance and association of *Acremonium coenophialum* fungal endophyte on tall fescue pasture. Agron. J. 75: 821-824. doi:10.2134/agronj1983.00021962007500050021x.

Keyser, P., G. Bates, J. Waller, C. Harper and E. Doxon. 2012a. Grazing native warm-season grasses in the mid-south. University of Tennessee Extension Publication SP731-C.

Keyser, P., G. Bates, J. Waller, C. Harper and E. Doxon. 2012b. Producing hay from native warm-season grasses in the mid-south. University of Tennessee Extension Publication SP731-D.

Kresse, E.J. and L.M. Naylor. 1987. Municipal sewage sludge: A 7 year research effort. Cooperative Extension Association of Oneida County, New York State.

Lemus, R., D. Parrish and O. Abaye. 2008. Nitrogen-use dynamics in switchgrass grown for biomass. BioEnergy Research 1: 153-162. doi:10.1007/s12155-008-9014-x.

Lewandowski, I. and A. Kicherer. 1997. Combustion quality of biomass: Practical relevance and experiments to modify the biomass quality of *Miscanthus x giganteus*. European Journal of Agronomy 6: 163-177. doi:http://dx.doi.org/10.1016/S1161-0301(96)02044-8.

McLaughlin, S.B. and M.E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy 14: 317-324. doi:http://dx.doi.org/10.1016/S0961-9534(97)10066-6.

Moore, K.J., S.L. Fales and E.A. Heaton. 2008. Biorenewable energy: New opportunities for grassland agriculture. Guangdong People's Publishing House, Guangzhou. p. 1023-1030.

Moser, L.E. and K.P. Vogel. 1995. Switchgrass, big bluestem and indiangrass. In: R. F. Barnes, D. A. Miller and C. J. Nelson, editors, Forages: An Introduction to Grassland Agriculture, Fifth Edition. Iowa State University Press, Ames, Iowa.

NRC. 2000. Nutrient requirements of beef cattle. 7th ed. National Academy Press. ISBN 0-309-06934-3.

NRCS. 1995. Animal manure management. USDA-NRCS Bulletin RCA Issue Breif # 7. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/?&cid=nrcs143_014211.

Obernberger, I., F. Biedermann, W. Widmann and R. Riedl. 1997. Concentrations of inorganic elements in biomass fuels and recovery in the different ash fractions. Biomass and Bioenergy 12: 211-224. doi:http://dx.doi.org/10.1016/S0961-9534(96)00051-7.

Olanders, B. and B.-M. Steenari. 1995. Characterization of ashes from wood and straw. Biomass and Bioenergy 8: 105-115. doi:http://dx.doi.org/10.1016/0961-9534(95)00004-Q.

Olson, G.L., S.R. Smith, J.C. Spitaleria, T.D. Phillips and G.D. Lacefield. 2009. 2009 Native warm-season perennial grasses report. UK Agric. Exper. Station Publication PR-599.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. DTIC Document.

Rasnake, M. 1996. Broiler litter production in Kentucky and potential use as a nutrient source. Publication AGR-168. Univ. Kentucky Coop. Extension Service, Lexington, KY.

Robuck, T. and S.R. Smith. 2014. Quantifying Cl and K residues in harvested switchgrass with varied fertilizer and maturity dates. In Proceedings of the American Forage and Grassland Council Annual Meeting. Memphis, TN. 12-14 January 2014.

Sanderson, M. and P. Adler. 2008. Perennial forages as second generation bioenergy crops. International Journal of Molecular Sciences 9: 768-788.

Schwab, G.J. and L.W. Murdock. 2010. Nitrogen transformation inhibitors and controlled release urea. UK Agric. Exper. Station Publication AGR-185.

Sena, K., D. Davis and S.R. Smith. 2011. Determination of switchgrass growth curves. American Forage and Grassland Council Annual Meeting 12-15 June 2011. Louisville, KY.

Smith, S.R., T. Keene, A. Probst and M. Montross. 2008. Biomass production on farms in the eastern United States. In Proceedings of the Joint IGC/IRC International Meetings. Hohhot, Inner Mongolia, China. 29- June-5 July 2008 China Grassland Society, Bejing, China.

Solow, J.L., R.A. Ney, M.S. Balch, J.L. Schnoor and O.J. Sivan. 2005. Estimating the economic impact of substituting switchgrass for coal for electric generation in iowa. University of Iowa, Center for Global and Reginal Environmental Research.

Tillman, D.A. 2000. Biomass cofiring: The technology, the experience, the combustion consequences. Biomass and Bioenergy 19: 365-384. doi:http://dx.doi.org/10.1016/S0961-9534(00)00049-0.

UN. 2009. World population to exceed 9 billion by 2050: In: P. Devision/DESA. http://www.un.org/esa/population/publications/wpp2008/pressrelease.pdf.

USA.com. 2014. USA.com. http://www.usa.com/morehead-ky-weather.htm.

USDA. 2012. Poultry - production and value 2011 summary. USDA-NASS. http://webcache.googleusercontent.com/search?q=cache:W9cVwrcK3wgJ:usda01.library.cornell.edu/usda/nass/PoulProdVa//2010s/2012/PoulProdVa-04-26-2012.pdf+&cd=2&hl=en&ct=clnk&gl=us&client=firefox-a.

Vogel, K., B. Dien, H. Jung, M. Casler, S. Masterson and R. Mitchell. 2011. Quantifying actual and theoretical ethanol yields for switchgrass strains using NIRS analyses. BioEnergy Research 4: 96-110. doi:10.1007/s12155-010-9104-4.

Vogel, K.P. 1996. Energy production from forages (or American agriculture—back to the future). Journal of Soil and Water Conservation 51: 137-139.

Vogel, K.P., J.J. Brejda, D.T. Walters and D. Buxton, R. 2002. Switchgrass biomass production in the midwest USA: Harvest and nitrogen management. Agronomy Journal 94: 413-420.

Vogel, K.P., J.F. Pedersen, S.D. Masterson and J.J. Toy. 1999. Evaluation of a filter bag system for NDF, ADF, and IVDMD forage analysis. Crop Sci. 39: 276-279.

Walker, J., L. Knight and L. Stein. 1994. Land application of biosolids. Guide to the EPA Part 503 Biosolids Rule. p. 25-56.

Weaver, J.E. 1968. Prairie Plants and Their Environment. A Fifty-Year Study in the Midwest, University of Nebraska Press. Lincoln, NE.

Xia, Y., E. Greissworth, C. Mucci, M.A. Williams and S. De Bolt. 2013. Characterization of culturable bacterial endophytes of switchgrass (*Panicum virgatum* L.) and their capacity to influence plant growth. GCB Bioenergy 5: 674-682. doi:10.1111/j.1757-1707.2012.01208.x.

Zhang, H., D.W. Hamilton and J. Payne. 2013. Using poultry litter as fertilizer. Oklahoma State University Cooperative Extension Fact Sheet PSS-2246.

Zheng, Y., P.A. Jensen, A.D. Jensen, B. Sander and H. Junker. 2007. Ash transformation during co-firing coal and straw. Fuel 86: 1008-1020.

## Vita

Thomas (Tom) C. Keene is a native of Washington County, Kentucky. After graduating from Bethlehem High School in Bardstown KY in 1975, Tom attended the University of Kentucky College of Agriculture. He graduated in 1979 with a Bachelor of Science Degree in Production Agriculture. Upon graduation, Tom was employed by Spendthrift Farm as Agricultural Manager until 1985 when he assumed the same position at North Ridge Farm. In 1989, he began working for Creech, Inc., a hay and straw broker, as a sourcing agent, procuring hay and straw from around the United States and delivering it worldwide. In 2005, Tom came back to the University of Kentucky to assume a newly created position as “Hay Marketing Specialist”. Over the next 3 years, he also took on the added roles of “Horse Pasture Evaluation Coordinator” and Biomass Specialist. He is currently Agronomy Specialist within the Plant and Soil Science Department in the College of Agriculture at the University of Kentucky with responsibility on main campus and at the Robinson Center for Appalachian Resource Sustainability in Quicksand, KY in Breathitt County.