Development of Fertilizer Recommendations for Native Biofuel Crops and Nutrient Release from Cattle Feces

by

Richard Zachary Brown

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 13, 2010

Keywords: nutrient management, soil fertility,
biofuels, fertilizer, cattle feces

Approved by

C. Wesley Wood, Co-Chair, Professor of Agronomy and Soils
Keith A. Cummins, Co-Chair, Professor of Animal Science
Edzard van Santen, Professor of Agronomy and Soils
Charles C. Mitchell, Professor of Agronomy and Soils
David I. Bransby, Professor of Agronomy and Soils

Abstract

Plant biomass is a viable raw material for renewable energy production. The use of perennial grasses is a possible option, however information on their nutrient management in the southeastern U.S. is deficient. The objective of this study was to determine the response of switchgrass (*Panicum virgatum*) and big bluestem (*Andropogon gerardii*) to different levels of nitrogen (N), phosphorus (P), and potassium (K) fertilization.

The study was conducted during 2007-2009 near Brewton, Alabama, USA on the 'Rate of NPK' plots (circa 1954) that have been maintained at various levels of soil fertility. Plots were planted in 2007 and allowed one year to establish a stand before the experiment began. In the spring of each year, varying rates of N, P, and K were applied to both grasses. Nutrient concentration data was collected throughout the growing season by sampling plant tissue, and dry matter yield (DMY) was obtained by a once-a-year harvest in November of both years. Dry matter yield showed a diminishing returns response to N fertilization while no response was observed for P or K. Maximum agronomic yield (MAY) was attained at 155 and 161 kg N ha^{-1} for big bluestem and switchgrass, respectively. Economic analysis showed net return increased with N fertilization at high and low biomass prices for switchgrass, while an increase was only observed only at the high biomass price for big bluestem. Nutrient removal for all elements in both species increased with rate of fertilizer applied. Apparent N recovery (ANR) was calculated and switchgrass displayed a diminishing return response ,while responses for big bluestem varied. Since yield showed no response to P or K fertilization, nutrient concentration data were analyzed for N treatments only, and decreased across the growing season. Concentration of N varied between 0 and 158 kg N ha^{-1} indicating that plant tissue sampling, when taken early enough in the growing season, can detect N deficiency.

Cattle (*Bos taurus)* manure has been historically used as a soil amendment to increase fertility, but information on the impacts of cattle defecation in pastures on soil fertility is lacking. A study was conducted in Auburn, AL from 2008 to 2009 to measure nutrient release from dairy feces. Feces and soil samples were collected throughout two seasons in the winter of 2008-2009 and the summer of 2009. Results indicated that N, P, K, calcium (Ca), magnesium (Mg), copper (Cu), and zinc (Zn) were released from feces at different rates throughout the experiment. Season affected the release rate of all nutrients. Feces retained small amounts of each nutrient after an initial decline. An increase in soil nutrients across time was observed for all elements except Cu. Rates of nutrient response varied by element and was affected by season. The results suggested that feces can have an effect on the soil nutrient status.

Acknowledgements

The author would like to express his appreciation to his major professor, Dr. Wes Wood, for his support and guidance throughout this study. He would also like to extend thanks to the members of his committee: Dr. Keith A. Cummins, Dr. Edzard van Santen, Dr. Charles C. Mitchell, and Dr. David I Bransby for their valuable knowledge and direction. The author also would like to thank Brenda Wood, Susan Sladden, and the student workers for their aid in the laboratory and field, which was essential in completion of the research. He would also like to acknowledge the personnel at the Brewton Agricultural Research Unit for their time and assistance. The author extends appreciation to the Agronomy and Soils Department for their assistance and the opportunity to continue his education. Last but not least he would like to extend his deepest gratitude to his family and friends for the continuous guidance and support throughout this endeavor.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AL	Alabama
ANR	Apparent nitrogen recovery
C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
CO_2	Carbon dioxide
CRP	Conservation Reserve Program
Cu	Copper
cm	Centimeter
DAA	Days after application
DMY	Dry matter yield
EC	Electrical conductivity
g	Gram
GHG	Greenhouse gas
ha	Hectare
ICAP	Inductively coupled argon plasma spectroscopy
IPCC	Intergovernmental Panel on Climate Change
IU	International Unit
K	Potassium

kg	Kilogram
L	Liter
m	Meter
MAY	Maximum agronomic yield
MEY	Maximum economic yield
MFE	Mineral fertilizer equivalent
Mg	Magnesium
Mg	Megagram
mg	Milligram
mm	Millimeter
N	Nitrogen
NR	Nitrogen removed
P	Phosphorus
USDA	United States Department of Agriculture
Zn	Zinc

I. Literature Review

Biofuel Crop Fertility Recommendations

Renewable energy sources have been of recent interest owing to growing concerns about sustainability and security of fossils fuels, and the greenhouse effect. The need for energy sources that can compete with oil has led to research in other areas. Environmental concerns associated with carbon dioxide (CO_2) emissions and their role in global climate change has spurred the search for fuels that could help mitigate environmental impacts. Burning petroleum based fuels emits fossil carbon (C) that adds to the atmospheric load of CO_2, while renewable energy sources either do not use C as an energy source or recycle C already present on the earth's surface.

The use of renewable fuels has continued to grow. In 2004, the total primary energy consumption from renewable sources was 6.2 percent of the total energy consumption in the U.S., and by 2009 consumption had risen to 8.2 percent (US DOE-EIA, 2010). Advanced technologies that derive energy from solar, wind, and biomass showed large increases. In 2008, biomass surpassed hydroelectric power to become the largest source of renewable energy. The U.S. Department of Energy-Energy Information Administration reported that consumption of energy from biomass increased by 1.1 percent of total U.S. consumption between 2004 and 2009 from 3.0 to 4.1 percent of the total energy consumption (US DOE-EIA, 2010). These statistics include ethanol, which is the primary liquid alternative fuel used in the U.S.

The U.S. has set forth a goal for biomass to supply five percent of America's power, 20 percent of its transportation fuel, and 25 percent of its chemicals by 2030 (Perlack et al., 2005). In order to reach this goal, a supply of 907 million Mg of biomass will be required annually by 2030 (Sanderson et al., 2006). Additionally, Section 202 of the Energy Independence and Security Act of 2007 set forth the provision that 60.5 billion liters of cellulosic biofuels be produced annually by 2022. Cellulosic biofuels are produced by converting plant sugars into liquid fuels such as ethanol. The ability to increase current biomass production will be pivotal in success of reaching any goals for biomass energy production.

Biomass energy has potential to alleviate some of the impact greenhouse gases have on the environment. In 2001, the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that greenhouse gas emissions caused by human influences have had a distinguishable impact on Earth's climate (IPCC, 2001). Many of our current energy sources, including petroleum and coal, release greenhouse gases such as CO_2 into the atmosphere. This creates a negative C balance that takes buried C and transfers it to the atmosphere. Biomass energy could help mitigate the amount of C emitted into the atmosphere by burning underground energy sources. Plants absorb CO_2 from the atmosphere and turn that C into biomass, which then can be used to create energy. Theoretically this cycle could be C neutral. However, this does not take into account CO_2 emitted in association with establishment, management, and production of biomass.

Biomass for energy production can be made available from many sources. Forestlands and agricultural lands are two possible sources that could produce a large amount of biomass (Perlack et al., 2005). In the U.S., forestlands and agricultural lands are projected to have the ability to produce 368 million dry tons and 1 billion dry tons, respectively (Perlack et al., 2005). Dedicated bioenergy crops associated with agriculture and forestry production could displace 30% of the current petroleum consumption (Perlack et al., 2005). Of course, not all biomass could be utilized, but this estimate gives a perspective to the total amount that might be available. Biomass energy is particularly important because it is the only current source of renewable liquid transportation fuel (Perlack et al., 2005). Since transportation accounted for 29% of our total end-use energy consumption in 2009, using renewable biomass energy in this sector could reduce the use of fossil fuels substantially (US DOE-EIA, 2010).

Perennial grasses have been under investigation recently as a potential source of biomass for energy production (Sanderson and Adler, 2008; McLaughlin and Walsh, 1998). Perennial grasses have been used historically as forage to feed livestock and work animals, but new goals are being developed for their use as bioenergy crops (Vogel 1996). Compared to other terrestrial biomass sources, perennial grasses are more efficient since they require less management and produce more energy (Sanderson and Adler, 2008). They also reduce GHG emissions by having decreased energy requirements in their management, production, and utilization (Adler et al, 2007). Their potential for bioenergy is based on their ability to produce large amounts of biomass that can be turned into energy through various conversion technologies. Technologies to convert biomass to energy utilize plant sugars or simple combustion of plant biomass

(Sanderson et al., 2006; Giampietro et al., 1997). In order for biomass to be employed as transportation fuel, the conversion of plant sugars into ethanol can be seen as the most useful strategy (Sanderson et al. 2006).

Much concern has been given to the amount of land used in food production that would be displaced for the use of dedicated bioenergy crops. Conversion of land used for grain and food production into land used for bioenergy production should be avoided. Grassland resources such as land in the Conservation Reserve Program (CRP) are a possible source of large amounts of biomass (Perlack et al., 2005). Since the primary goal of CRP lands is to promote conservation through reducing soil erosion, improving water quality, and creating habitat for wildlife, management practices would be needed that are consistent with these goals. In the Northern Great Plains trials have been done on the management of perennial grasses used for biofuels and practices have been developed that would allow for production while preserving the integrity of the CRP program (Mulkey et al., 2006). Perennial grasses produce well on marginal or arable land that is not suited for other crop production (Parrish and Fike, 2005). This means areas not suited for food and grain production could be utilized to grow perennial grasses for bioenergy.

Big bluestem (*Andropogon gerardii*) and switchgrass (*Panicum virgatum*) are two perennial grass species that could be used as bioenergy crops. Research has been conducted on switchgrass for bioenergy, however, little has been done to understand how big bluestem can be utilized as a bioenergy crop. Both are warm-season grasses that are native to the prairies of North America (Mulkey et al., 2008; Moser and Vogel, 2005; Coleman et al., 2004). They are important in forage production and for their utilization as pasture grasses during hot summers when water is less available (Mitchell et al., 2001). Since these grasses are native, they are well adapted to most environmental conditions in the U.S. Switchgrass has received much notoriety as a bioenergy crop because it has inherent traits that make it suitable from a management and production standpoint. Big bluestem is not as well known as a bioenergy species, but since its characteristics are similar to switchgrass it is possible that it could be suitable for bioenergy production.

Schmer et al. (2007) studied net energy of cellulosic ethanol from switchgrass and found that switchgrass biomass produced 540 percent more energy than it consumed. Conversion of switchgrass to ethanol resulted in greater than 3500 L ha^{-1} being produced on high yielding farms. Schmer et al (2007) also studied GHG emissions, and estimated ethanol from switchgrass lowered GHG emissions by 94 percent compared to gasoline. Indications from this study are that switchgrass biomass used for ethanol production can be efficient and reduce GHG emissions making it feasible as a bioenergy crop.

Big bluestem and switchgrass are both warm-season C_4 plants. The C_4 pathway is known for greater photosynthetic efficiency, water use efficiency, and N use efficiency compared to the C_3 pathway (Parrish and Fike, 2005). C_4 plants typically tolerate conditions that would be less suitable for other crops such as heat, drought or N stress. Thus, dependence on intensive agronomic practices may not be necessary. Switchgrass (Figure 1) is described as a grass that has an erect growth habit that can grow 0.5 to 3 m tall with shoots and leaves present throughout the canopy of the stand (Moser and Vogel, 1995). Big bluestem (Figure 2) is considered a bunch grass since it maintains leaves at the base of the plant and has seed heads that extend upward from 1 to 3 m (Coleman et al. 2004). These grasses have both shown the ability to produce large amounts of biomass.

Figure 1. Switchgrass

Figure 2. Big bluestem

Management of these grasses needs to be carried out correctly throughout the entirety of a stand. Establishment is critical in acquiring a good stand and can often be a challenging task. Many methods have been investigated to determine what works best for perennial grasses, but environmental conditions play a large role in getting good establishment (Smart et al., 2003). Biomass yield has been shown to vary widely depending on many different factors such as rainfall, harvest management, and cultivar (McLaughlin and Kszos, 2005). Since these grasses are to be used as biofuels, the main goal is to increase biomass yield while lowering inputs, while traditional uses as forage require different management techniques to provide good forage quality.

Harvest management of grasses used for biomass and forage are similar; therefore some management issues can be avoided since many farmers are familiar with these practices (Sanderson et al., 2006). Harvest management has been investigated with many different strategies showing good yields. Perennial grasses are known to translocate nutrients to the rhizomes and roots late in the growing season as a result of water stress

(Heckathorn and Delucia, 1996). Thus, the method that has shown the best yields in switchgrass with lowest inputs is a once per year harvest late in the growing season (Haque et al., 2009; McLaughlin and Kszos, 2005, Reynolds et al., 2000). Although literature for harvest management of big bluestem for biomass is limited, experiments utilizing a once per year harvest late in the growing season have produced the best yields (Mulkey et al., 2008).

In order for switchgrass and big bluestem to produce adequate biomass there is a need for soil fertility recommendations. In grass production, it is typical to observe a positive response in yield due to N fertilization, however this may not be the case for switchgrass. Many studies have been conducted to investigate the response of biomass yield to N fertilization with varying results, and the question of optimal N rate still remains (Parrish and Fike, 2005). Literature on the nutrient management of big bluestem for biomass production is limited and more research needs to be conducted to help determine optimal rates of fertilization. Phosphorus fertilization is also needed for proper grass growth even though some studies have shown that it may not be necessary to produce maximum biomass yield (Parrish and Fike, 2005). Responses to K seem to be similar to those of P (Parrish and Fike, 2005). Understanding how to properly manage the nutrient requirements of these grasses will increase yield and ensure excess fertilization does not occur, thus increasing profitability and lessening environmental impacts.

According to Parrish and Fike (2005) no aspect of switchgrass management for biomass is more unresolved than recommendations for its fertilization. The same can be said for most perennial grasses including big bluestem. Many studies have suggested that no fertilizer can be sufficient, whereas others have proposed that fertilization has a positive response on yield (Parrish and Fike, 2005).

Nitrogen management is an area of contention for perennial grasses. Nitrogen balances in switchgrass were considered by Bransby et al. (1997), and they observed that, relative to other crops, switchgrass may be superior at recovering applied N. There also is a belief that lower application rates of N are needed for switchgrass stands that are well established (McLaughlin et al., 1999). Bransby et al. (2002) conducted a three-year study on application frequencies and rates of N fertilizer indicating that even in unfertilized plots switchgrass yield was high. Their findings regarding fertilization frequency indicated that best economic return may be obtained when N fertilizer was applied only on a three year interval.

Muir et al. (2001) researched the response of switchgrass yield to N fertilization in Texas by applying N at rates ranging from 0 to 224 kg N ha^{-1}. They found that 168 kg N ha^{-1} once in the spring produced maximum yield under a once per year harvest system. Switchgrass biomass production averaged 13.4 Mg ha^{-1} with this application rate. They observed that very high N rates caused lodging under a once per year cutting regime, while stands with no N diminished over time indicating that N fertilizer is needed for long-term biomass production.

A study in Oklahoma by Thomason et al., (2004), that evaluated effects of N application and harvest frequency on biomass yield, suggested their maximum application rate of 448 kg N ha^{-1} produced best yields for switchgrass under a three times per year harvest system. Yield under this treatment and harvest system averaged 18.0 Mg

ha^{-1}. Even though 448 kg N ha^{-1} produced the maximum yield, 0 kg N ha^{-1} produced a similar yield under the same harvest system.

Lemus et al. (2008a) conducted research in Iowa on the effects of N fertilization on switchgrass yield. Their research indicated N was most efficiently used at levels between 56 and 112 kg N ha^{-1}. The study was conducted over 5 years with biomass yield increasing each year even on unfertilized plots. Since this stand was previously unmanaged, the authors suggested that management of previously established and unmanaged stands could increase yield. However, to get optimal yield, N fertilization is recommended. Heggenstaller et al. (2009) studied the response of biomass yield to N fertilization on four perennial grasses including big bluestem and switchgrass in Iowa and had similar results. Their research suggested that the optimum rate of N fertilization for big bluestem and switchgrass in central Iowa is near 140 kg N ha^{-1}.

A study conducted by Lemus et al. (2008b), in Virginia on a well established stand of switchgrass that had no previous N fertilizer applications, and found biomass yield responded positively when N fertilizer was added. Yield was highest on plots that received 270 kg N ha^{-1}. The results of this study suggest that applying less than 90 kg N ha^{-1} would provide good yields under a two times per year harvest system for biomass in Virginia. The authors also stated that one harvest at the end of the season would reduce N removal and applications, which is consistent with previous research by Reynolds et al. (2000).

Haque et al. (2009) conducted a study in Oklahoma on N rate and harvest frequency on four different perennial grasses and found switchgrass had the best yields under a single harvest late in the growing season. A fertilizer rate of 67 kg N ha^{-1}

produced optimal biomass yield. This study also examined economics of N rate and harvest system, and found that for eight out of nine price combinations the optimal strategy is to apply 65 kg N ha^{-1} and harvest once per year.

Hall et al. (1982) studied the impact of N fertilization on big bluestem and switchgrass yield. Their results indicated yield had a positive response to N fertilization, for both species, up to 75 kg N ha^{-1} and often responses were observed through 150 kg N ha^{-1}. Big bluestem and switchgrass yield showed a response to N in a study by McMurphy et al. (1975). Big bluestem yield responded best at 90 kg N ha^{-1} with higher rates resulting in severe lodging while switchgrass yield responded up to 180 kg N ha^{-1}. Switchgrass was the most productive species in this experiment. The grasses in this experiment were managed under a multiple harvest forage regime. Since forage harvests are done to maximize the forage quality of plant matter, it can be concluded that N amendments to crops being used for forage purposes could overestimate the amount of N required to produce biomass for energy (Parrish and Fike, 2005). The limited response of perennial grasses to N may be attributed to their evolution in low N environments (Thomason et al., 2004). Therefore, proper N management for switchgrass and big bluestem grown for biomass production should be elucidated to maximize yield but minimize excessive fertilizer application.

Phosphorus fertilization of perennial grasses is important to maintain proper plant nutrition. Studies have shown that switchgrass is inherently good at utilizing P, whereas data on big bluestem is limited (Parrish and Fike, 2005). Mycorrhizae are thought to be responsible for assisting in the uptake of less available P (Brejda et al., 1993). It has been proposed that perennial grasses and mycorrhizae co-evolved from tropical environments in soils of low pH and less readily available P (Hetrick et al., 1988). These factors may suggest why there may be a limited response to P fertilization since these grasses are capable of retrieving less available P.

Research has been conducted on the response of biomass yield to P fertilization with mixed results. Hall et al. (1982) conducted a study on low pH soils in Iowa and saw no response in big bluestem and switchgrass yield to P fertilization even on soils that were low in P. In a study by McMurphy et al. (1975), big bluestem and switchgrass yields were highest in applications of 40 kg P ha^{-1} with 90 kg N ha^{-1} and 40 kg P ha^{-1} with 180 kg N ha^{-1}, respectively. Rehm (1984) conducted a study on the response of warm-season grasses to P fertilization and found 24 kg P ha^{-1} was optimal for switchgrass and big bluestem. There is a possibility that P fertilization may induce a response on perennial grass yield. Research is needed in the southeastern U.S. to determine effects on switchgrass and big bluestem grown for biomass production.

Potassium fertilization is important for the proper nutrient management of perennial grasses. Warm-season grasses have been known to be good at utilizing K and often show little or no yield response to K fertilization (Parrish and Fike, 2005). Hall et al. (1982) saw no response in switchgrass or big bluestem yield to K fertilization even on soils that were relatively low in K. A study by Friedrich et al. (1977), examining multiple levels of K fertilization up to 896 kg K ha^{-1} for switchgrass, showed no yield response. It was observed that the highest levels of K fertilizer reduced inflorescence production to 59% of lower levels. Smith (1979) found no response in DMY to K fertilization. Most research shows that switchgrass and big bluestem are not influenced by K fertilization. Since K is a macronutrient for plant nutrition, research is needed to determine whether this nutrient should be incorporated in a nutrient management strategy for biomass production.

In summary, scant information is available regarding nutrient management for perennial grasses as biofuels in the southeastern U.S. In order to produce optimal yield it is imperative that the nutrient needs of the bioenergy crops are well understood. Moreover, the over-application of fertilizer is an environmental hazard that needs to be avoided. In order to achieve goals for maximum production, environmental quality, and decreased production costs it is essential to develop fertility recommendations that can be relied upon to ensure the best possible production of perennial grass for biomass. The first objective of this study was to determine N, P, and K requirements of switchgrass and big bluestem grown for use as a bioenergy crop.

Nutrient Release from Cattle Feces

Cattle manure has often been utilized as an organic amendment to increase soil fertility. However, cattle manure applications can have an adverse effect on the environment when employed incorrectly. Manure typically contains all essential nutrients necessary for plant growth, and is a good amendment to soils for fertilization of crops (Eghball and Powers 1994). Nutrients that have relatively high concentrations in manure are N and P. These elements are important in terrestrial plant growth, but when released into waterways can cause algal blooms that can have detrimental impacts on aquatic wildlife. Cattle manure can also cause nutrient buildups in the soil and leaching of nutrients that may pose health and environmental risks.

Dairy cattle in pastures excrete feces that are left on the ground to decompose. The amount of feces excreted by dairy cattle can be related to many factors. Traditionally body weight was thought to be a good indication of the amount of feces excreted by dairy cattle, but it has been shown that other factors also have an influence (Nennich et al., 2005). The amount of nutrients in the manure is dependent on factors such as feed intake, size and species of animal, and housing and rearing management (Eghball 2000).

Wilkerson et al. (1997) conducted research on predicting manure excretion from dairy cattle and found amount of milk produced per day was related to the amount of total manure excreted. They found lactating cows averaging 29 kg milk day^{-1} produced on average 89.0 kg feces day^{-1} per 1000 kg of body weight, whereas lactating cows averaging 14 kg milk day^{-1} produced on average 65.9 kg feces day^{-1} per 1000 kg of body weight. This is similar to data from the ASAE Standards (2005) suggesting that lactating cows, dry cows, and heifers produce 68, 38, and 22 kg feces day^{-1}, respectively.

Oudshoorn et al. (2008) studied frequency and distribution of dairy cattle defecation and found that dairy cows defecated an average of 10.5 times a day. This study also showed increased defecation around cattle resting areas. These results are similar to those of Castle et al. (1950) that suggested cattle defecate 11.6 times per day.

A similar study conducted by Aland et al. (2002), examining diurnal distribution of dairy cattle defecation, found cattle defecated an average of 16.1 times per day. They also observed that defecation primarily occurred during feeding and milking periods. Defecation during resting and milking plus feeding hours was 25 and 75 percent, respectively, of the total defecation during the day. Immediately after resting periods, 95 percent of the cattle defecated and after eating or drinking about 60 percent defecated or urinated.

Franzluebbers et al. (2000) examined spatial distribution of soil N pools in grazed pastured and observed that soil inorganic N was greatest immediately adjacent to shade or water sources and decreased with distance. The authors suggested these results are owing to increases in urination and defecation at shade and water sources. A similar study by West et al. (1989) on variability of P and K found similar results with higher extractable soil P and K around water sources. These results indicated that most feces is deposited in areas where cattle spend the greatest amount of time.

Nennich et al. (2005) conducted research to predict the amount of manure and nutrients excreted by cattle. They found that excretion averaged 66.3 kg day^{-1} in lactating cows that had an average weight of 630 kg and dry matter intake of 21.7 kg day^{-1}. Their results also showed a difference in excretion between lactating cows, dry cows, replacement heifers, and calves. Lactating cows excreted on average 0.5 kg N day^{-1}, 0.07 kg P day^{-1}, and 0.2 kg K day^{-1}. They also suggested that nutrient excretion was the combined effect of many different factors including dry matter intake, milk yield, and intake of each nutrient.

Concentrations of nutrients in manure can be affected by feed composition. Sorensen et al. (2003) conducted a study to test dietary effects on composition and plant availability of nutrients in cattle manure. They fed dairy cattle seven different forages and determined concentration and plant availability of N in manure slurries. The mineral fertilizer equivalent (MFE) of manures was used to compare different forages. Mineral fertilizer equivalent is defined as the percent of mineral fertilizer needed to produce the same response as manure applied at the same nutrient rate (Reijs et al. 2005). Nitrogen concentration in feces varied from 18 to 38 g N kg^{-1} dry matter and increased with digestibility of feed. The MFE of cattle slurry varied from 51% to 78% and was negatively correlated to neutral detergent fiber and crude fiber in the diet, but positively correlated to protein content. It was also concluded that C:N ratio had no effect on N mineralization of the slurries.

Nitrogen is in higher concentration in manure relative to other nutrients. Lactating dairy cows have been suggested to release 0.45 kg total N day^{-1} in urine and feces (ASAE Standards, 2005). Fresh dairy cattle manure contains N in the form of unstable urea in the liquid portion and stable organic N in the feces (Klausner et al., 1994). Urea hydrolyses to NH_4 and is rapidly converted to NH_3, while organic N is more stable and mineralized over time (Klausner et al., 1994). Nitrogen mineralized from cattle manure can take different routes during decomposition by either remaining in soil to become part of the net mineral N pool, becoming immobilized by microbes or nitrate derived from the manure may be denitrified into N_2O or N_2 gas (Calderon et al., 2005). The rate at which this process occurs is primarily dependent on soil temperature, thus when the temperature rises mineralization increases (Cassman and Munns, 1980; Eghball, 2000). Since mineralization varies under these conditions, there is no universal standard to quantify mineralization and estimations are required for individual physiographic and climatic regions (Klausner et al., 1994).

Rates of conversion of the organic portion of cattle manure to plant available N are important. Klausner et al. (1994) conducted an experiment in New York to estimate N release from land applied dairy cattle manure. This experiment involved manure spread over fields at different rates and times. They found that 21% of the organic N applied was available for crop uptake within the first year. Motavalli et al. (1989) conducted an experiment on the availability of nutrients in injected dairy manure. They compared rates of mineral fertilizer to each manure trial and determined nutrient availability based on uptake by corn plants. Their experiment showed that 32% of total N had become available within the first year. Their experiment involved three sites that had different characteristics that affected nutrient availability leading them to believe that site specific factors are responsible for wide variations in nutrient release. Montavalli et al. (1989) also suggested there is a need for more reliable biological and chemical indices to estimate nutrient availability that can account for the effects of environment and the contribution of residual nutrients in soil.

An incubation study done by Abassi et al. (2007) determined the effect of different manure treatments on release of mineral N into soil. They observed that dairy cattle manure released 23.7 mg kg^{-1} of mineral N into the soil over 120 days after manure application. Mineral N released per day in dairy cattle manure varied from 0.01 to 0.74 mg kg^{-1} day^{-1}. They also examined ammonium and nitrate losses and observed that 10.5 mg NH_4 kg^{-1} soil and 13.2 mg NO_3 kg^{-1} soil were accumulated. The amount of NH_4 accumulated in the soil on experimental plots was similar to the control which accumulated 9.4 mg NH_4 kg^{-1} soil. Nitrate in soils applied with manure accumulated 78% more NO_3 than the control.

Watts et al. (2007) conducted an incubation study on N mineralization of dairy manure compost in different soils and wetting/drying cycles. They found that mineralization was influenced by soil type and soil temperature, but not by cycling of soil moisture. Soil types for this study included Caitlin (silt loam), Goldsboro (loam), and Bama (sandy loam). The Caitlin soil mineralized more N than Goldsboro and Bama soils over all sampling periods. There was a difference between Goldsboro and Bama soils over all sampling periods. Soils were incubated at 25, 18, and 11^{o}C with mineralization totals being 67.7, 60.4, and 48.0 mg kg^{-1}, respectively. Wetting and drying cycles were not shown to affect N mineralization. The drying cycle chosen, 3 weeks, may have allowed microbial adjustment and the avoidance of mortality.

Phosphorus is an important plant nutrient contained in manure. Dietary content of P in cattle is directly related to the concentration of P in feces (Chapuis-Lardy et al., 2004; Morse et al., 1994). Lactating dairy cows have been suggested to release 0.08 kg total P day^{-1} in urine and feces (ASAE Standards, 2005). Phosphorus in dairy manure is mainly in the inorganic form with 75 % of total P being inorganic P (Eghball 2002). This P can be beneficial for crop production when used properly. However, since P can be a major source of eutrophication in water systems it can have adverse effects on the environment.

He et al. (2004) suggested that the average total P concentration in manure was 9.1 g kg^{-1} dry matter. The variability of P in manure was high and could be attributed to diet. Barnett (1994) observed that total P in dairy manure averaged 9.0 g kg^{-1} manure, and ranged from 6.0 to 16.0 g kg^{-1} manure. In a study by Sharpley and Moyer (2000), total P in manure averaged 3.5 g kg^{-1} manure and ranged from 1.5 to 7.8 g kg^{-1} manure. These studies suggest that variability in manure total P concentration can be dependent on diet, making generalizations difficult.

Motavalli et al. (1989) found that availability of P in the first year for injected dairy manure was between 12% and 89% with an average of 49%. An incubation study, on the response of soil nutrients to different application rates of manure, by Whalen et al. (2000) showed that, immediately after application, available P was higher in soils amended by manure. At the end of the study available P levels remained high for higher application rates.

Whalen et al. (2001) examined N and P mineralization potentials from different manure applications in an incubation study. They observed that soil inorganic P increased with increasing application rate after 5 annual manure applications. There was an increase in soil inorganic P in the first 12 weeks, and they observed a drastic drop after week twelve.

Manure also contains other nutrients needed for plant growth such as K, Ca and Mg. Potassium in manure is readily available to plants and has an availability similar to fertilizer K (Eghball 2002). Potassium is mainly found in the urine portion of manure; greater than 70% of K in feces has been reported to be found in urine (Safely et al., 1985). Lactating dairy cows have been suggested to release 0.10 kg K day^{-1} in urine and feces (ASAE Standards, 2005). Calcium and Mg are found in manure bound to organic matter and can become available through mineralization (Fletcher and Beckett, 1987). Mineralization of Ca and Mg is known to vary based on characteristics and decomposition dynamics of the organic matter (Eneji et al., 2003).

Motavelli et al. (1989) observed that K availability in soil one year post manure application ranged from 24 to 152% with a mean availability of 74% using fertilizer equivalence. Eneji et al. (2003) studied K, Ca, and Mg mineralization in soils and found that mineralization of Ca and Mg varied by soil type. Potassium showed little change due to soil type over eight weeks except in an Andisol, which had a sharp decrease at two weeks and never regained initial levels. Release of exchangeable K was highest in cattle manure treatments. Calcium had its lowest values in sand dune soil and the Andisol. In red-yellow soil, Ca decreased between weeks 1 and 5 where it increased thereafter. Magnesium in cattle manure treatments increased steadily except during week five and lowest concentrations were found in the sand dune soil (Eneji et al., 2003). In the Andisol, Mg mineralization rate decreased after week one and never returned to initial levels.

Whalen et al. (2000) conducted an incubation study regarding the effects of cattle manure on low pH soils and found K, Ca, and Mg concentrations in soils treated with manure were much higher than non-treated soils. In soils that received applications of 20, 30 and 40 g manure kg^{-1} soil, the levels of Ca and Mg in soil increased immediately after application, while K concentration was only higher in applications of 30 and 40 g manure kg^{-1} soil. Available K in soil after incubation was also greater, but only at rates of 30 and 40 g manure kg^{-1} soil. Soils from two sites were used in the experiment and each responded differently with regard to Ca and Mg concentration after incubation with one having a difference and another having no difference. The amount of available Ca and Mg was only greater in soils amended with the highest amount of manure.

Copper and Zn are two micronutrients found in manure due to their use in animal feeds (McBride and Spiers, 2001). These nutrients are commonly added in small doses to livestock feeds to enhance various body functions (National Research Council, 2001). Copper is known to be associated with organic matter where it can be held tightly and becomes less available with increasing organic matter (Fletcher and Beckett, 1987). Zinc can show the same association with organic matter, however, it is not as strongly held as Cu. This association may influence availability of Cu and Zn in soils amended with manure.

Long-term applications of manure may cause accumulation of Cu and Zn in topsoil beyond levels that are tolerated by plants (Brock et al., 2006). Toxicity of plants to Cu and Zn is possible and may influence yield. Large supplies of Cu and Zn inhibit root growth and can cause deficiencies in other cations such as Mg and iron (Marschner 1995). These potential impacts make it necessary to quantify Cu and Zn in organic fertilizers in order to anticipate the loading potentials of soil. McBride and Spiers (2001) analyzed dairy manures for its concentration of heavy metals and observed that manures were on average low in concentration of all trace elements and heavy metals with the exception of Cu and Zn. Copper and Zn had mean concentrations of 139 mg kg^{-1} and 191 mg kg^{-1}, respectively. These levels were high enough for feed supplements not to be the only influence on excreted Cu and Zn. Therefore, other sources may have been present to influence Cu and Zn concentrations in manure such as periodically discarded hoof baths in which copper-sulfate is commonly used.

In New York, Zn and Cu accumulation in fields amended with dairy-manure were tested by Brock et al., (2006). They applied manure that distributed Cu at a rate of 8.2 to 9.2 kg ha^{-1} and Zn at 4.8 to 5.4 kg ha^{-1}. Total Cu and Zn in plow layer ranged from 14.0 to 52.4 mg Cu kg^{-1} soil and 70.1 to 137.0 mg Zn kg^{-1} soil. These totals showed an accumulation over time based on previous records of soil fertility at the experiment site.

According to their findings leaching of Cu and Zn does not pose a threat since little Cu and Zn were found at depths below the plow layer.

In Canada, the long-term effect of manure applications on trace element loading in soils was investigated by Benke et al. (2008). Twenty-five years of manure application only resulted in a small increase in total Cu under rainfed conditions. However, under irrigated conditions the highest manure application had higher soil Cu and Zn concentrations than the control. Experimental plots where manure was only applied for the first 11 years had higher soil Cu and Zn concentrations than control plots. This indicates that long-term application of manure can cause high levels of soil Cu and Zn even after manure application has been discontinued.

Since all manure cannot be managed for crop production, specifically feces excreted by cattle in pastures, we need to realize the nutrients they add to the soil. Nutrients added to the environment via cattle defecation can easily be lost through natural processes causing environmental issues. Most research has been focused towards the effects of applied manure on soil nutrients while limited information can be found on feces deposited naturally in pastures. Long-term applications of manure may cause accumulation of heavy metals like Cu and Zn. These may also pose problems in crop production and environmental quality. This makes it necessary to understand the amount at which these nutrients are being added to the environment. The objective of this study was to measure the nutrient release from cattle feces and its effect on the soil nutrient status.

II. Management of Nitrogen, Phosphorus, and Potassium in Big Bluestem and Switchgrass for Biomass Production

Abstract

Recent interest has been given to utilization of biomass crops for energy. Definitive nutrient management for perennial grasses as a source of biomass in the southeastern U.S. is lacking. The objective of this study was to examine switchgrass (*Panicum virgatum*) and big bluestem (*Andropogen gerardii*) response to different levels of nitrogen (N), phosphorus (P), and potassium (K) soil fertility. The experiment was conducted on a Benndale loamy sand near Brewton, AL from 2007 to 2009 on a circa 1954 experiment with rates of N, P, and K. Residual levels of soil test P and K ranged from low to high depending on long-term treatment. A split-plot randomized complete block design with four replications was the experimental design. Dry matter yield (DMY) exhibited a diminishing returns response to N fertilization in both species. Rates of maximum agronomic yield (MAY) were calculated at 155 and 161 kg N ha^{-1} for big bluestem and switchgrass, respectively. No response to P or K fertilization was observed. Economic analysis was conducted for N treatments at variable biomass prices. Big bluestem only showed a diminishing return response when biomass price was high, whereas switchgrass showed a diminishing return response at both high and low biomass prices. Nutrient removal for all elements in both species was observed to increase with

rate of fertilizer applied. Apparent N recovery (ANR) was calculated for the N treatments where switchgrass demonstrated a diminishing returns response. Apparent N recovery of big bluestem varied within year. Nutrient concentration in plant tissue was analyzed across the growing season for each N treatment and found to decrease across time in both species. Differences were detected between the 158 kg N ha^{-1} and the 0 kg N ha^{-1} rates indicating that nutrient deficiency can be detected during the growing season. This study suggests that in both species N is required at 150 kg N ha^{-1} for optimal biomass yield while P and K additions are unnecessary. Furthermore, plant tissue samples can be analyzed early in the growing season and used to correct N deficiency.

Introduction

In recent years renewable energy has become a viable alternative to fossil fuels. The high price of fuel and environmental concerns has spurred the need for a more stable and cleaner source of energy. Renewable energy includes sources such as solar, wind, hydroelectric, geothermal, and biomass. The U.S. Department of Energy-Energy Information Administration reported that from 2004 to 2009 consumption of energy from renewable sources increased from 6.2 percent to 8.2 percent.

Energy generated from biomass has become the largest sector of renewable energy in the U.S. In 2009 energy consumed from biomass accounted for 4.1 percent of the total energy consumption in the U.S (US DOE-EIA, 2010). In order to increase the use of biomass, the U.S. has set forth a goal to create 5 percent of its power, 20 percent of its transportation fuel, and 25 percent of its chemicals from biomass by 2030 (Perlack et al., 2005). In order to meet this goal it has been projected that 907 million Mg of biomass will be needed annually by 2030 (Sanderson et al., 2006).

Perennial grasses are a potential source of biomass (Sanderson and Adler, 2008; McLaughlin and Walsh, 1998). These grasses historically have been used as forages but new interest has focused on their production for biomass (Vogel, 1996). Their potential for energy production is based on their ability to produce large amounts of biomass under little management (Sanderson and Adler, 2008).

Switchgrass and big bluestem are two native perennial grass species that could become biomass crops. Extensive research has been conducted on switchgrass but little is known about the potential of big bluestem. These grasses both utilize the C_4 photosynthetic pathway which is known for its high tolerance of N, heat, and water stresses (Parrish and Fike, 2005). Thus, the need for intensive agronomic practices may not be necessary.

Proper nutrient management is needed for the optimal production of any crop. Grasses typically show an increase in biomass yield when N fertilizer is added (Parrish and Fike, 2005). However, the need for extensive fertilization for these grasses may not be necessary given that they are efficient at utilizing plant nutrients. Since the goal of biomass production is to increase biomass yield while reducing inputs, proper N, P, and K management should be determined.

Much research has been conducted on N responses in switchgrass but research is limited on big bluestem. Muir et al. (2001) recommends 168 kg N ha^{-1} for optimal yield under a once-a-year harvest for switchgrass. Thomason et al. (2004) produced best yields at 448 kg N ha^{-1} using a three-times-per-year harvest. Looking at both species Hall et al. (1982) observed responses at 75 kg N ha^{-1} and often through 150 kg N ha^{-1}. Managing under a multiple harvest system for forage production, McMurphy et al. (1975) observed optimal yield at 90 kg N ha^{-1} for big bluestem and 180 kg N ha^{-1} for switchgrass. In biomass production, it has been shown that a once-per-year harvest provides the best yield with least inputs. Thus, fertilizer recommendations for the southeastern U.S. should be determined on this harvest system (Haque et al., 2009; McLaughlin and Kszos, 2005, Reynolds et al., 2000).

Responses to P fertilizer have been shown to be limited, however P is considered an essential plant nutrient and its value in a nutrient management plan needs to be assessed. The relationship of these grasses with mycorrhizae has been thought to assist in uptake of less available forms of P (Brejda et al., 1993). Hall et al. (1982) observed no response to P additions in switchgrass. McMurphy et al. (1975) observed 40 kg P ha^{-1} to be optimal for switchgrass and big bluestem. Rehm (1984) showed similar findings with 24 kg P ha^{-1} being optimal for both species.

Warm-season grasses are known to be proficient at utilizing K, and often show little or no response to K fertilization (Parrish and Fike, 2005). Similar results were shown in studies by Hall et al. (1982) and Smith (1979) where both species showed no response to additional K fertilizer. In a study on switchgrass, Friedrich (1977) observed no response as well.

The objective of this study was to determine application rates of N, P, and K needed to achieve optimal yield in switchgrass and big bluestem for biomass production on a Southeastern U.S. Coastal Plain soil.

Materials and Methods

Research was conducted from 2007 to 2009 at the Brewton Agricultural Research Unit (31° 8’ N, 87° 3’ W) near Brewton, Alabama on a Benndale fine sandy loam

(Coarse loamy, siliceous, semiactive, thermic Typic Paleudult). The site is a part of the long-term fertility trial on the 'Rates of NPK' plots (circa 1954) that have been maintain with different levels of N, P, and K fertility (Cope, 1970 and Cope 1984). The plots at this site contain varying levels of soil test P and K that have been kept up depending on the treatment. Precipitation and temperature data were obtained through a weather station located at the research unit (Figure 1 and 2).

The experimental design was a split-plot randomized complete block with four replications. Plot size was 6 m x 9 m with 4 rows of each grass species assigned to a 3 m x 9 m subplot. Row spacing was 76 cm. Perennial grass species 'Alamo' switchgrass and 'Big Earl' big bluestem were seeded in July 2007 at a rate of 42 and 92 g plot^{-1}, respectively. Seed was planted in prepared seedbeds that were tilled via moldboard plow and disk harrow. Grasses were allowed one year for establishment before sampling began. The year prior to the study there was no crop grown, and the study area was maintained as a fallow.

The experiment contained sixteen treatments with varying levels of N, P, and K fertilizer applications (Table 1). Fertilizer treatments were applied to each plot in June 2008 and April 2009. A mixture of ammonium sulfate and urea (33-0-0) was the N fertilizer used for all plots except treatment six which was a no sulfur treatment. Urea (46-0-0) was used on treatment six plots as the N fertilizer. Triple super phosphate (0-45-0) and muriate of potash (0-0-60) were applied for P and K sources, respectively. Fertilizers were weighed into separate bags based on the protocol for each plot, mixed and spread by hand. Soil samples were taken in May 2007 from each plot and in May 2009 from each subplot. Samples were extracted using a dilute double-acid extraction

(Mehlich I), and analyzed for P and K by inductively-coupled argon plasma spectroscopy (ICAP) (SPECTRO CIROS CCD, Side on Plasma, GERMANY). Soil test data can be found in Table 2.

Plant samples were collected throughout the growing season to acquire nutrient concentration data. Sampling began in July 2008 and April 2009 and ended in November of both years (Table 3). Samples were taken by cutting three shoots 10 cm above ground from ten random locations within the middle two rows of each subplot. Plant samples were oven dried at 60° C and then ground using a Wiley Mill (Thomas Scientific, Philadelphia, PA) to pass a 1 mm sieve. Nitrogen concentration of dried grass tissue was determined via dry combustion method with a LECO TruSpec CN analyzer (LECO Corp., St. Joseph, MI). To determine P and K in plant tissue, samples were prepared using the dry-ashing method and analyzed via ICAP (Hue and Evans, 1986; SPECTRO CIROS CCD).

Dry matter yield was determined once per year in November of 2008 and 2009. The two middle rows of each subplot were harvested using a sickle bar mower in 2008. In 2009, switchgrass plots were harvested using a sickle bar mower and big bluestem plots with a forage harvester. Harvested biomass was collected and weighed to determine total subplot yield. A subsample from the harvested biomass was collected and used to determine percent dry matter. Dry matter yield was determined by multiplying percent dry matter with total subplot yield. Nutrient removal was calculated from DMY and nutrient concentration data, as determined by methods described above, by multiplying nutrient concentration at harvest by biomass yield.

Biomass and nutrient concentration data were analyzed by using PROC MIXED provided by the Statistical Analysis Systems (SAS, 2003). Net return was calculated using the following equation: Net Return ha^{-1} = (DMY * Biomass Price)-(N rate * 1.30). Price of N was set at \$1.30 kg N^{-1}. This price was based on 2010 USDA data for fertilizer prices (USDA-ERS, 2010). Since biomass for bioenergy production is not an established commodity, prices were set at \$65 and \$100 Mg^{-1} of biomass to show possible variability in economic responseApparent N recovery was calculated as follows: ANR = $((NR_i – NR_o)/N_i)$ where NR_i is the N removed at a given rate, NR_o is N removed at 0 kg N ha^{-1}, and N_i is the N applied at a given rate (Bock 1984). Main effects and interactions were determined using F-tests. Pseudo-R^2 values were used for regression models and derived from likelihood ratio tests (Kramer, 2005).

Results and Discussion

Biomass Yield

Analysis of variance indicated a difference in big bluestem and switchgrass DMY therefore analysis for biomass yield was conducted by species (Table 4). Switchgrass consistently produced higher yields for all treatments and years. Dry matter yield in 2009 when compared to 2008 was greater for switchgrass and lower for big bluestem (Table 5). Higher yields were expected in 2009 for both species due to the age and continued establishment of the stand. Highest big bluestem yield occurred at the 53 kg P_2O_5 ha^{-1} treatment with 4716 kg ha^{-1} in 2008 while the lowest yield was at the 0 kg N ha^{-1} treatment with 1810 kg ha^{-1} in 2009. Switchgrass yield was highest in 2009 at the 158 kg N ha^{-1} with 20352 kg ha^{-1} and lowest in 2008 at the 0 kg N ha^{-1} with 5677 kg ha^{-1}. The decrease in big bluestem yield in 2009 may have been the result of irregular environmental conditions or shading caused by nearby switchgrass plots.

The 0 kg N ha^{-1} plots had the lowest yield for both species within N treatments, indicating a possible response to N fertilization. Year was found to affect DMY in N treatments for both species. In order to normalize data across years relative yield was calculated with 118 kg N ha^{-1} serving as 100% yield. This rate was the closest to rate the MAY that was calculated for DMY data. Relative yield in both species showed a diminishing returns response to N fertilization (Figure 3). Data was fitted to quadratic regression models by species (Tables 6). Rates where the MAY occurred were calculated at 155 and 161 kg N ha^{-1} for big bluestem and switchgrass, respectively (Table 7). These rates produced maximum yield and higher rates did not increase biomass production. These findings are similar to those of Muir et al. (2001), Heggenstaller et al. (2009), and Hall et al. (1982) who observed best responses in switchgrass around 150 kg N ha^{-1}. As indicated by this study, N fertilizer should be applied at the MAY rates to provide the best yield.

In P and K treatments, biomass yield showed no response to P or K fertilization in either species. Similar to N, year was found to have an influence on yield in both species, however no relative yields were calculated since no response was observed (Table 8). In 2009 big bluestem showed a small response to P and K treatments, but in 2008 no response was observed for either element (Figure 4). Switchgrass responses were similar to big bluestem with only a small response being observed in 2008 for K treatments (Figure 5). Dry matter yield data for P and K treatments were fitted to quadratic regression models by species (Table 9). Since these models did not follow a diminishing return response, this study recommends that P or K fertilizer should not be applied for either species. These findings are consistent with those of Hall et al. (1982), Friedrich et al. (1977), and Smith (1979) who recommended no P or K fertilizer. The observations in this study are important since no response was detected on soils with varying levels of P and K fertility.

Net Return

Economic analysis was conducted to determine the rate at which N fertilizer should be applied based on net return. Net return was only determined for cost of N and other production costs were not taken into account. Analysis was not conducted on P or K treatments since they did not show a response to fertilization. Analysis of variance for both prices indicated a difference in species, therefore analysis was conducted by species (Table 10). Switchgrass produced higher net returns than big bluestem for both biomass prices and years.

Big bluestem showed a quadratic response to fertilization for both scenarios with only \$100 Mg^{-1} showing an increase in net return (Figure 6 and Table 11). Rates of maximum economic yield (MEY) were calculated to be 13 kg N ha^{-1} in 2008 and 57 kg N ha^{-1} in 2009 for \$100 Mg^{-1} (Table 12). When biomass price was set at \$65 Mg^{-1} big bluestem showed no increase in net return and no rates of MEY were calculated. When biomass prices are low it is suggested that it is not profitable to add N fertilizer to big bluestem. Fertilization may be done when biomass price is high, but it is possible that only a small increase in net return will be realized. Maximum economic yield rates are observed to be much lower than MAY rates due to the insufficient amount of biomass that can be generated from big bluestem with increasing N rate. This indicates that the big bluestem MAY rates overestimate the amount of N fertilizer that should be added for profitable biomass production. In order to increase profitability in big bluestem it is suggested that N fertilizer applications be decreased below what is needed to achieve maximum yield.

Switchgrass showed an increase in net return with the addition of N fertilizer for both years (Table 11). A diminishing returns response was shown for all scenarios (Figure 7). Year was shown to affect net return with 2009 having a higher net return due to greater biomass production. Greater biomass production in 2009 also caused rates of MEY rates to be lower in 2008 than 2009 (Table 12). This indicates that in situations where biomass yield is expected to be lower, similar to what would be expected in less established stands, less fertilizer would be recommended in order to obtain the greatest return. Maximum economic yield rates in 2009 for switchgrass are similar to MAY rates indicating that when high biomass is produced the crop is the most profitable. In more established stands greater responses may be observed, therefore greater rates can be applied to acquire maximum return. This analysis indicates that switchgrass production can be profitable, under either biomass price, with the addition of N fertilizer. In comparison to big bluestem, switchgrass provided greater yield and net return making it more suitable for biomass production.

Nutrient Removal

Species was shown to have an effect on the removal of all nutrients (Table 13). Switchgrass removed more of each nutrient than big bluestem. This is likely due to higher yields that were produced by switchgrass. Removal for all elements followed a linear pattern and regression analysis was used to determine the effect of fertilization.

Each species and element did not follow the same pattern and were analyzed separately to determine which model best represented the data.

Nitrogen removal for big bluestem was not influenced by year when N rate was nested within years, therefore this model was discarded (Table 14). When rates were not nested within years, year was shown to affect N removal (Table 15). This model also indicated the data had a linear response and was chosen to represent big bluestem N data (Figure 8). Year did not affect N removal in switchgrass when data was nested either within or without year (Tables 14 and 15). Rate was shown to have a linear effect across both years (Table 16). This model was determined to be the best representation of N removal in switchgrass (Figure 9). Linear regression equations were fitted according to the results of these analyses and are shown in Table 17.

These results are consistent with Heggenstaller et al. (2009) who observed N removal in big bluestem ranging from 8 to 59 kg N ha^{-1}, and in switchgrass from 22 to 84 kg N ha^{-1}. Vogel et al. (2002) reported switchgrass had an increase in N removal with rate and N removal across all rates was around 60 kg N ha^{-1}. This study suggests that both species display luxury consumption of N beyond the rate of MAY. Big bluestem and switchgrass will continue to remove N when it is applied in excess rates without any increase in yield. Since N content is of no concern in biomass production this excess removal of N is unnecessary.

Big bluestem N removal in 2009 was greater than in 2008. In 2009 yields were lower therefore higher nutrient removal in this year was caused by a higher nutrient concentration at harvest. This indicates that in 2009 even though biomass yield was affected, N removal was not. This suggests that big bluestem will take up N when other factors inhibit biomass production, or that in 2009 big bluestem was unable to translocate N from above ground biomass to roots. Switchgrass removal was not affected by year indicating the opposite where in 2009 nutrient concentration at harvest was lower while yields were higher. This could be due to the dilution of N in biomass since yield in 2009 was greater. Another explanation could be that since fertilizer treatments were applied later in 2008, plants did not have adequate time to translocate similar amounts of N as were removed in 2009.

Phosphorus removal for both species was influenced by year when rates were nested within years (Table 14). Contrasts were conducted for regression lines of each year and no difference was found. Analysis was then conducted without rates nested within years. This model was deemed adequate for big bluestem since year was significant (Table 15). Rate was shown to not affect uptake in big bluestem suggesting P removal was the same across application rates (Figure 10). In switchgrass, year and rate had an effect on P removal (Table 15). Similar to N, P removal in switchgrass was shown to increase with P fertilization (Figure 11). Since there was no increase in yield due to P fertilization this indicates that switchgrass exhibits luxury consumption of P. Excess P removal can be seen as unnecessary since the primary goal of this study was to increase biomass yield. Linear regression equations were fitted according to the analysis of each species and are shown in Table 17. The year effect for each species was different with higher removal occurring in 2008 for big bluestem and in 2009 for switchgrass. In each year nutrient uptake for both species was highest when yield was highest. This is expected since higher biomass yield is likely to cause a higher nutrient removal.

Potassium removal for big bluestem illustrated a year effect when rates were nested within year while switchgrass did not (Table 14). Rate was shown to affect K removal and contrasts indicated a difference in regression lines for each year in big bluestem. This model showed an adequate fit for K removal in big bluestem (Figure 12). Switchgrass showed no difference in regression lines when rates were nested within years. When data was analyzed with rates not nested within years, removal demonstrated a linear response to fertilization (Table 15). This model provided the appropriate illustration of K removal in switchgrass (Figure 13). Linear regression equations were fitted according to the analysis and are shown in Table 17. Both species demonstrated luxury consumption by removing K with no increase in yield. These data suggest that by increasing K fertilizer rates, uptake will be increased while yield will not. Big bluestem data is consistent with Smith (1979) who observed an increase in K removal with rate. Similar to P, highest removal was detected in years with highest biomass yield. Since more biomass is being removed it is expected that more K will be removed.

Apparent Nitrogen Recovery

Apparent N recovery was higher in switchgrass than big bluestem throughout the study (Table 18). Results ranged from -6 to 17 percent for big bluestem and 6 to 53 percent for switchgrass. Data was modeled to fit different types of quadratic regression curves based on which fit best for each year and species. When rates were nested within years big bluestem displayed a response due to year while switchgrass did not (Table 19). In 2008 big bluestem showed a quadratic response while in 2009 there was neither a linear nor a quadratic response. Since a year effect was detected this model provided the best assessment of the big bluestem data (Figure 14). No further examination was done with 2008 data since no response was observed. Switchgrass showed no year response when rates were not nested within year, thus ANR was analyzed across years (Table 20). Data displayed a diminishing response curve where ANR peaked and then declined as rate increased (Figure 15). These data for both species were fitted to quadratic regression equations (Table 21). In 2008 ANR was highest for big bluestem at 129 kg N ha^{-1} and in switchgrass across both years maximum ANR occurred at 112 kg N ha^{-1}. These data indicate that the most N is utilized at these rates and gives a better insight into the proper N management of these species for biomass production.

Apparent N recovery data may be underestimating the amount of N recovered by the plants. Perennial grasses translocate nutrients into roots after senescence and this N sink is not accounted for in this study (Heckathorn and Delucia, 1996). These data are calculated from biomass that was harvest after senescence, making it possible that biomass does not contain all N utilized that season. Big bluestem ANR is considered to be low with some values being negative. This means the grass is utilizing less N than the 0 kg N ha^{-1} treatment. These results suggest that the amount of N utilized from added N fertilizer may not be enough to justify applying it. Most of the N being applied to big bluestem is being lost to other sources or translocated to the roots. Utilization in switchgrass is higher than big bluestem but still most of the N is not being recovered. For switchgrass these values are consistent with Staley et al. (1991) who notice an N recovery of 29 percent.

Perennial grasses have been known for their ability to survive in conditions that are limiting for nutrients. These data indicate that switchgrass and big bluestem may utilize N when it is applied but efficiency decreases when application rate goes beyond the rate of maximum N recovery. These ANR values are low and these grasses should be improved genetically to increase N utilization which in turn could result in higher yields.

Nutrient Concentration

Nutrient concentration analysis was only conducted for N since neither species showed a response to P or K fertilization. Since the purpose of this data is to model N concentration over time for plants that have optimal N nutrition, data from the 158 kg N ha^{-1} rate was considered to be the optimal N concentration for both species. This was the treatment closest to the rates of MAY determine for relative yield. Regression analysis was conducted on N concentration data and quadratic regression curves were fitted to both species. Each year and species was observed to have a different trend of nutrient concentration over time, thus data was analyzed within year and species (Figure 16 and 17). The difference in years may be due to the different fertilizer application times. It appears that application time may affect N dynamics in both species with later applications causing a steeper decline in nutrient concentration across time and possibly delaying senescence. Another explanation for the year effect is that younger and less established stands could exhibit characteristics of N use different from older stands. Younger stands may exhibit a trend similar to what was observed in 2008 while more established stands may exhibit a trend similar to 2009.

Both species showed a quadratic response to N concentration over time (Table 22). Nitrogen concentration was modeled across days after fertilizer application (DAA). This was deemed the best way to model the data since tissue samples were not always taken at one month intervals and fertilizer application dates were not the same. In both years concentration was highest early in the growing season before decreasing and then leveling out near harvest in November. Contrasts were conducted between 158 kg N ha^{-1} and all other rates in order to determine differences in N concentration regression lines.

In 2008 no difference was found between 158 kg N ha^{-1} and any other rate in big bluestem, while switchgrass showed a difference at 0 kg N ha^{-1} (Table 23). In 2009 differences were detected at the 0 and 39 kg N ha^{-1} for both species. This indicates modeling of N concentration in plant tissue can be used for switchgrass and big bluestem to identify N deficiency. Figure 16 indicates that tissue sampling of big bluestem may be the most useful before 60 DAA, or June. In switchgrass it may be optimal to apply supplemental fertilizer up to 90 days after application or July. These dates are when lines of deficient and sufficient plants begin to converge making it difficult to provide an accurate comparison. Regression equations were fitted and can be utilized to provide optimal N concentration throughout the growing season (Table 24). Data from 2009 is optimal since the application time is more consistent with when producers would be applying fertilizer. Data for 2008 is useful to show that application time will affect N concentration. If applications are applied at a later than optimal date this model may be more applicable.

Conclusions

In this study switchgrass was determined to be the best perennial grass species for biomass production. Yields and net return were much higher for switchgrass when compared to big bluestem. Both species showed a yield response to N fertilization while neither species had a response to P or K fertilization. Economic analysis showed that adding N fertilizer to switchgrass was viable at low and high biomass prices while big bluestem only showed a positive response to N fertilization when the biomass price was high. Nutrient removal was affected by addition of all elements where nutrient removal increased with rate. This indicated excessive uptake of nutrients beyond what is needed for optimal yield. Apparent N recovery was affected by N fertilization in switchgrass, suggesting the efficiency of N use decreases as application increases past 112 kg N ha^{-1}. For biomass production, we recommend 150 kg N ha^{-1} to produce best yields in both species. These rates may need to be adjusted based on fertilizer and biomass prices. Our results suggest that no P or K fertilizer should be applied to big bluestem or switchgrass for biomass production. Models of N concentration across the growing season were developed to detect N deficiency. Samples should be taken before June on big bluestem and July on switchgrass to determine deficiency. Tissue testing done after these points may not provide a reliable indication of N deficiency. Further research should be conducted to validate the N dynamics of these species across the growing season. Apparent N recovery should take into account N in roots and rhizomes to understand the amount of N being utilized. Nitrogen concentration may be affected by application timing thus further investigation should be done on this subject. Long-term research is essential to view affects of no P or K fertilization on stand quality and biomass production over time.

Table 1. Description of treatments for each plot at the Brewton Agricultural Research Unit on the "Rate of N,P,K" experiment (circa 1954).

		Nutrient Application		
Treatment	Residual soil level	N	P_2O_5	K_2O
		-------------kg ha^{-1}-------------		
1	No N	0	131	131
2	Low N	39	131	131
3	Intermediate N	79	131	131
4	High N	158	131	131
5	Control	118	131	131
6	Very High N	197	131	131
7	No P	158	0	131
8	Very low soil P	158	26	131
9	Intermediate soil P	158	53	131
10	High soil P	158	79	131
11	No K	158	131	0
12	Very low soil K	158	131	26
13	Low soil K	158	131	53
14	Intermediate soil K	158	131	79
15	High soil K	158	131	105
16†	No lime	158	131	131

† No lime plot were collected but not used for biomass analysis.

Table 2. Soil test data for phosphorus, potassium, and pH of treatments in 2007 and 2009. Samples in 2007 were taken within each plot while in 2009 samples were taken within each species subplot. Auburn University soil test ratings are located in parentheses.

	Year			Year			Year		
	2007	2009		2007	2009		2007	2009	
		Big bluestem	Switchgrass		Big bluestem	Switchgrass		Big bluestem	Switchgrass
	--mg kg^{-1}			--					
	Phosphorus†			Potassium			pH		
1	69(VH)	118(VH)	119(VH)	36(M)	101(VH)	91(VH)	5.9	6.8	6.9
2	58(VH)	118(VH)	99(VH)	33(M)	92(VH)	89(VH)	5.9	6.8	6.8
3	60(VH)	105(VH)	100(VH)	37(M)	98(VH)	116(VH)	5.7	6.8	6.8
4	62(VH)	96(VH)	122(VH)	33(M)	86(VH)	106(VH)	5.6	6.5	6.6
5	63(VH)	95(VH)	119(VH)	30(M)	81(VH)	75(H)	5.8	6.8	6.7
6	62(VH)	100(VH)	93(VH)	31(M)	116(VH)	98(VH)	5.7	6.8	6.8
7	17(M)	22(M)	21(M)	29(M)	92(VH)	100(VH)	5.8	6.9	6.8
8	18(M)	36(H)	23(M)	27(M)	88(VH)	72(H)	5.8	6.6	6.8
9	35(H)	41(H)	36(H)	36(M)	88(VH)	68(H)	5.7	6.7	6.8
10	26(H)	50(H)	47(H)	23(M)	73(H)	70(H)	5.6	6.6	6.5
11	58(VH)	97(VH)	93(VH)	17(L)	25(M)	19(L)	5.9	6.6	6.6
12	64(VH)	110(VH)	115(VH)	26(M)	39(M)	39(M)	5.7	6.5	6.4
13	62(VH)	112(VH)	98(VH)	27(M)	49(H)	38(M)	5.8	6.5	6.6
14	59(VH)	111(VH)	102(VH)	24(M)	69(H)	64(H)	5.7	6.8	6.7
15	60(VH)	106(VH)	98(VH)	29(M)	91(VH)	70(H)	5.8	6.6	6.5
16	74(VH)	96(VH)	115(VH)	17(L)	78(H)	90(VH)	5.0	5.6	5.5

† L = Low, M = Medium, H = High, VH = Very High

Table 3. Fertilizer application, nutrient tissue sampling, and harvest dates at the Brewton Agricultural Research Unit

	2008	2009
Application Date	June 3	April 17
April sampling	†	April 17
May sampling	†	May 19
June sampling	†	June 19
July sampling	July 11	July 17
August sampling	August 29	August 24
September sampling	September 24	September 30
Harvest	November 7	November 16 & 17

† Sampling in 2008 did not start until July

Table 4. Analysis of variance probability greater than F (Pr>F) for dry matter yield.

Source	N	P	K
	--------------------Pr > F--------------------		
Rate	<0.0001	0.0671	0.0335
Species	<0.0001	<0.0001	<0.0001
Rate*Species	<0.0001	0.1241	0.0822
Year	0.0299	0.0166	0.0039
Rate*Year	0.0081	0.4600	0.9505
Year*Species	<0.0001	<0.0001	<0.0001
Rate*Year*Species	0.0110	0.6720	0.8077

Table 5. Dry matter yield of all treatments for both species and years. Standard error of the mean is located in parentheses.

Nutrient Application			Big bluestem		Switchgrass	
N	P_2O_5	K_2O	2008	2009	2008	2009
-----------kg ha^{-1}-----------			--DMY Mg ha^{-1}--			
0	131	131	3.2(0.3)	1.8(0.1)	5.7(0.2)	6.5(0.7)
39	131	131	3.5(0.2)	2.4(0.1)	8.1(0.6)	9.9(0.2)
79	131	131	3.4(0.4)	3.1(0.4)	8.9(0.9)	15.1(.5)
158	131	131	4.4(0.2)	3.4(0.2)	10.2(0.7)	20.4(3.4)
118	131	131	4.6(0.4)	3.2(0.2)	11.0(0.8)	17.4(1040)
197	131	131	4.0(0.1)	3.3(0.6)	10.1(1.0)	17.5(1.2)
158	0	131	4.1(0.2)	2.9(0.4)	9.4(0.4)	14.9(0.9)
158	26	131	4.3(0.3)	3.2(0.2)	9.7(0.2)	14.8(1.0)
158	53	131	4.7(0.4)	3.5(0.5)	10.3(0.7)	14.6(1.0)
158	79	131	3.6(0.2)	3.0(0.5)	9.4(0.9)	15.8(0.5)
158	131	0	4.3(0.3)	2.8(0.3)	8.4(0.7)	13.9(0.8)
158	131	26	3.7(0.3)	3.1(0.4)	9.2(1.0)	14.9(0.4)
158	131	53	4.3(0.4)	3.3(0.5)	10.3(0.9)	15.1(0.7)
158	131	79	3.9(0.2)	3.5(0.4)	9.7(1.3)	15.1(0.7)
158	131	105	4.0(0.3)	3.2(0.2)	9.7(0.2)	14.8(0.7)
158	131	131	3.6(0.4)	2.7(0.3)	9.3(0.7)	15.7(1.5)
			4.0(0.1)†	3.0(0.1)†	9.3(0.2)†	14.8(0.5)†
			3.5(0.1)‡		12.1(0.3)‡	

† Mean and standard error of each year in big bluestem and switchgrass.

‡ Mean and standard error of each species.

Table 6. Regression analysis probability of F ($Pr > F$) values for relative yield on nitrogen treatments of switchgrass and big bluestem.

Source	$Pr > F$
Switchgrass	
Rate	<0.0001
Rate*Rate	0.0247
Big bluestem	
Rate	0.0009
Rate*Rate	0.0004

Table 7. Regression equations and rate of maximum agronomic yield (MAY) for percent relative yield on N treatments for big bluestem and switchgrass.

Species	Equation	MAY Rate	R^2
		---kg N ha^{-1}---	
Big bluestem	$y = 45.4 + 0.6961x - 0.0006x^2$	155	0.17
Switchgrass	$y = 63.1 + 0.4229x - 0.0013x^2$	161	0.69

Table 8. Regression analysis probability of greater than F (Pr > F) values of dry matter yield on phosphorus and potassium treatments for big bluestem and switchgrass in 2008 and 2009.

		Species	
Source	Year	Big bluestem	Switchgrass
		----------------Pr > F----------------	
	Phosphorus		
Year		0.0485	0.0020
Rate(Year)	2008	0.6913	0.8960
Rate(Year)	2009	0.3534	0.7419
Rate*Rate(Year)	2008	0.5982	0.4778
Rate*Rate(Year)	2009	0.4229	0.2591
	Potassium		
Year		0.0211	0.0013
Rate(Year)	2008	0.2920	0.4118
Rate(Year)	2009	0.1663	0.9491
Rate*Rate(Year)	2008	0.1946	0.7998
Rate*Rate(Year)	2009	0.2417	0.3826

Table 9. Regression equations for dry matter yield on phosphorus and potassium treatments for big bluestem and switchgrass in 2008 and 2009. R^2 values indicate the pseudo-R^2 for the model of each species and year.

Species	Year	Equation	R^2
		Phosphorus	
Big bluestem	2008	$y = 4291 - 4.77x + 0.0452x^2$	0.59
Big bluestem	2009	$y = 2995 + 7.44x - 0.0457x^2$	
Switchgrass	2008	$y = 9583 - 2.44x + 0.0949x^2$	0.88
Switchgrass	2009	$y = 14845 - 8.86x + 0.2186x^2$	
		Potassium	
Big bluestem	2008	$y = 4220 - 10.53x + 0.0948x^2$	0.65
Big bluestem	2009	$y = 2857 + 12.75x - 0.0782x^2$	
Switchgrass	2008	$y = 8564 + 22.15x - 0.0497x^2$	0.86
Switchgrass	2009	$y = 14317 - 1.57x + 0.1568x^2$	

Table 10. Analysis of variance probability greater than F (Pr>F) for net return of N treatments.

Source	\$65 Mg^{-1}	\$100 Mg^{-1}
	------------Pr > F------------	
Rate	0.0059	0.0005
Species	<0.0001	<0.0001
Rate*Species	<0.0001	<0.0001
Year	0.0299	0.0299
Rate*Year	0.0081	0.0081
Year*Species	<0.0001	<0.0001
Rate*Year*Species	0.0110	0.0110

Table 11. Regression analysis probability greater than F (Pr > F) values for net return of nitrogen treatments with both species, years, and biomass prices

		\$65 Mg^{-1}		\$100 Mg^{-1}	
Source	Year	Big bluestem	Switchgrass	Big bluestem	Switchgrass
		----------------------------------Pr > F----------------------------------			
Year		0.0214	0.9775	0.0214	0.9775
Rate(Year)	2008	0.3857	0.0016	0.8657	0.0004
Rate(Year)	2009	0.9737	0.0002	0.1916	0.0001
Rate*Rate(Year)	2008	0.1940	0.0017	0.1940	0.0017
Rate*Rate(Year)	2009	0.0210	0.0053	0.0210	0.0053

Table 12. Regression equations, pseudo R^2, and maximum economic yield (MEY) for nitrogen treatments in both species, years, and biomass prices.

Year	Biomass Price	Regression Equation	R^2	MEY
	---\$ Mg^{-1}---			---kg N ha^{-1}---
		Big bluestem		
2008	65	$y = 200 - 0.381x - 0.0028x^2$	0.58	†
2009	65	$y = 117 - 0.012x - 0.0041x^2$		†
2008	100	$y = 238 + 0.114x - 0.0043x^2$	0.87	13
2009	100	$y = 180 + 0.717x - 0.0063x^2$		57
		Switchgrass		
2008	65	$y = 370 + 2.995x - 0.0146x^2$	0.88	103
2009	65	$y = 373 + 8.807x - 0.0301x^2$		146
2008	100	$y = 569 + 5.307x - 0.0224x^2$	0.80	118
2009	100	$y = 574 + 14.249x - 0.0464x^2$		153

† Maximum economic yield was not calculated since data did not show a positive response.

Table 13. Analysis of variance probability greater than F (Pr>F) for nutrient removal.

Source	N	P	K
	--------------------Pr > F--------------------		
Rate	<0.0001	0.0073	<0.0001
Species	<0.0001	<0.0001	<0.0001
Rate*Species	0.0015	0.0228	<0.0001
Year	0.3327	0.1703	0.0611
Rate*Year	0.5395	0.0875	0.4453
Year*Species	0.8630	<0.0001	<0.0001
Rate*Year*Species	0.8718	0.2816	0.1653

Table 14. Regression analysis probability greater than F (Pr > F) for nutrient uptake of all elements on rates nested within. Contrasts indicate Pr > F for comparison of linear regression models of each year.

Source	Year	Species	
		Big bluestem	Switchgrass
		-----------------------Pr > F-----------------------	
		Nitrogen	
Year		0.7307	0.5687
Rate(Year)	2008	0.0597	<0.0001
Rate(Year)	2009	<0.0001	<0.0001
Contrast 'Rate(Year)'		0.0406	0.9585
		Phosphorus	
Year		0.0033	0.0236
Rate(Year)	2008	0.2135	0.0008
Rate(Year)	2009	0.3528	0.0101
Contrast 'Rate(Year)'		0.4398	0.7282
		Potassium	
Year		0.0128	0.1782
Rate(Year)	2008	0.0005	<0.0001
Rate(Year)	2009	0.0189	<0.0001
Contrast 'Rate(Year)'		0.0079	0.1783

Table 15. Regression analysis probability greater than F (Pr>F) for nutrient uptake for both years with rates not nested within years.

Source	Species	
	Big bluestem	Switchgrass
	----------------------Pr > F----------------------	
	Nitrogen	
Year	0.0284	0.5159
Rate	<0.0001	<0.0001
	Phosphorus	
Year	0.0001	0.0047
Rate	0.1762	<0.0001
	Potassium	
Year	†	0.0035
Rate	†	<0.0001

† Previous model was adequate therefore no further analysis was conducted for this scenario.

Table 16. Regression analysis probability greater than F (Pr >F) for nitrogen uptake in switchgrass across both years.

Source	Pr > F
Rate	<0.0001

Table 17. Regression equations and R^2 for nutrient uptake in nitrogen, phosphorus, and potassium treatments for both species and years. R^2 values indicate the pseudo-R^2 of the model on each species.

Species	Year	Equation	R^2
		Nitrogen	
Big bluestem	2008	$y = 11.5 + 0.0590x$	0.63
Big bluestem	2009	$y = 16.6 + 0.0590x$	
Switchgrass		$y = 25.1 + 0.2452x$	0.83
		Phosphorus	
Big bluestem	2008	$y = 4.4 + 0.0032x$	0.39
Big bluestem	2009	$y = 1.9 + 0.0032x$	
Switchgrass	2008	$y = 5.8 + 0.0278x$	0.57
Switchgrass	2009	$y = 9.6 + 0.0278x$	
		Potassium	
Big bluestem	2008	$y = 8.2 + 0.0549x$	0.63
Big bluestem	2009	$y = 3.6 + 0.0123x$	
Switchgrass	2008	$y = 20.3 + 0.3084x$	0.87
Switchgrass	2009	$y = 38.4 + 0.3084x$	

Table 18. Analysis of variance probability greater than F (Pr>F) for apparent nitrogen recovery.

Source	Pr > F
Rate	0.4098
Species	<0.0001
Rate*Species	0.8387
Year	0.4013
Rate*Year	0.4840
Year*Species	0.6439
Rate*Year*Species	0.9355

Table 19. Regression analysis probability greater than F (Pr>F) of apparent nitrogen recovery for both species and years with rates nested within years.

Source	Year	Species	
		Big bluestem	Switchgrass
		--------------Pr > F--------------	
Year		0.0457	0.7077
Rate(Year)	2008	0.0405	0.2071
Rate(Year)	2009	0.6182	0.3018
Rate*Rate(year)	2008	0.0591	0.2157
Rate*Rate(year)	2009	0.5308	0.2299

Table 20. Regression analysis probability greater than F (Pr > F) for two models of apparent nitrogen recovery in switchgrass with rates not nested within years.

Source	Pr > F
Year	0.6834
Rate	0.0987
Rate*Rate	0.0820
Rate	0.0987
Rate*Rate	0.0820

Table 21. Regression equations of apparent nitrogen recovery in both years and species. R^2 values indicate the pseudo-R^2 for the model on each species.

Species	Year	Equation	R^2	Max. ANR Rate
				--kg N ha^{-1}--
Big bluestem	2008	$y = -11.5 + 0.2582x - 0.0010x^2$	0.63	129
Big bluestem	2009	$y = 7.2 + 0.0373x - 0.0002x^2$		†
Switchgrass		$y = 15.4 + 0.2676x - 0.0012x^2$	0.83	112

† Maximum ANR rate was not calculated since 2009 big bluestem data did not show a quadratic response

Table 22. Probability greater than F (Pr>F) of nitrogen concentration regression analysis for both species and years. Nutrient concentration was modeled over days after application (DAA).

Source	Big bluestem	Switchgrass
	--------------Pr > F--------------	
	2008	
Rate	<0.0001	<0.0001
DAA(Rate)	<0.0001	<0.0001
DAA*DAA(Rate)	<0.0001	<0.0001
	2009	
Rate	<0.0001	<0.0001
DAA(Rate)	<0.0001	<0.0001
DAA*DAA(Rate)	<0.0001	<0.0001

Table 23. Probability greater than F (Pr>F) of contrast for nitrogen concentration regression. Contrasts were made on each rate compared to 158 kg N ha^{-1} for both species and years.

Source	Big bluestem	Switchgrass
	---------------------Pr > F--------------------	
	2008	
0 vs 158	0.3908	0.0539
39 vs 158	0.1979	0.9865
78 vs 158	0.5175	0.6096
118 vs 158	0.7966	0.2277
197 vs 158	0.8336	0.2767
	2009	
0 vs 158	0.0056	0.0028
39 vs 158	0.0689	0.0001
78 vs 158	0.8611	0.2168
118 vs 158	0.4473	0.4061
197 vs 158	0.6539	0.5713

Table 24. Estimates and standard errors of regression equation coefficients for nutrient concentration at 0 and 158 kg N ha^{-1} of big bluestem and switchgrass in 2008 and 2009.

Year	Rate	Intercept		Linear		Quadratic	
		Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
	--kg N ha^{-1}--	---g kg^{-1}---					
				Big bluestem			
2008	0	22.1	2.1	-0.245	0.048	0.0009	0.0002
2008	158	24.6	2.1	-0.253	0.048	0.0008	0.0002
2009	0	19.0	0.7	-0.143	0.017	0.0004	0.0001
2009	158	21.8	0.7	-0.172	0.017	0.0005	0.0001
				Switchgrass			
2008	0	21.9	1.7	-0.253	0.039	0.0009	0.0002
2008	158	26.4	1.7	-0.250	0.039	0.0007	0.0002
2009	0	13.9	0.7	-0.122	0.016	0.0004	0.0001
2009	158	17.0	0.7	-0.133	0.016	0.0003	0.0001

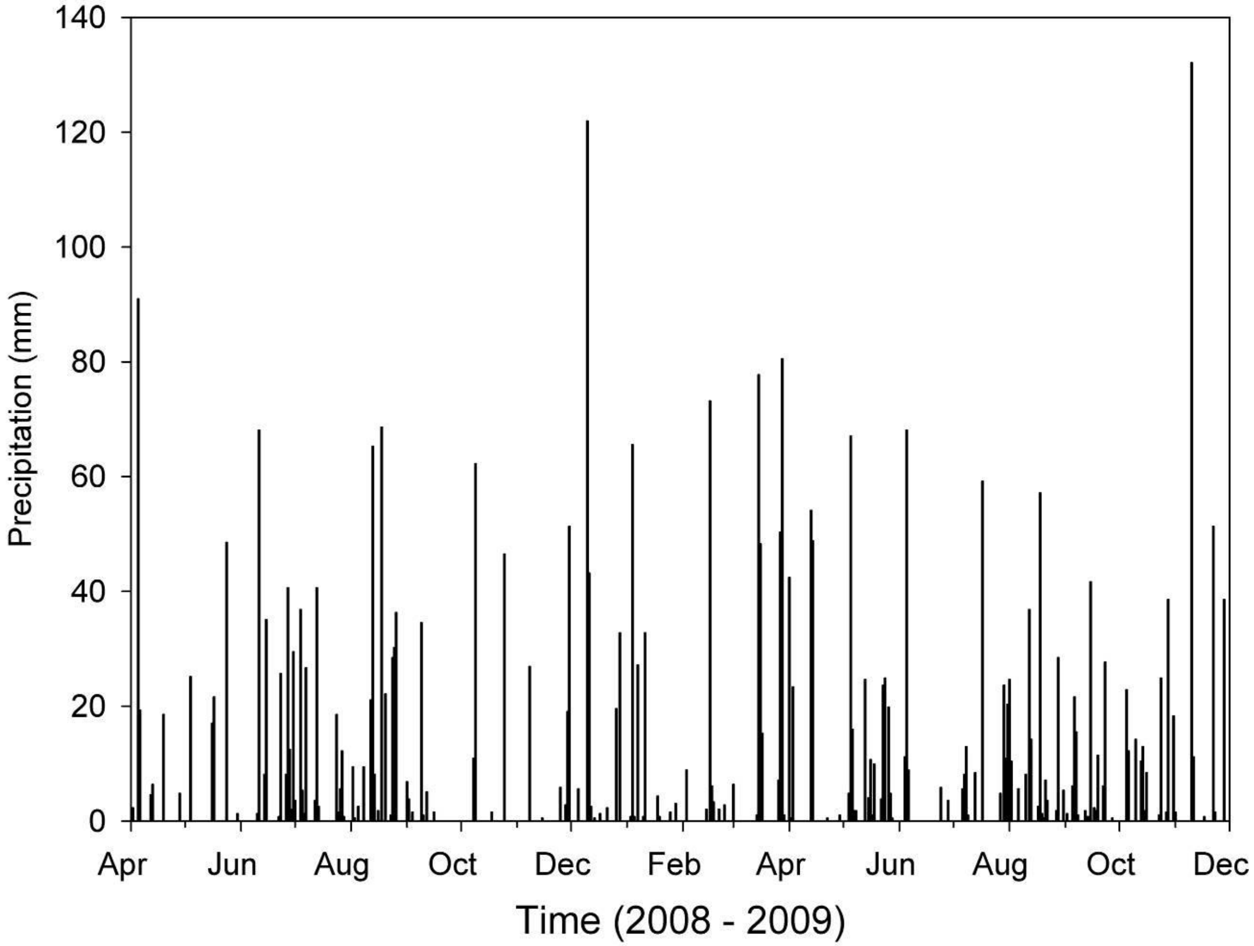

Figure 1. Precipitation at the Brewton Agricultural Research Unit from April 2008 to November 2009.

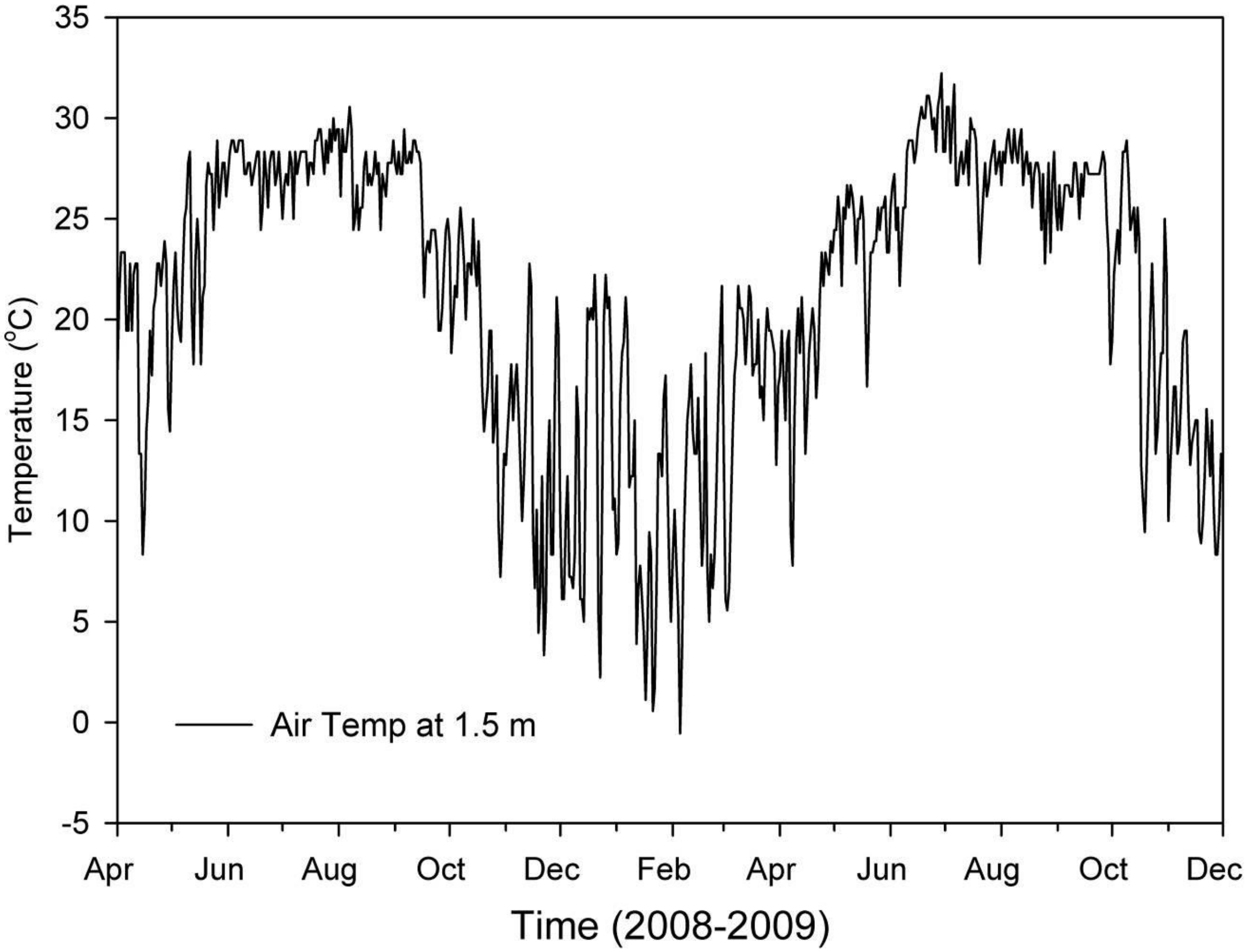

Figure 2. Air temperature at Brewton Agricultural Research Unit from April 2008 to November 2009.

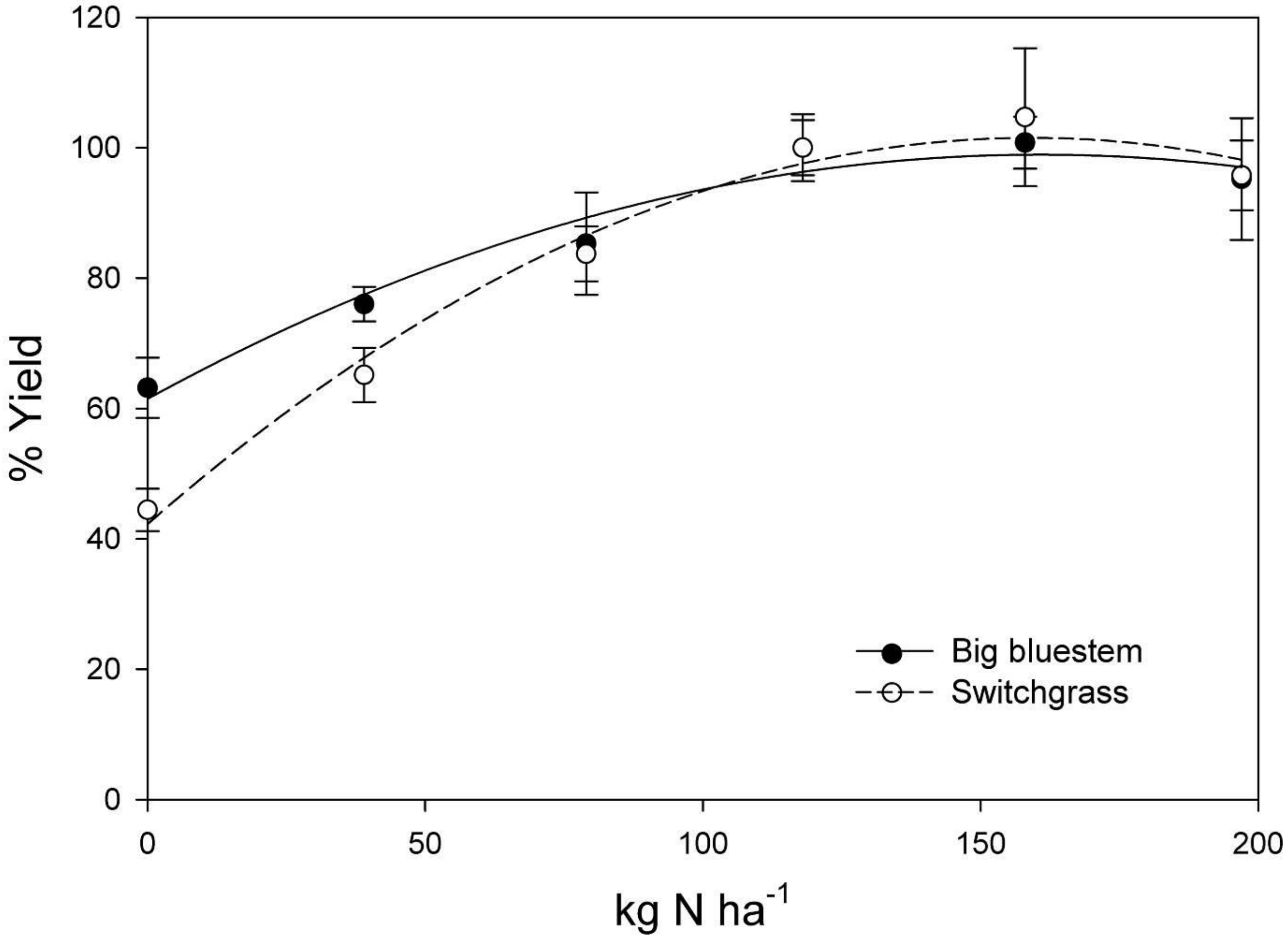

Figure 3. Relative yield of nitrogen treatments for big bluestem and switchgrass normalized across 2008 and 2009. Error bars represent standard errors of the mean.

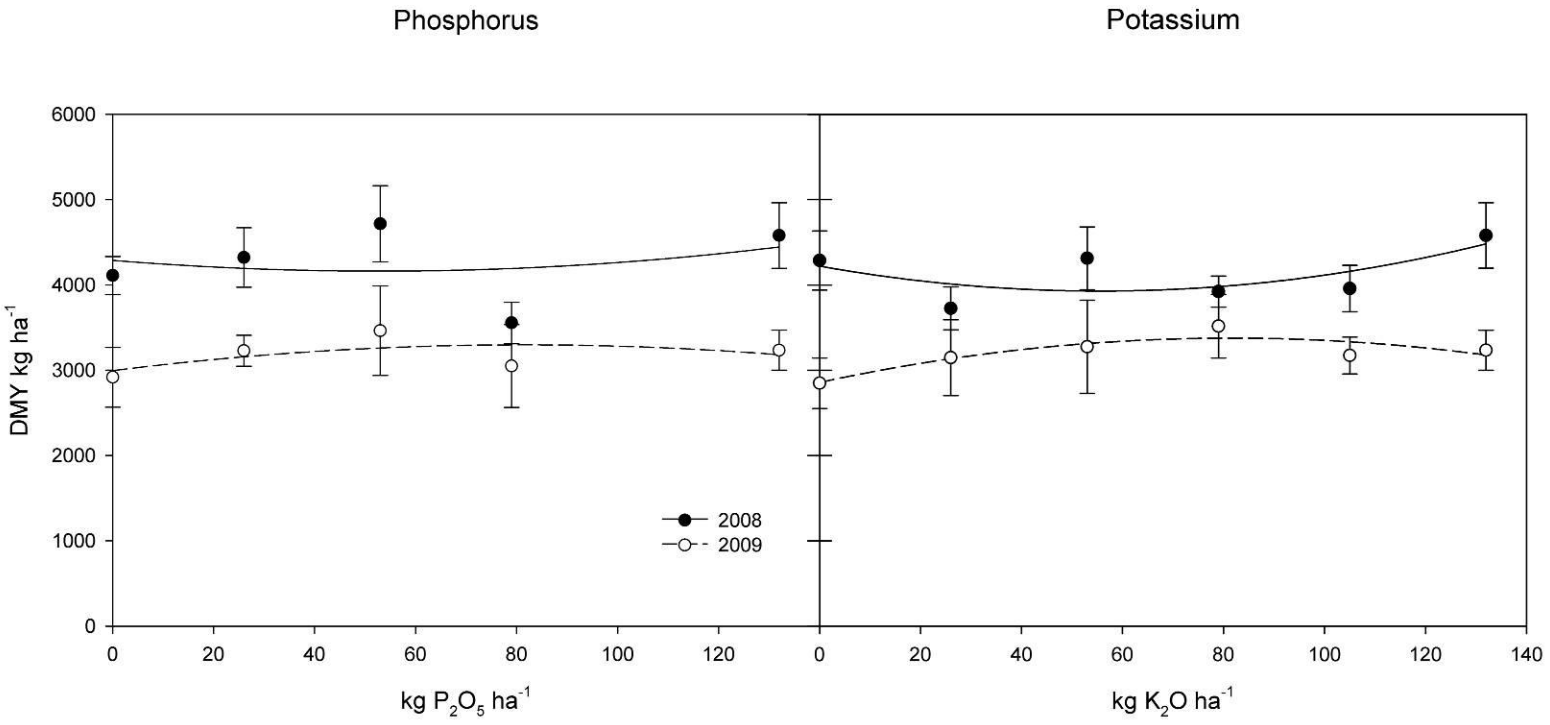

Figure 4. Dry matter yield of phosphorus and potassium treatments for big bluestem in 2008 and 2009. Error bars represent standard errors of the mean.

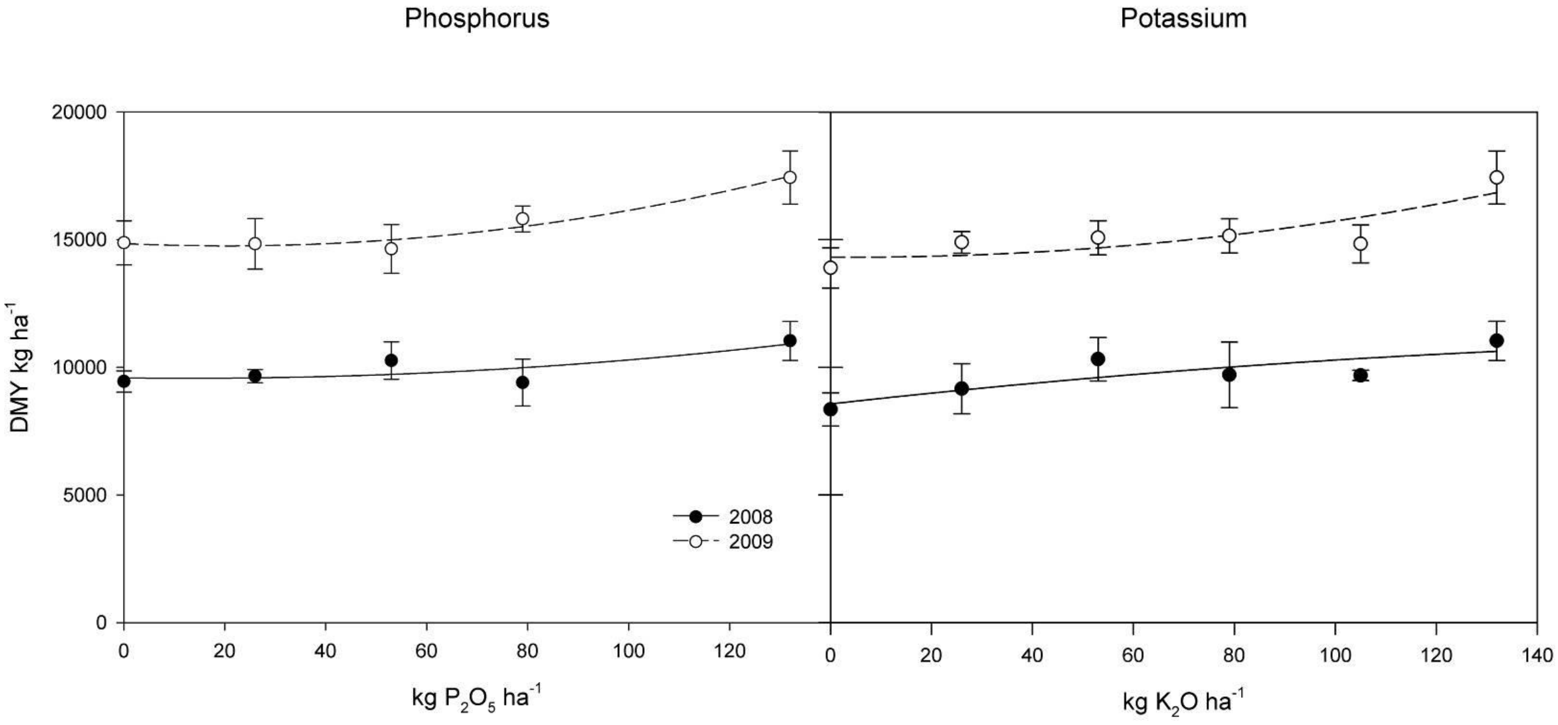

Figure 5. Dry matter yield of phosphorus and potassium treatments for switchgrass in 2008 and 2009. Error bars represent standard errors of the mean.

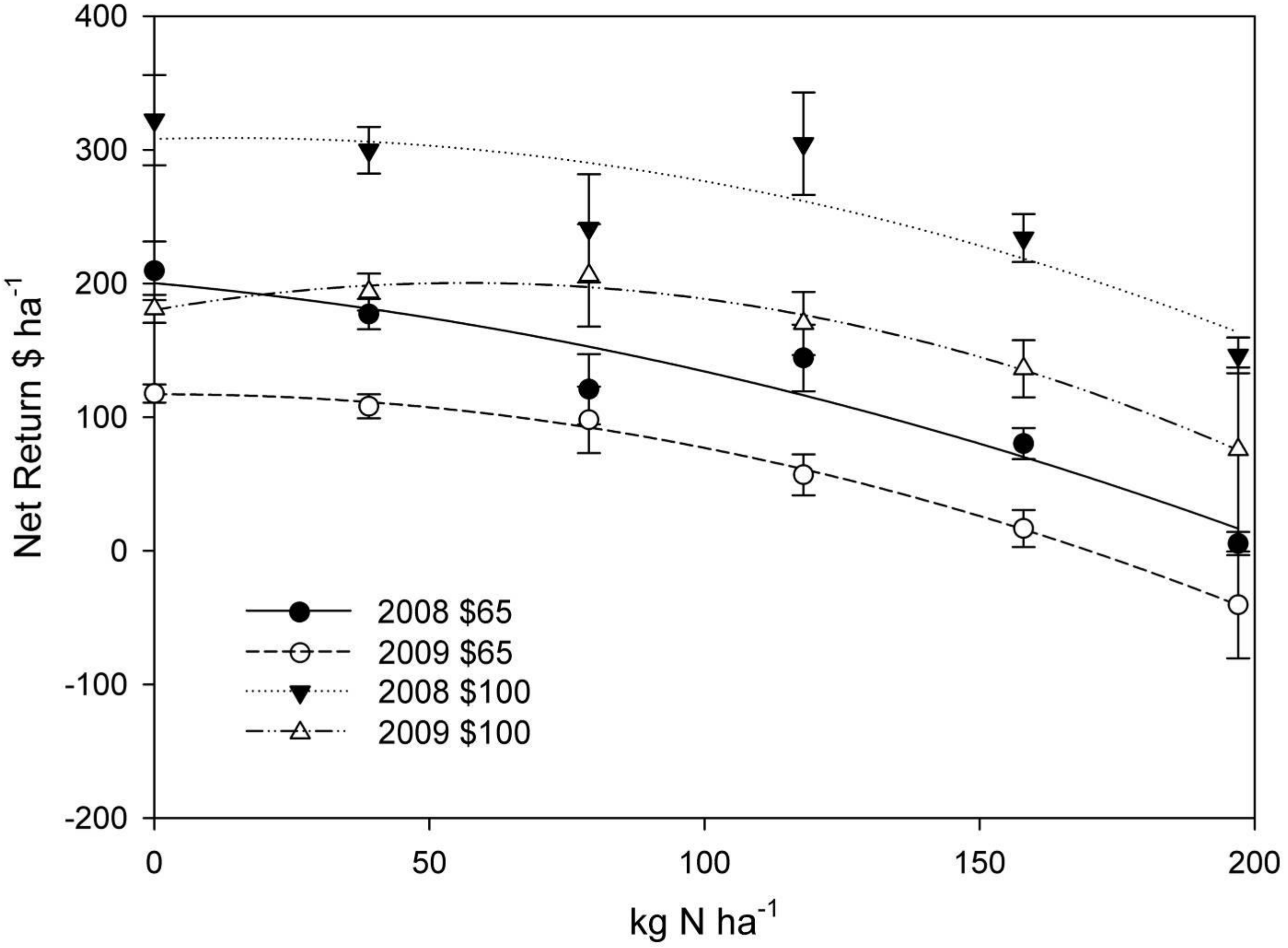

Figure 6. Net return of big bluestem in 2008 and 2009 for nitrogen treatments. Prices were set at \$65 and \$100 Mg^{-1}. Error bars represent standard errors of the mean.

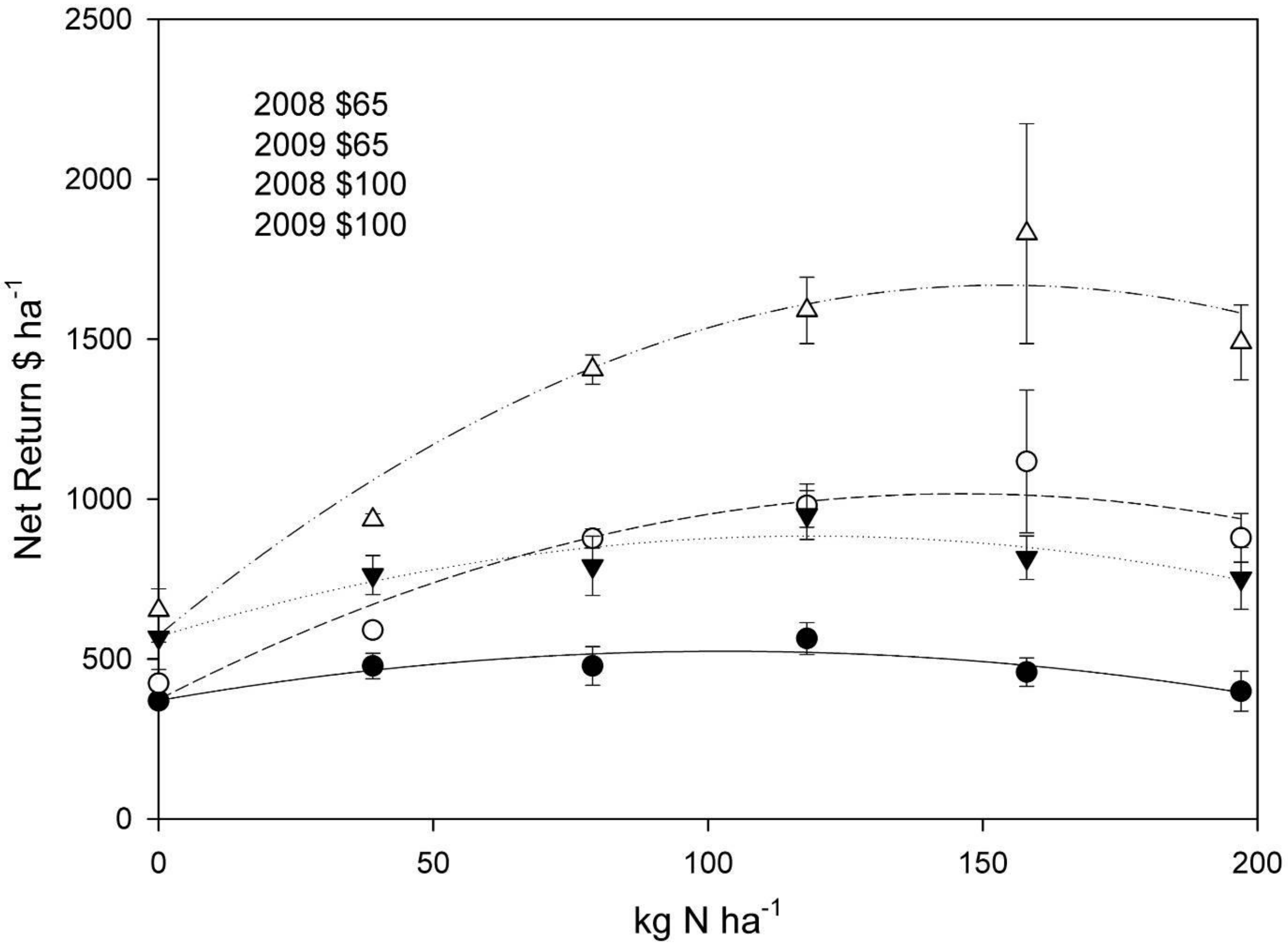

Figure 7. Net return of switchgrass in 2008 and 2009 for nitrogen treatments. Prices were set at \$65 and \$ 100 Mg^{-1}. Error bars represent standard errors of the mean.

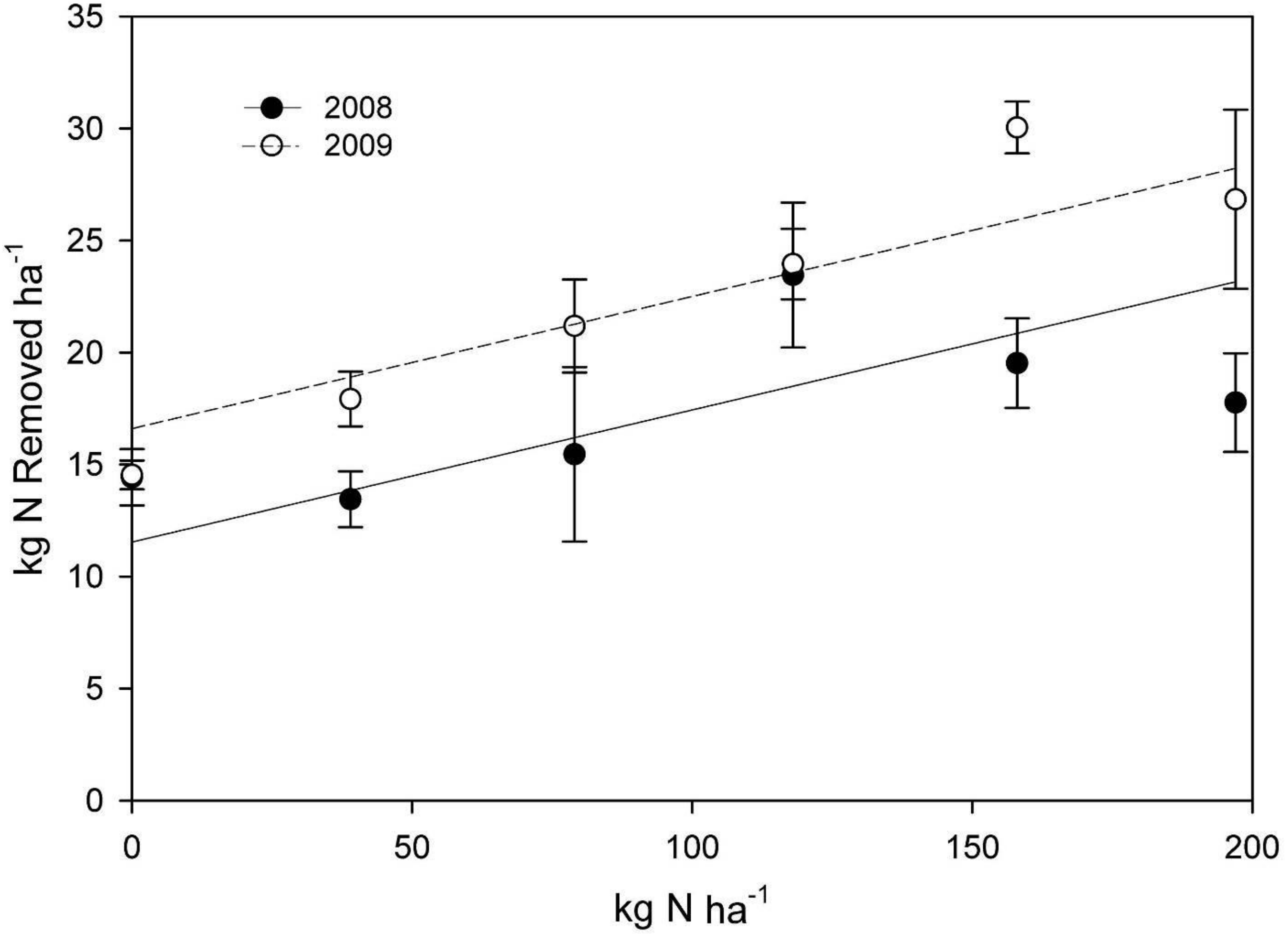

Figure 8. Big bluestem nitrogen removal in 2008 and 2009 for nitrogen treatments. Error bars represent standard errors of the mean.

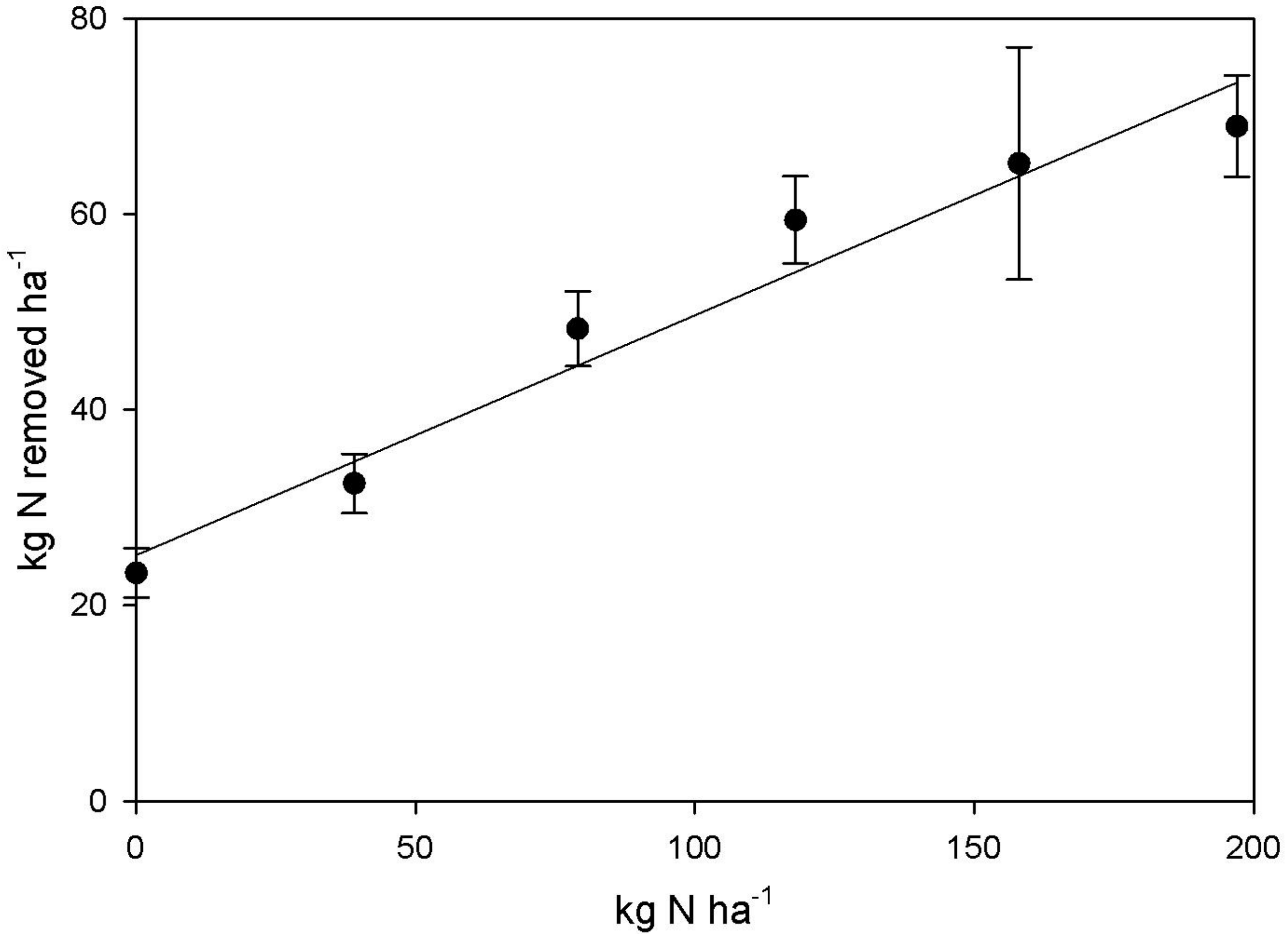

Figure 9. Switchgrass nitrogen removal in 2008 and 2009 for nitrogen treatments. Error bars represent standard errors of the mean.

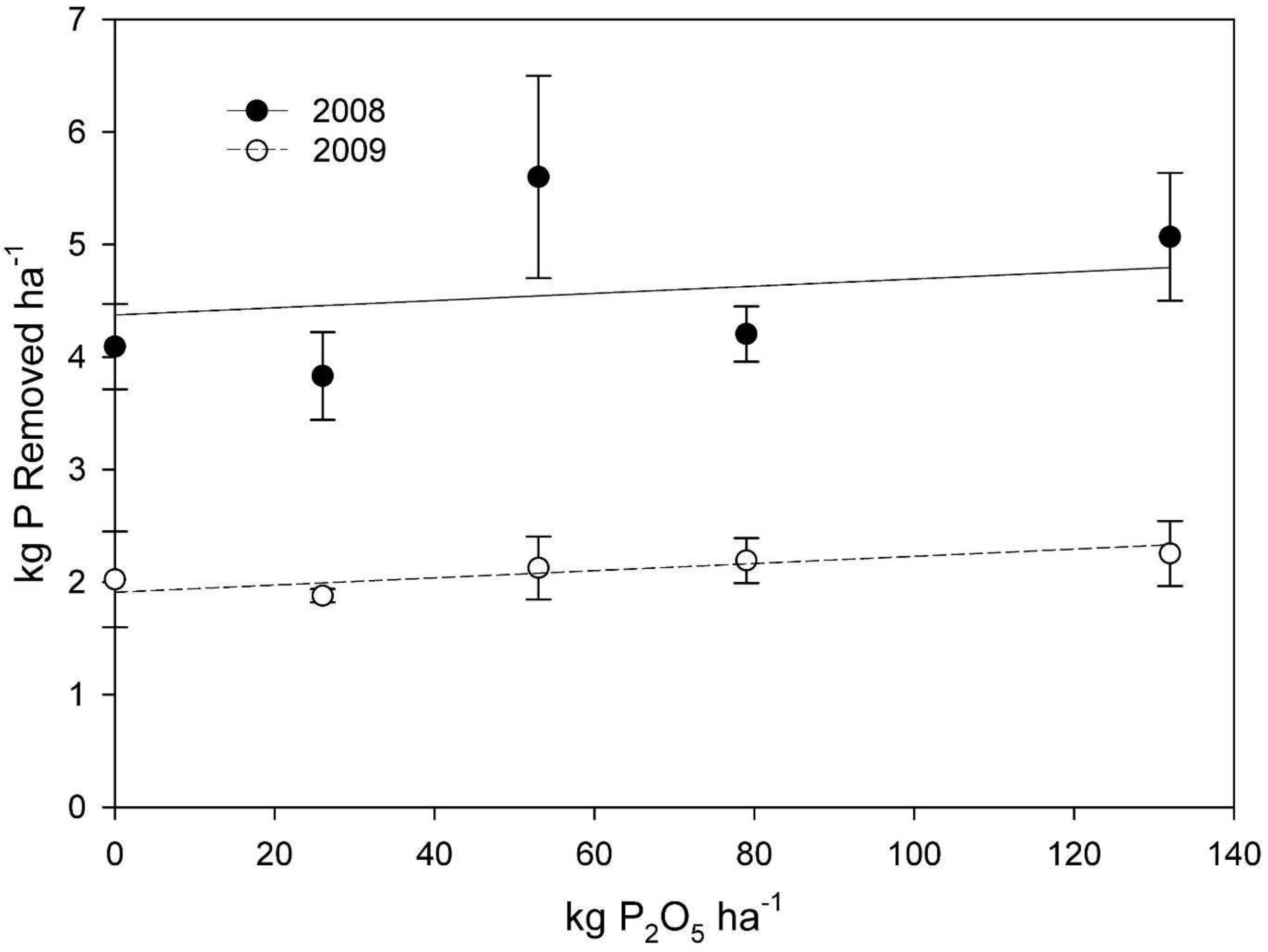

Figure 10. Big bluestem phosphorus removal in 2008 and 2009 for phosphorus treatments. Error bars represent standard errors of the mean.

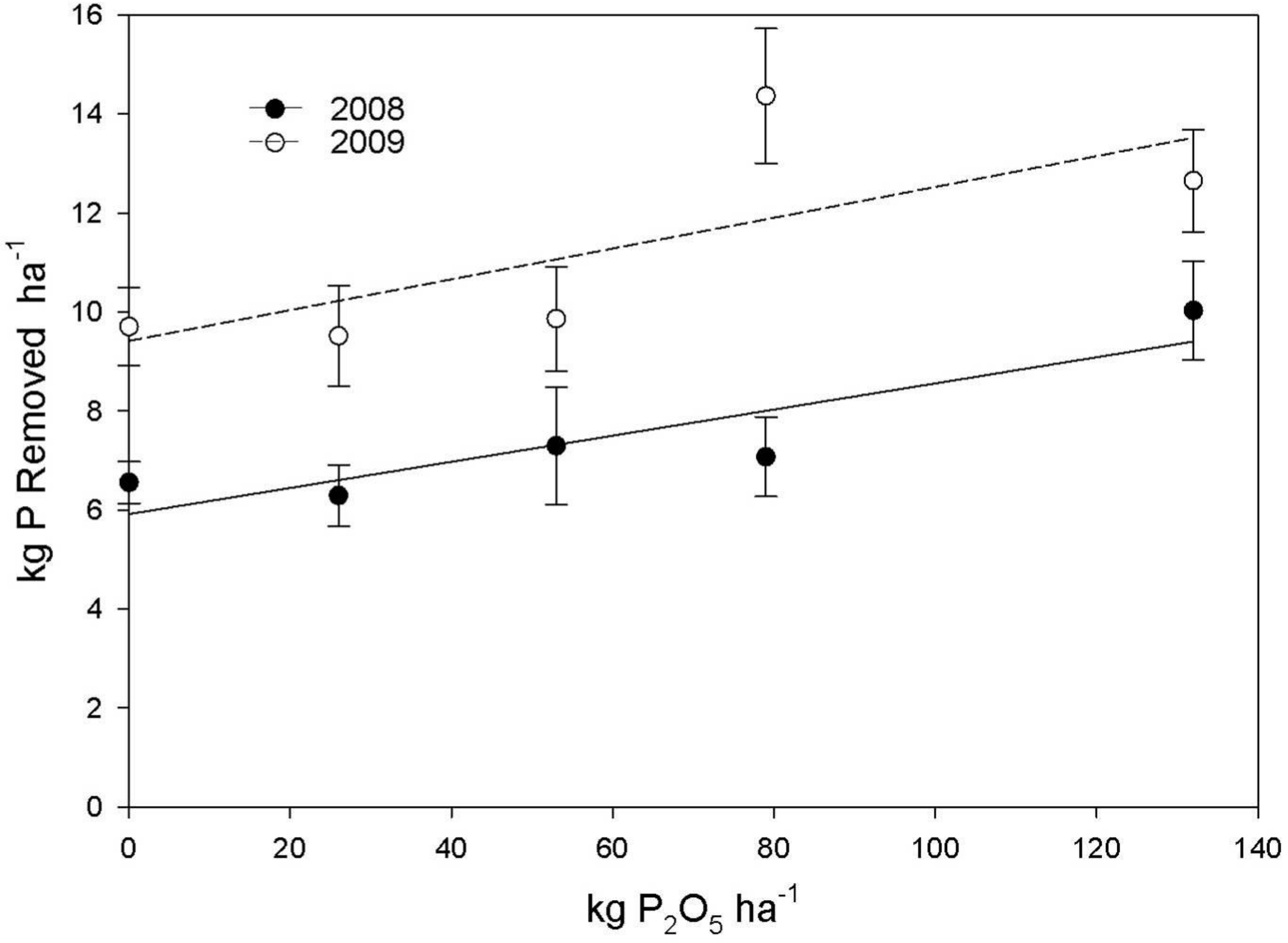

Figure 11. Switchgrass phosphorus removal in 2008 and 2009 for phosphorus treatments. Error bars represent standard errors of the mean.

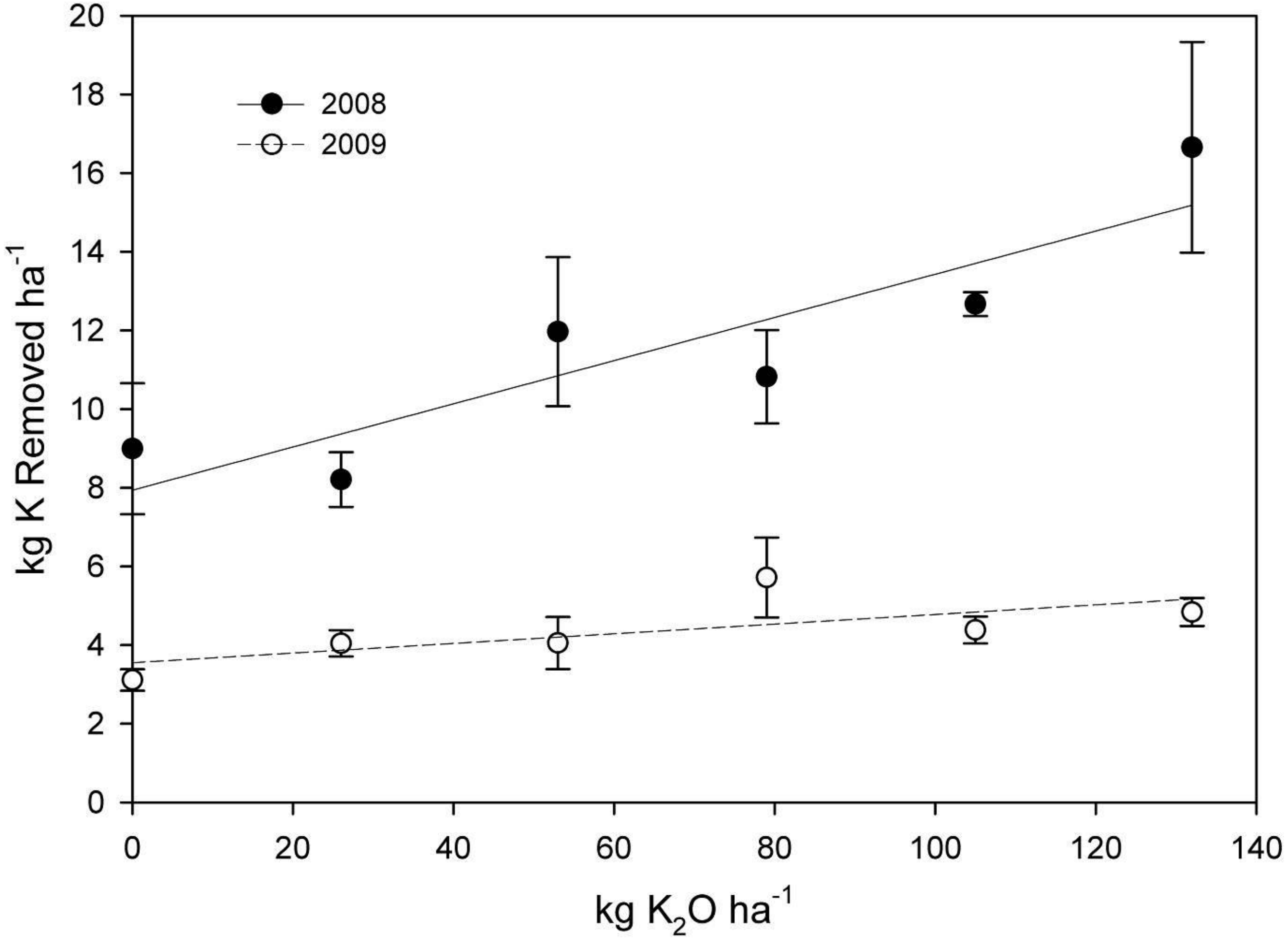

Figure 12. Big bluestem potassium removal in 2008 and 2009 for potassium treatments. Error bars represent standard errors of the mean.

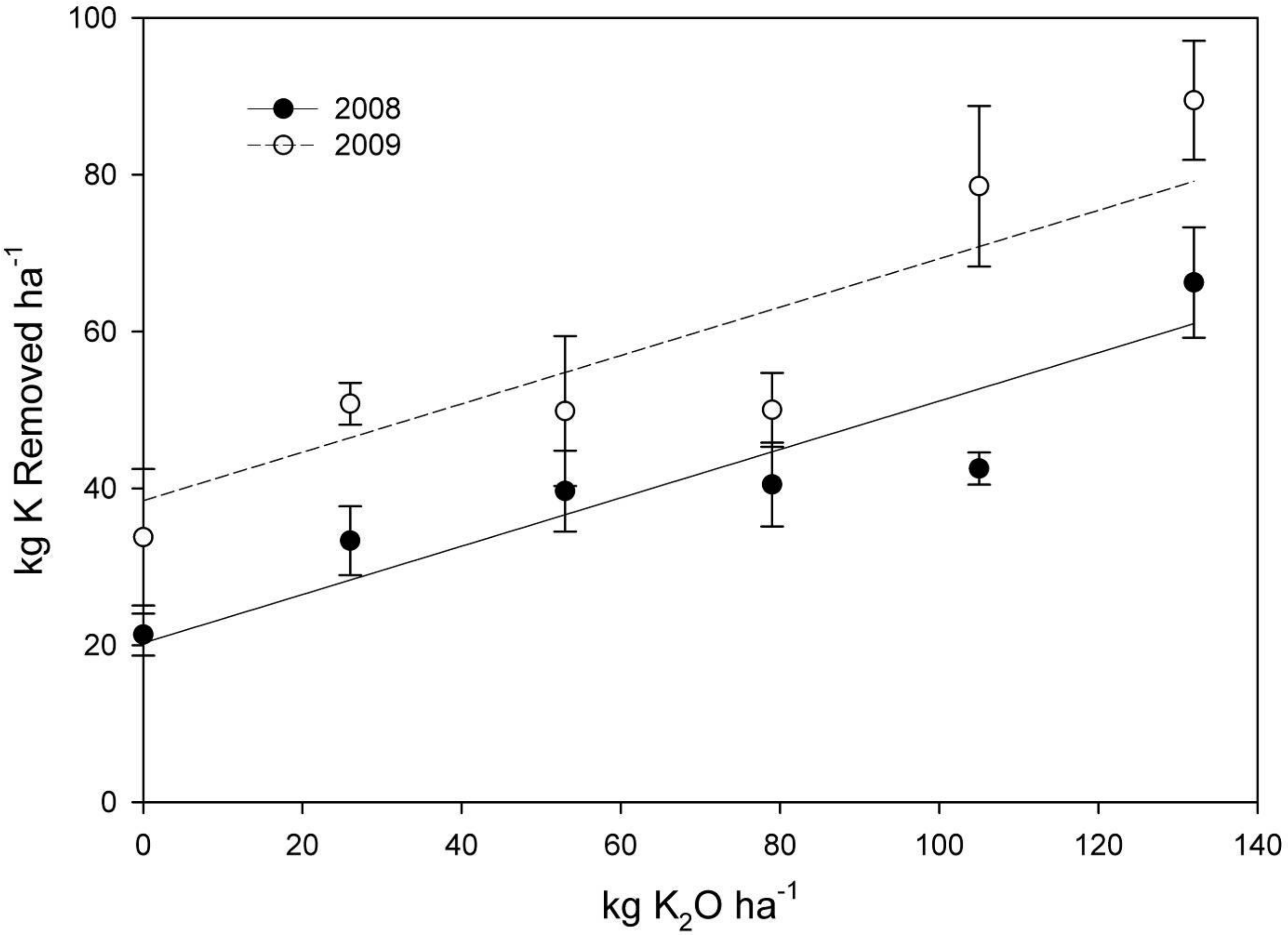

Figure 13. Switchgrass potassium removal in 2008 and 2009 for potassium treatments. Error bars represent standard errors of the mean.

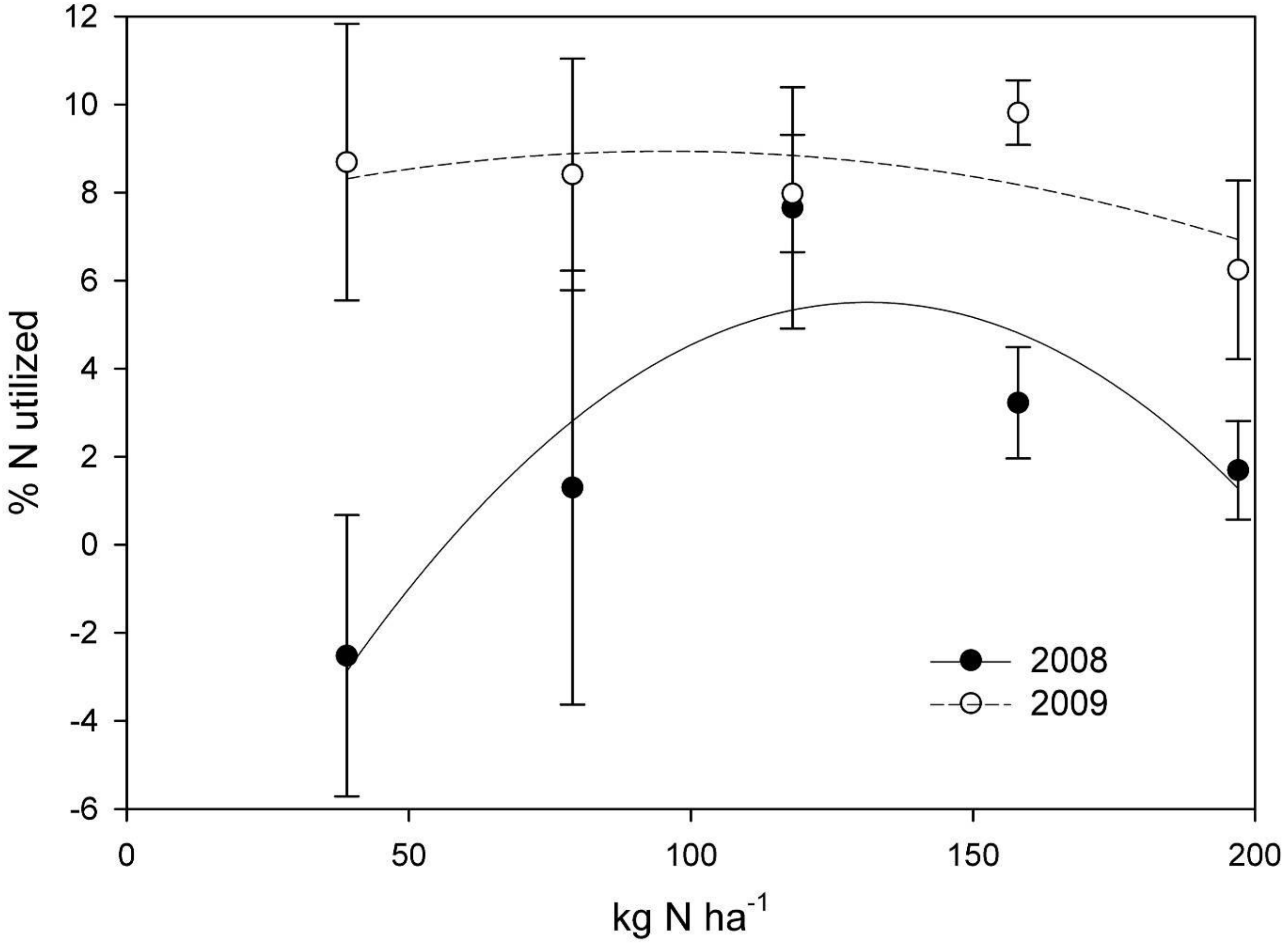

Figure 14. Big bluestem apparent nitrogen recovery during 2008 and 2009. Error bars represent standard errors of the mean.

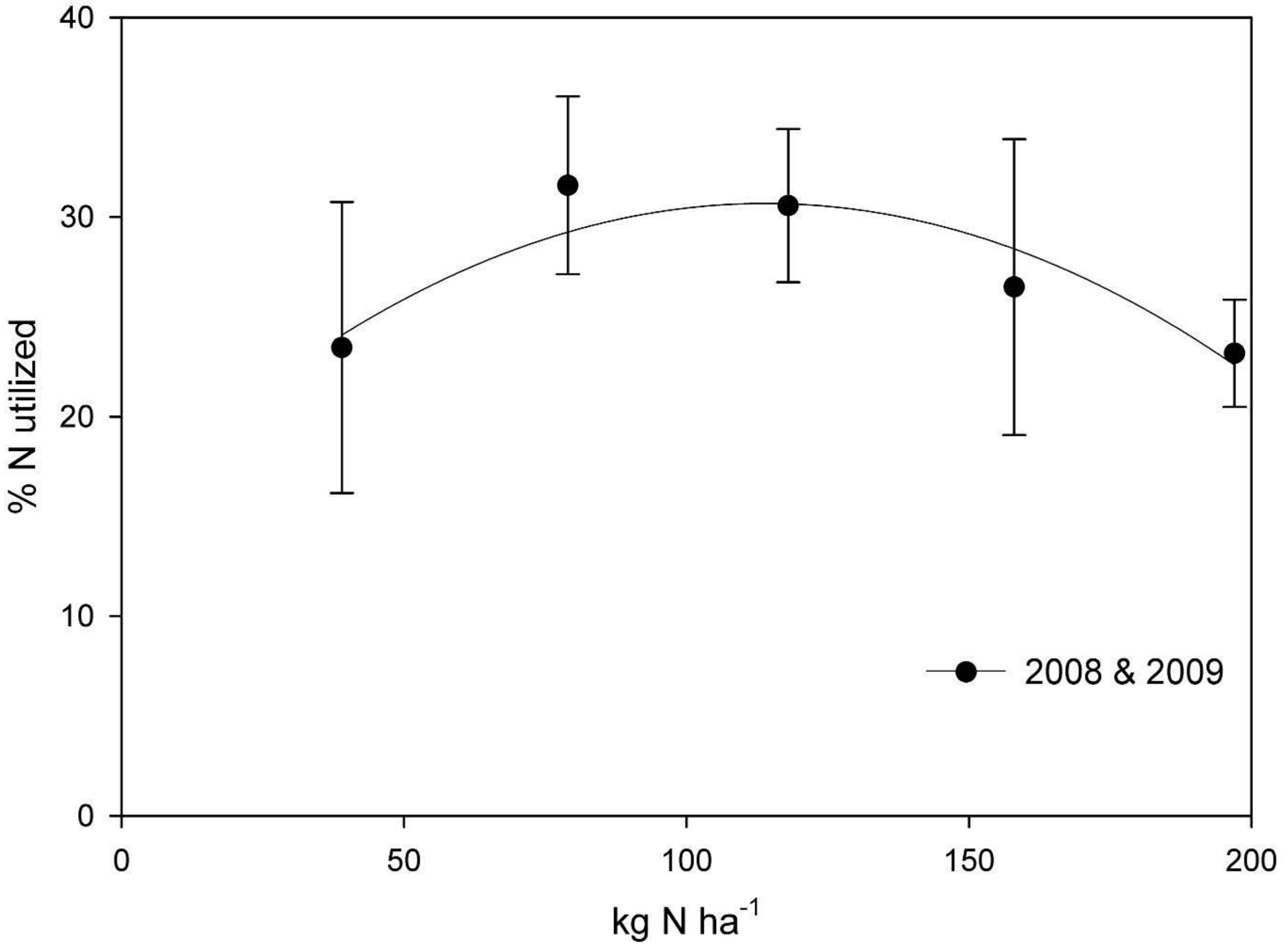

Figure 15. Switchgrass apparent nitrogen recovery across 2008 and 2009. Error bars represent standard errors of the mean.

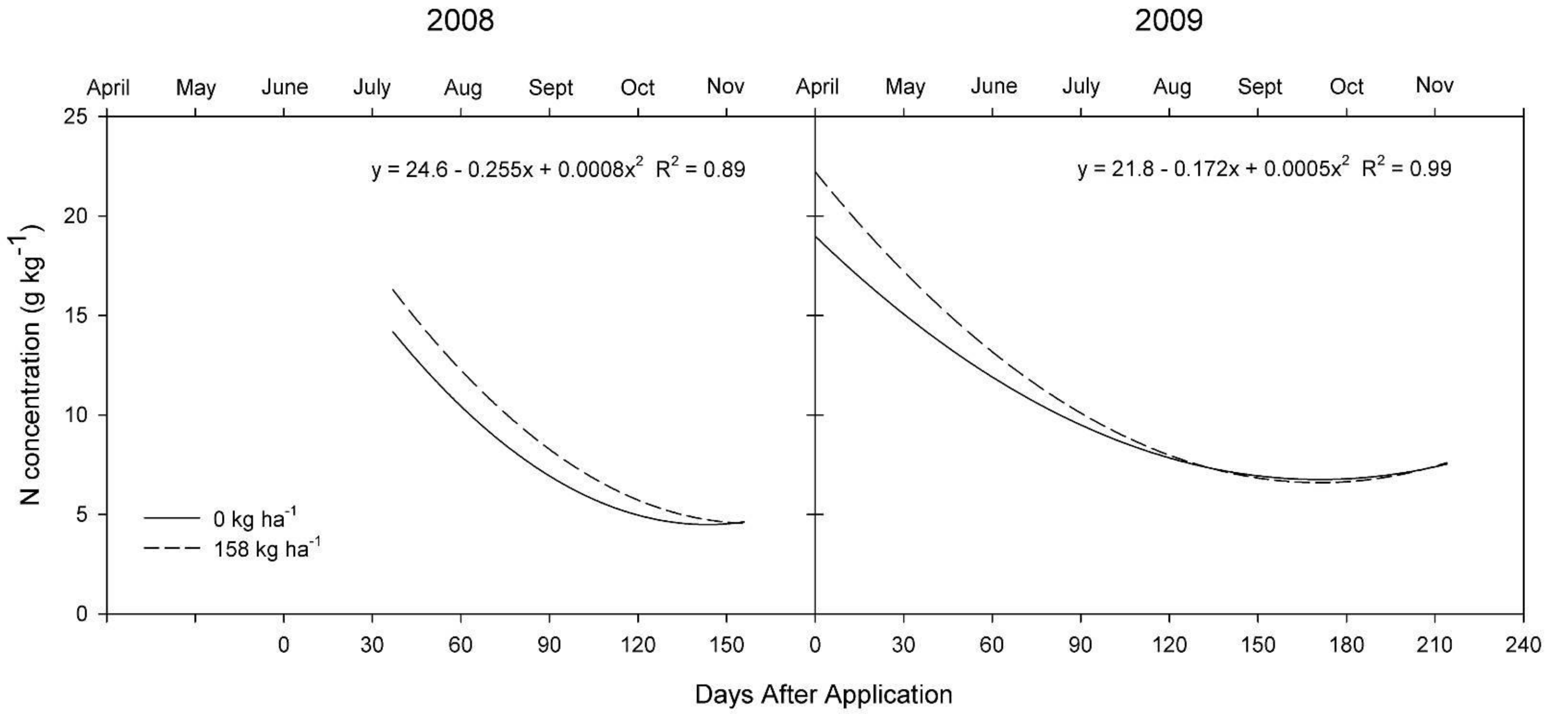

Figure 16. Big bluestem regression lines for 0 and 158 kg N ha^{-1} in 2008 and 2009. Regressions equations and R^2 values represent the 158 kg N ha^{-1} line in each year. R^2 values indicate pseudo-R^2 values for the model on each year.

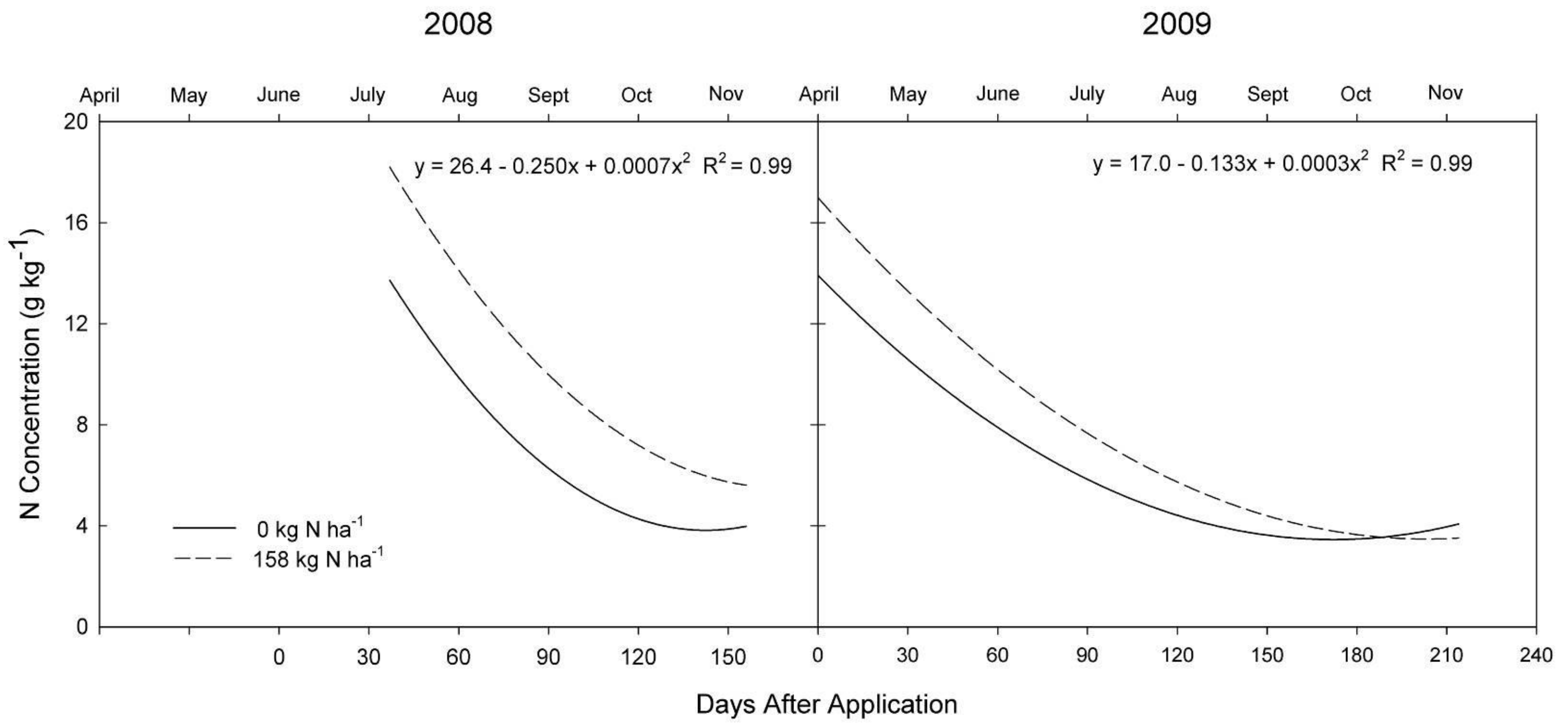

Figure 17. Switchgrass regression lines for 0 and 158 kg N ha^{-1} in 2008 and 2009. Regression equations and R^2 values represent the 158 kg N ha^{-1} line in each year. R^2 values indicate pseudo-R^2 for the model on each year.

III. Effects of Cattle Defecation on Soil Nutrients

Abstract

Cattle (*Bos taurus*) manure is frequently used as an amendment to increase soil fertility. Cattle defecating in fields are a potential source of soil nutrients. The objective of this study was to measure nutrient release from dairy cattle feces and determine its effect on soil nutrients. The experiment was conducted in Auburn, AL from 2008 to 2009 over a winter and summer season. Cattle feces was placed on soil that was managed to eliminate plant uptake. Feces and soil samples were collected throughout each season. Results indicated feces decay occurred quicker in winter than in summer and the release of nutrients from feces was different depending on nutrient and season. Nitrogen (N) was mineralized and released from feces. Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and copper (Cu) were released at greatest rates during the beginning of each season. Feces deposition was shown to affect soil nutrients and chemical properties. Response varied by season and nutrient, but overall the nutrient status of the soil increased.

Introduction

Organic fertilizers are commonly used as soil amendments to increase fertility. Dairy cattle manure usually contains all essential elements needed for plant growth, making it suitable as an organic fertilizer (Eghball, 2002). However, when used improperly the addition of manure can have adverse effects on the environment. Manure contains higher concentrations of N and P relative to other essential plant nutrients. These elements are macronutrients needed in larger quantities for plant growth and prominent non-point source pollutants that can cause eutrophication in aquatic systems. There may also be concerns with nutrient build up in soils, which can pose potential health and environmental risks.

Dairy cattle in pastures defecate throughout the day and leave feces in fields to decompose. The amount of feces excreted by cattle is related to many factors. Body weight is believed to be a primary indicator of amount excreted (Nennich et al., 2005). Milk yield has also been shown to play a role where higher yielding cows excrete more feces and N (Wilkerson et al., 1997). Studies looking at frequency of defecation found that dairy cattle defecate between 10.5 to 16.1 times per day (Aland et al., 2002; Castle et al., 1950; Oudshroom et al., 2006). These same studies investigated spatial distribution, and showed that cattle defecate more frequently around water, resting, and milking areas. These areas are where cattle spend the most time, therefore, making them more susceptible to excess nutrient additions.

Nutrient concentration in manure is affected by many factors including feed intake, feed composition, size, species, housing and rearing management, intake of nutrients, and milk production (Chapluis-Landy et al., 2004; Eghball et al., 2002; Morse et al., 1994; Sorenson et al., 2003; Wilkerson et al., 1997). Lactating dairy cows have been shown to release in urine and feces 0.45, 0.08, and 0.10 kg of N, P, and K day^{-1}, respectively (ASAE Standards, 2005).

Nitrogen is in an organic form in feces and is not directly available for plant uptake (Klausner et al., 1994). Mineralization has to occur in order for N to become available to plants. Nitrogen mineralization rates are dictated primarily by soil temperature, where higher temperatures mineralize more N (Cassman and Munns, 1980; Eghball 2000). Thus, there is no universal standard for N mineralization, and estimates are required for each physiographic and climatic region (Klausner et al., 1994).

Some studies have attempted to quantify nutrient availability using plant uptake. Klausner et al. (1994) observed that 21 percent of N in manure became available within the first year after application. Similar data by Montavalli et al. (1989) suggests 32 percent of N in manure became available within one year after application. A study by Abassi et al. (2007) suggested 23.7 mg kg^{-1} of organic N was released within 120 days after application (DAA). Release rates per day varied from 0.01 to 0.74 mg kg^{-1} day^{-1}.

Phosphorus in dairy manure is mainly in inorganic form. Studies have suggested 75 percent of total P in manure is inorganic P (Eghball, 2002). Phosphorus concentration in manure varies widely and is primarily dependent on P intake (Chapuis-Lardy et al., 2004; Morse et al., 1994). Phosphorus has been shown to be most available immediately after application (Whalen et al., 2000) Looking at P availability in spread manure, Motavalli et al. (1989) suggested 49 percent of P in manure was available within the first year.

Potassium is mainly in the urine portion of manure, where greater than 70 percent of the K is thought to be found (Safely et al., 1985). Potassium in manure is readily available to plants and has an availability similar to K fertilizer (Eghball, 2002). Motavalli et al. (1989) observed 74 percent of K in manure became available to plants within the first year. Potassium is in lower concentrations than N and P, and influences on soil K have only been observed at higher manure application rates (Whalen et al, 2000).

Calcium and Mg are also found in manure bound in organic matter. These nutrients must be mineralized before becoming available to plants (Eghball et al., 2002). Similar to K, they are found in smaller quantities and only at high manure application rates has there been an effect on soil Ca and Mg (Whalen et al., 2000).

Copper and zinc (Zn) are two plant essential micronutrients found in manure. They are added in small doses to livestock feeds to enhance various body functions (National Research Council, 2001). Long-term application of manure may cause Cu and Zn build up in soils beyond a healthy level for plants (Brock et al., 2006). Research examining soil Cu and Zn levels in fields amended with manure over long periods showed that soil Cu and Zn levels were elevated (Brock et al., 2006; Benke et al., 2008).

Since not all nutrients can be managed for crop production, especially nutrients from feces excreted in pasture, it is important to understand the effects these nutrients may have on the soil. No research has focused on nutrients associated with cattle defecation in pastures, and since nutrients are being added to the soil their contribution to soil fertility and environmental problems needs to be understood. The objective of this study was to measure nutrient release from cattle feces and atteudant changes in soil nutrient status in a field situation over time.

Materials and Methods

Research was conducted in 2008 and 2009 at the Auburn University Swine Research Unit (32° 35´ N, 85° 30´ W) on a Marvyn loamy sand (Fine-loamy, kaolinitic, thermic Typic Kanhapludult). Experimental plots were located in a field that was only disturbed by seasonal mowing with a bushhog. Prodiamine was sprayed prior to the experiment and glyphosate was sprayed prior to and during the experiment to inhibit plant growth. The study was arranged in a completely randomized design with four replications. Treatments were dairy feces and an untreated control with sampling dates for each treatment at 0, 1, 3, 7, 14, 21, 28, 56, 84, 112, 140, 168, and 196 DAA (Table 25). Plots were 1 m^2 and randomly assigned to a treatment and sampling date. Experiments took place from October 29, 2008 to May 13, 2009 and April 6, 2009 to October 19, 2009. Plots received the same treatment for each season and manure was placed in the opposite corner of the plot to eliminate cross contamination. Precipitation data was collected on site, and temperature data was obtained through a weather station located near the research unit (Figures 18 and 19).

Holstein and Jersey dairy cattle feces taken from the E. V. Smith Research Center Dairy Unit, Shorter, AL was used in this experiment. Cattle were fed a total mix ration (Table 26). Dairy cattle feces were collected immediately from the field after defecation, placed in containers, and transported to the Auburn University Swine Research Unit to minimize time between defecation and application of feces. Immediately prior to application, feces was mixed thoroughly. To simulate defecation, 1 kg of feces on a wet weight basis was placed on the soil inside a 20 cm diameter PVC pipe that was removed after application.

Manure sampling was conducted by removing and weighing remaining feces on the soil surface. Seven soil samples were then taken with a one inch diameter soil probe from directly underneath the feces. Samples were separated by depth: 0-5 cm, 5-10 cm, and 10-20 cm. Manure and soil samples were then dried at 60° C. Soil samples were sieved to pass a 2 mm screen. Soil samples that were analyzed for total N were further ground with mortar and pestel. Manure samples were ground using a Wiley Mill (Thomas Scientific, Philadelphia, PA) to pass a 1 mm screen.

Soil total N was analyzed on first and last sampling dates of each trial. Manure total N was analyzed for all sampling dates. Total N was determined via dry combustion using a LECO TruSpec CN (LECO Corp, St Joseph, MI). Soil and manure NH_4-N and NO_3-N were extracted with 1 mol L^{-1} KCl and analyzed colorimetrically via the microplate method (Sims et al., 1995). Total P, K, Ca, Mg, Zn, and Cu in manure were analyzed by the dry-ashing method for inductively coupled argon plasma spectroscopy (ICAP) (Hue and Evans, 1986; SPECTRO CIROS CCD). Soil samples were extracted using dilute double-acid (Mehlich I) and analyzed via ICAP to determine P, K, Ca, Mg, Zn, and Cu (Hue and Evans, 1986; SPECTRO CIROS CCD).

Feces nutrients were analyzed statistically by calculating nutrient remaining in manure using the following equation to put nutrients in terms of mass (g): Nutrient remaining = ([Nutrient_i] *Dry Weight_i)/1000 where [Nutrient_i] is the concentration of the nutrient on a given day and Dry Weight_i is the dry weight of feces on a given day. Analysis was conducted separately for manure and soil using PROC NLMIXED and PROC MIXED provided by the Statistical Analysis Systems for nonlinear and linear models, respectively (SAS, 2003). Main effects and interactions were determined using F-tests. Pearson correlation coefficients were determined using PROC CORR.

Results and Discussion

Initial nutrient mass values for feces used in this study are found in Table 27. Initial concentrations of soil nutrients are found in Table 28.

Feces Decay

Dry weight of feces was affected by day after application and season (Table 29). Values for dry weight at the beginning of each season were 126 and 140g for winter and summer, respectively. By the end of the study, dry weight had decreased to 95 g in winter and 76 g in summer (Figure 20). In winter, no feces remained after day 112. The sample date for day 140 was in March 2009 and it is believed that warmer temperatures between day 112 and 140 caused increased microbial activity that decayed feces to a point where it could not be collected (Figure 19). Data showed a linear decline across time that varied with season (Table 30). Regression equations were fitted and are shown in Table 31. These results are similar to those found by Mundus et al. (2008) who observed a similar decrease in dry matter remaining of applied manure across time.

It was expected that season would affect dry weight since summer temperatures should be more favorable for decay. Percent moisture was calculated and graphed to show that in winter feces held more moisture throughout the study (Table 32). In summer, percent moisture was more variable indicating wetting and drying of the feces (Figure 21). This variability in moisture across time could be responsible for the difference in feces decay. Summer conditions may have been less conducive to decay since feces appeared to dry out quicker after rainfall events.

Nitrogen

Nitrogen remaining in feces was affected by day after application and season (Table 29). Values for N remaining ranged from 0.5 to 4.0 g in winter and 0.6 to 3.3 g in summer. Nitrogen remaining exhibited a linear decline across time during both seasons (Table 33). Regression equations were fitted and are shown in Table 31. The effect of season was evident as N loss occurred quicker in winter than in summer (Figure 22). Environmental conditions could have influenced the loss of N where fluctuating temperatures in winter could have increased N release. The drying out of feces in summer may have also slowed the release of N (Figure 21). Mundus et al. (2008) showed a similar decrease in N remaining in feces across time. However, their study observed a plateau trend beyond day 40 that could be attributed to the use of older manure. Lupwayi and Haque (1999) observed 79 percent of N remaining after 15 weeks, which is greater than what we observed in winter where 34 percent remained, but similar to summer where 71 percent remained after the same amount of time. Esse et al. (2001) observed no change in N concentration over time but N released from manure was shown to increase.

Soil total N was affected by season for all depths (Table 34). No treatment effect was found for any depth. Analysis of variance was conducted on each depth to determine differences within season and treatment over time. Least square means for day within seasons and treatments can be found in Table 35. At 0-5 cm, day, season, season*treatment, and day*treatment were found to affect soil total N. In winter, the control did not change while a decrease in soil total N across time was observed on feces plots (Table 36). In summer, the opposite was observed where soil total N in feces treatments did not change while the control showed a decrease across time. At 5-10 cm, soil total N decreased across time in winter feces plots whereas in the control there was no change. Soil total N in summer did not change for either treatment across time. At 10-20 cm, soil total N decreased across time in winter for both treatments while in summer, soil total N did not change for either treatment.

In feces and soil, mineralized forms of N, NO_3-N and NH_4-N, were combined for analysis. In feces, NO_3-N+NH_4-N was affected by season and day after application (Table 29). The data displayed a quadratic response across time (Table 33). Concentrations peaked in winter at 210 mg kg^{-1} on day 49 and in summer at 90 mg kg^{-1} on day 168. The concentrations at the beginning of the study were similar for both seasons, but in winter a steeper increase in NO_3-N+NH_4-N was observed (Figure 23). Regression equations were fitted and are shown in Table 31.

In soil, NO_3-N+NH_4-N was affected by day after application for all depths (Table 34). At 0-5 cm, a treatment effect and a treatment*day interaction were detected. A linear slope trend was observed for both treatments that increased to day 21 for the control and day 26 for feces plots where it then decreased until the end of the study (Table 37). For feces plots, the increase was greater and reached a higher concentration (Figure 24). At the end of the study, NO_3-N+NH_4-N for both treatments was similar. At 5-10 cm in winter, NO_3-N+NH_4-N displayed a cubic trend across time while in summer a linear decrease was observed (Figure 25). No treatment effect was detected at 10-20 cm so data was modeled across treatments. The trend for winter was the same as at 5-10 cm while in summer NO_3-N+NH_4-N did not change. Regression coefficients and inflection points for nonlinear models can be found in Tables 38 and 39.

Pearson correlation coefficients were used to determine if the change in NO_3-N+NH_4-N in feces correlated to the change in soil NO_3-N+NH_4-N at each depth during both seasons. Analysis indicated no correlation between the changes in NO_3-N+NH_4-N in feces and soil NO_3-N+NH_4-N (Table 40). It is possible that this analysis may not recognize a correlation due to the quadratic responses that were seen for NO_3-N+NH_4-N in feces and soil which is caused by the transformation of N in the environment. This may violate the assumption of Pearson correlation coefficients that there is a linear relationship between the data. Nonetheless, strong responses were seen for NO_3-N+NH_4-N in feces and soil NO_3-N+NH_4-N indicating that feces deposition has an effect on NO_3-N+NH_4-N.

The large increase in NO_3-N+NH_4-N concentrations in feces during winter coincides with the higher temperatures that occurred between day 40 and 60 (Figure 19). Since NO_3-N and NH_4-N are products of the mineralization of organic forms of N, this indicates a period of high mineralization. In summer, NO_3-N+NH_4-N leveled off more than in winter indicating a more consistent mineralization over time. The lack of fluctuations in temperature was observed during summer which could have provided constant mineralization over time. The drying out of feces in summer may have prohibited high mineralization as well since moist conditions are needed for optimal mineralization (Figure 21). Evidence of a lag time between feces application and increases in mineral N was observed indicating that N in feces is primarily in organic forms and somewhat resistant to decay. This is similar to ideas offered by Paustian et al. (1997) that animal manures contain a high proportion of recalcitrant material since labile portions have been removed by digestion. These recalcitrant portions are more resistant to decay and could influence N mineralization.

This study suggests that addition of mineralized N to soil at 0-5 cm is not dependent on season. The lack of a season effect could be due to the increase in temperatures during winter from 40-60 DAA (Figure 19). This seems to have increased N mineralization during that time and negated any effect of season. The influence of feces on soil NO_3-N+NH_4-N is evident and there is an increase in N mineralization due to feces application. Mineral N in soil varied across time indicating loss of N through leaching, runoff or volatilization or gain in N through mineralization. Data for all depths indicated that N from feces may be leached, however, the lack of a treatment difference suggests that this may only be due to temporal changes in soil NO_3-N+NH_4-N.

The results of this study are similar to those of Eghball et al. (2000) who observed an increase in amount of N mineralized from manure across time. Abassi et al. (2007) measured mineral N released from manure and observed an initial increase in mineral N at day 40, however, much variation in mineral N was observed during the study. This study also found NO_3-N and NH_4-N were added to the soil. The loss of soil total N could be due to the decay of organic matter that was present on the soil surface at the beginning of the study. The volatilization or runoff of N could also be responsible for losses. Soil total N may not be an effective measure of N released from feces into soil since N can be transformed and lost readily. The measurement of mineral forms of N may provide the best way of determining the release of N from feces into the soil.

Phosphorus

Phosphorus remaining in feces was affected by season and day after application (Table 29). Phosphorus remaining decreased across time at different rates depending on season. Data for both seasons were first fit to linear slope models. In summer, P remaining had a linear decline for both segments while in winter a decline was only observed for the first segment (Table 41). Since no decrease was observed in the second segment, winter data was modeled using a linear plateau model (Figure 26). In summer, the initial rate of decline decreased after day 3 whereas in winter the amount of P remaining in feces after day 73 remained unchanged until feces completely decayed. Rate of P lost from feces varied with season whereas in winter, P was lost at a slower rate (Table 42). In summer, most P in feces was lost within a week after application. This may be due to a rainfall event that occurred immediately after application in summer which could have caused P to be removed soon after application (Figure 18). By allowing feces to remain stable for a longer amount of time before rain in winter, there may have been less chance for P to leach resulting in P being held in feces longer.

Esse et al (2001) and Lupwayi and Haque (1999) observed that P loss was consistent with the loss of dry matter which is similar to the results of this study. In this study, an immediate decrease in P remaining in feces was observed at the beginning of the experiment, which was not found by Esse et al. (2001) or Lupwayi and Haque (1999). Sharpley and Moyer (2000) observed that large amounts of P could be lost due to rainfall events which could relate well to P loss shortly after application in the summer study.

At all depths, extractable soil P was affected by season, treatment, and day after application (Table 34). A treatment*day interaction was observed at 0-5 and 5-10 cm and a season*treatment interaction was detected at 0-5 cm. In winter at all depths, extractable soil P for both treatments increased until a given day and then decrease at a lower rate until the end of the study (Table 43). In winter, the greatest increase in extractable soil P was found at 0-5 cm where it increased until day 52 before decreasing until the end of the study (Figure 27). At 5-10 and 10-20 cm, the same pattern was observed, but increases and decreases occurred at a lower rate. Extractable soil P in the winter control, at all depths, did not increase as much as the feces plots, and the inflection points occurred earlier (Table 44). In summer, extractable soil P increased linearly across time for all depths. The greatest increase occurred at 0-5 cm.

The results of the winter data correspond well to the results found by Whalen et al. (2000) who observed an increase in inorganic soil P immediately after application. Whalen et al. (2001) also showed an increase in inorganic soil P during the first 12 weeks and then a decline thereafter. Sharpley et al. (2004) observed the accumulation of P in soil after long-term applications of manure. Increases in extractable soil P in this study relate well to the increase in extractable soil P found by West et al. (1989) who observed that extractable soil P in pastures was greatest around water sources. Implications for cattle defecation around water sources are evident in this research, since extractable soil P can be increased from a single defecation event. The difference in treatments is important since both treatments had the same pattern across time but at different concentrations. The increase in extractable soil P in the control is most likely due to decay of organic matter on the soil surface at the beginning of the study. The results observed in summer may be due to the rainfall event immediately after application that could have removed P from feces (Figure 18). This rain event may have removed P via runoff, thus not allowing the P in feces to have the same effect on extractable soil P as was observed in winter.

Pearson correlation coefficients were used to determine if the decrease in P remaining in feces correlated to the change in extractable soil P at each depth during both seasons. Analysis showed that at 0-5 cm there was an inverse correlation for both seasons (Table 40). At 5-10 cm a correlation was observed during summer but not winter. No correlation was detected at 10-20 cm for either season. This suggests that the loss of P from feces corresponds to the increase in extractable soil P. The best correlation can be found at 0-5 cm, indicating that P in feces will influence extractable soil P at this depth. Below 5 cm the release of P from feces may not correspond to the changes in extractable soil P.

Potassium

Potassium remaining in feces was affected by season and day after application (Table 29). Data displayed a linear plateau response across time (Table 45). Both seasons had a decrease in K remaining until a certain day where it remained the same until the end of the study (Figure 28). Days when K remaining stopped declining were 31 and 22 DAA for winter and summer, respectively. Regression coefficients can be found in Table 42. This data suggests that most K in feces is removed within the first month after application. The rapid release of K is caused by the lack of the ability of feces to hold large amounts of soluble K. The feces are able to maintain some K within feces which is expressed by the linear plateau models used in this study. Organic matter in feces does have cation exchange capacity (CEC) allowing it to hold some K.

These data are consistent with that of Safely et al. (1985) who suggested that K in manure is highly soluble and can move out of manure quickly. Lupwayi et al. (1999) observed 9.9 percent of K was remaining which is similar to results seen in this study which showed 21 and 20 percent remaining after the same amount of time. Esse et al. (2001) and Lupwayi et al. (1999) observed high solubility of K and high removal soon after application which is similar to the immediate loss of K from feces observed in this study.

Extractable soil K was affected by day after application for all depths (Table 34). Season and treatment effects were found at 0-5 and 5-10 cm. A day*treatment interaction was detected at 0-5 cm. In winter, data for 0-5 and 5-10 cm were fitted to linear slope models to show the increase in extractable soil K to a certain day before showing a decline until the end of the study (Figure 29). Extractable soil K in feces plots at 0-5 and 5-10 cm during winter increased and then decreased at a lower rate until the end of the study (Table 46). At 5-10 cm during winter, extractable soil K had a similar trend across time for both treatments. In summer at 0-5 and 5-10 cm, extractable soil K was modeled using a linear model. Changes in extractable soil K were only found at 0-5 cm where extractable soil K decreased across time in both treatments. Data for 5-10 cm during summer showed no response across time. An increase in extractable soil K was observed at 0-5 cm immediately after application but the data was not modeled to show this increase since day 0 was the only time where values were lower. Data for 10-20 cm was modeled linearly across seasons and treatments. Extractable soil K showed a small decrease over time across seasons (Figure 30). Regression coefficients and inflection points for nonlinear models can be found in Table 47.

The results of the winter data suggest that K in feces may be available soon after application. This is similar to Safely et al. (1985) who suggested that K in manure is readily available. Whalen et al. (2000) also observed changes in available soil K at high application rates of cattle manure. The effect of season was apparent in this study and may have been influenced by the occurrence of rainfall immediately after application in the summer study that could have removed K from feces (Figure 18). This study suggests that feces can influence extractable soil K within 10 cm. Additionally seasonal effects were shown to influence extractable soil K, but since no season*treatment interaction was found it is suggested that any change due to season has the same effect on soils with or without the addition of feces.

Pearson correlation coefficients were used to determine if the decrease in K remaining in feces correlated to the change in extractable soil K at each depth during both seasons. Analysis indicated no correlation between the changes in K remaining in feces and extractable soil K (Table 40). This analysis may not recognize a correlation due to the nonlinear nature of the data which is caused by the high mobility of K. This may violate the assumption of Pearson correlation coefficients that there is a linear relationship between the data. Nonetheless, strong responses were seen for K remaining in feces and extractable soil K indicating that feces deposition has an effect on extractable soil K.

Calcium and Magnesium

Calcium and Mg remaining in feces were affected by season and day after application (Table 29). Data for both elements revealed an initial decrease across time during both seasons (Figures 31 and 32). Calcium and Mg remaining were fitted to segmented linear slope models. In summer data showed a decline for both segments while in winter, a decline was only observed for the first segment (Table 48). For the winter data of both elements, a linear plateau model was deemed more suitable. Inflection points for Ca and Mg remaining in winter were 69 and 45 DAA, respectively. In summer, the inflection points occurred at 3 DAA for both elements. In summer, a steep decline in Ca and Mg remaining was observed until day 3 where the rate of decline decreased. In winter, no decline was observed after days 69 and 45 for Ca and Mg remaining, respectively. Regression equations can be found in Table 42. Similar conclusions can be made for Ca and Mg as were made for K. The rainfall event immediately after application in summer may have been responsible for removing Ca and Mg from the feces (Figure 18). Even though Ca and Mg may not be as soluble and easy removed as K, they may still be removed relatively easily in fresh feces. The feces in winter did not receive rainfall until 9 DAA allowing the feces to remain stable longer. Calcium and Mg in manure are known to be bound to organic matter, however, this study suggests that in fresh feces, Ca and Mg may be more soluble (Fletcher and Beckett, 1987). The differences in season may be due to the cooler temperatures observed in winter months where less Ca and Mg are mineralized. This study disagrees with the results of Lupwayi and Haque (1999), who observed an increase in Ca and Mg remaining that was attributed it to immobilization by manure. Eneji et al. (2003) reported data similar to this study where Ca and Mg were mineralized and released from manure over time.

Extractable soil Ca was affected by treatment and day after application at all depths (Table 34). Season only affected extractable soil Ca at 5-10 and 10-20 cm. At 0-5 cm, linear regression was conducted across seasons and no change in extractable soil Ca across time was observed for either treatment (Table 49). At this depth extractable soil Ca was greater in plots where feces was deposited (Figure 33) At 5-10 and 10-20 cm, linear slope models were used for feces plots in winter while all other data was analyzed by using linear regression. In the control plots, no response was observed during either season at 5-10 or 10-20 cm (Figure 34). At 5-10 and 10-20 cm during the winter in feces plots, extractable soil Ca had a linear slope response across time with an initial increase in extractable soil Ca until day 49 at 5-10 cm and day 84 at 10-20 cm before decreasing at a lower rate until the end of the study. In summer, no response across time was detected for either treatment at 5-10 or 10-20 cm. Regression coefficients and inflection points for nonlinear models can be found in Table 50.

This data disagrees with the conclusions of Whalen et al. (2000) who observed an increase in available soil Ca immediately after application. Sharpley et al (2004) found an increase in extractable soil Ca on soils applied with manure. A treatment difference was found for all depths. Thus, it can be suggested that extractable soil Ca is affected by the addition of feces, however, there may be little change across time. Since at 0-5 cm no response in extractable soil Ca across time was observed, it is difficult to suggest that at lower depths there was a change in extractable soil Ca. Seasonal changes in extractable soil Ca were observed but, since no season*treatment interaction was found the response of season and treatment is the result of their respective effect on extractable soil Ca.

Extractable soil Mg was affected by treatment for all depths (Table 34). Season and day after application effects were observed at 0-5 and 10-20 cm but not at 5-10 cm. Treatment was the only source that was found to affect extractable soil Mg at 5-10 cm where extractable soil Mg was greater in feces plots. In winter, feces plots were fitted to linear slope models. Extractable soil Mg in winter feces plots increased until day 39 for 0-5 cm and day 84 for 10-20 cm before decreasing until the end of the study (Figure 35). Control plots in winter showed no change in extractable soil Mg across time (Table 51). In summer, data was modeled via linear regression. Extractable soil Mg in feces plots was observed to decrease across time at 0-5 cm while at 10-20 cm extractable soil Mg did not change. Similar results were observed in summer control plots where there was a decrease in extractable soil Mg across time at 0-5 cm and no change at 10-20 cm. Regression coefficients and inflection points for nonlinear models can be found in Table 52.

Results from winter correspond to those found by Whalen et al. (2000) who showed increases in available soil Mg immediately after application. Summer data did not follow this trend, and only decreases were observed across time. Whalen et al. (2000) also only observed the increase in available soil Mg at high manure application rates. This study suggests that small deposits of feces can affect extractable soil Mg directly under the feces. Seasonal effects can be observed at 0-5 and 10-20 cm, however since no season*treatment interaction was detected the effect of each is thought not to be related. Feces had the greatest effect on extractable soil Mg within 5 cm and limited responses were observed below that depth

Pearson correlation coefficients were used to determine if the decrease in Ca and Mg remaining in feces correlated to the change in extractable soil Ca and Mg at each depth during both seasons. Analysis indicated a correlation at 0-5 cm in winter for both elements (Table 40). No correlation was found at 5-10 or 10-20 cm during either season.

This suggests that when Ca and Mg remaining in feces decreases there is an increase in extractable soil Ca and Mg within 5 cm during the winter. During summer at 0-5 cm, the change in extractable soil Ca and Mg was not correlated to the decrease in Ca and Mg remaining in feces.

Copper and Zinc

Copper and Zn remaining in feces were affected by season and day after application (Table 29). A linear plateau model was the best fit for Cu remaining indicating an initial loss then after a certain day Cu remaining stayed the same until feces completely decayed (Figure 36). Regression coefficients can be found in Table 42. The initial loss of Cu was different for each season with the decline being steeper in summer. The point where Cu remaining stopped decreasing was 42 and 3 DAA for winter and summer, respectively (Table 53). Zinc remaining across time showed a linear decrease for both seasons (Table 54). The response of Zn remaining was different for both seasons suggesting that the loss of Zn was more rapid in winter (Figure 37). Regression coefficients can be found in Table 31.

Since in summer a rainfall event occurred immediately after application, this data suggests that Cu can be removed from feces when rainfall events occur soon after deposition (Figure 18). A similar drop was observed in Zn remaining, but it was not enough to justify using a segmented linear model. This loss of Zn may have contributed to the slower decline in Zn remaining in summer. These results suggest that if allowed to stabilize, Cu and Zn may be released slower. Copper and Zn can be held tightly to organic matter, however, these results suggest that these nutrients may not be held as tightly in dairy feces immediately after deposition (Fletcher and Beckett, 1987). The effect of season may also contribute to the rate of Cu and Zn loss across time.

Extractable soil Cu was only affected by day after application for all depths (Table 34). Data for all depths was analyzed across treatments using linear regression. At 0-5 cm, a season effect was observed and data was analyzed within season while all other depths were analyzed across season (Table 55). At 0-5 cm, an increase was observed for summer while in winter, extractable soil Cu did not change (Figure 38). Extractable soil Cu showed increases at both 5-10 and 10-20 cm (Figure 39). Regression coefficients for linear models can be found in Table 56.

Extractable soil Zn was affected by day after application for all depths (Table 34). Season and treatment effects were found at 0-5 and 5-10 cm. A treatment*day interaction was found at 5-10 cm. A linear slope model was used for the feces treatment in winter at 0-5 cm. Otherwise, linear regression analysis was conducted at all depths, seasons, and treatments. At 0-5 cm, no change in extractable soil Zn across time in control plots was observed for either season while changes in extractable soil Zn varied by season in feces plots (Table 57). Data for feces treatments in winter displayed a linear slope trend where extractable soil Zn increased until day 70 then decreased until the end of the study (Figure 40). In summer feces plots, extractable soil Zn decreased linearly throughout the study. At 5-10 cm, data was modeled across seasons. A response in extractable soil Zn was only found in the control plots (Figure 41). At 10-20 cm, data was modeled across seasons and treatments but no change in extractable soil Zn was found. Regression coefficients and inflection points for nonlinear models can be found in Table 58.

Pearson correlation coefficients were used to determine if the decrease in Cu and Zn remaining in feces correlated to the change in extractable soil Cu and Zn at each depth during both seasons. Analysis indicated the changes in extractable soil Cu at all depths were not correlated to the change in Cu remaining in feces (Table 40). Extractable soil Zn was only correlated to Zn remaining in feces at 0-5 cm during the winter. A positive correlation was observed at 5-10 cm during the summer but it is difficult to suggest that the loss of Zn from feces results in the loss of extractable soil Zn.

This study suggests that extractable soil Cu is not affected by the addition of feces, but extractable soil Zn is at 0-5 and 5-10 cm. The effects of Cu and Zn added to the soil from manure have only been observed on fields where manure has been applied over long periods of time (Benke et al., 2008 and Brock et al., 2006). The results of this study are consistent with those of Chang et al. (1991) who observed no increase in extractable soil Cu and an increase in extractable soil Zn with increasing rates of manure applied. Even though a single defecation event may have only a small effect on extractable soil Cu and Zn, the effect of constant feces deposition in pastures over long periods of time may be prominent.

pH

Feces pH was affected by season and day after application (Table 29). Initial pH of feces was 8.2 for winter and 8.0 for summer and by the end of each experiment it had decreased to 7.2 for both seasons. A linear decrease was shown across time for both seasons (Table 54). In winter, feces pH decreased more rapidly than in summer (Figure 42). Regression coefficients can be found in Table 31. The decrease in feces pH could be attributed to the mineralization of N. The conversion of organic N to NH_4–N then to

NO_3–N creates acidity and lowers the pH. Since NO_3–N+NH_4-N increased throughout both seasons it is suggested that mineralization is occurring which would lower the feces pH.

Soil pH was affected by season and day after application for all depths (Table 34). Treatments effects were observed at 0-5 and 5-10 cm, but not at 10-20 cm. At 0-5 cm, the response of soil pH varied by season. In winter, feces plots showed a linear slope trend that increased until day 84 then decreased until the end of the experiment (Figure 43). A linear increase across time was observed for control plots during winter (Table 59). In summer, a linear decrease across time was observed for both treatments. A season*treatment and treatment*day interactions were also observed at 0-5 cm. At 5-10 cm, the response of soil pH varied by season where a linear plateau trend was observed in winter and a linear decline in summer. At 0-5 and 5-10 cm during both seasons, soil pH was higher for feces plots than for the control. At 10-20 cm, no treatment effect was found so data was analyzed across treatments. Regression coefficients and inflection points for nonlinear models can be found in Table 60.

Pearson correlation coefficients were used to determine if the decrease in feces pH correlated to the change soil pH at each depth during both seasons. Analysis showed that during winter at all depths there was a correlation, while during summer no depth showed a correlation (Table 40). An inverse correlation was seen in the winter indicating that when manure pH goes down soil pH increases. This suggests that there may be a liming effect caused by the addition of feces. The lack of a response in summer may be due to multiple factors including the rainfall event immediately after application that may have removed alkaline properties of the manure before they got a chance to enter the soil.

The soil pH of feces amended plots was consistently higher than the control plots which infers that feces may have some effect on soil pH. At 0-5 cm, the change in soil pH varied by treatment and season. The linear slope response during the winter suggests that feces increases soil pH but, since the values at the end of the study are similar the effect over time may be minimal. In summer, the decrease in soil pH on plots amended with feces was not as great as the control plots suggesting the addition of feces may have helped maintain the soil pH. Whalen et al. (2000) and Sharpley et al. (2004) found that soil pH increased in areas where manure was applied. Chang et al. (1991) observed similar results where soil pH increased at depths down to 90 cm but the greatest effect was found from 0-15 cm. This study indicates feces can have some effect on soil pH in acid soils directly under the area of deposition. The ability to buffer soil pH across time may be limited due to factors in soils that produce acidity, therefore this study does not recommend that soil pH in pastures will be maintained solely by cattle defecation.

Electrical Conductivity

Electrical conductivity (EC) in feces was affected by season and day after application (Table 29). Initial EC during both seasons was 0.265 S m^{-1} for winter and 0.192 S m^{-1} for summer before decreasing to 0.04 S m^{-1} for both seasons. The decrease in EC followed an exponential double decay trend across time (Figure 44). In summer, the decrease in the first segment was much steeper than in winter before both season leveled off near the same value. Since EC can be related to K, Ca, and Mg salts, these data correlate well with previous data for these nutrients. The large decrease in EC at the beginning of summer could be caused by the same factors mentioned for these nutrients.

Seasonal effects could be caused by temperature which may dictate the release of cations from feces. Regression equations for EC can be found in Table 61.

Electrical conductivity in soil was affected by day after application at all depths (Table 34). At 0-5 cm, season and treatment had an effect on soil EC. In winter, soil EC in feces treatments displayed a nonlinear trend where EC increased until day 23 then decreased until day 101 and then remained constant until the end of the experiment (Figure 45). The control plots showed no increase but only a decrease until day 103 before remaining constant until the end of the study In summer, both treatments increased linearly throughout the study (Figure 46). At 5-10 and 10 20 cm, no response in soil EC over time was observed when data was modeled across seasons and treatments (Table 62). Regression coefficients and inflection points for nonlinear models can be found in Table 63.

Pearson correlation coefficients were used to determine if the decrease in feces EC correlated to the change in soil EC at each depth during both seasons. Analysis indicated no correlation between the changes in feces EC and soil EC (Table 40). Similar to the result observed with K data, this analysis may not recognize a correlation due to the nonlinear nature of the data which is caused by the mobility of soluble salts. This may violate the assumption of Pearson correlation coefficients that there is a linear relationship between the data. However, strong responses were observed in feces EC and soil EC which indicate soluble salts are lost from feces and may translate to an increase in soil EC.

The increase in soil EC at 0-5 cm correlates well to the previous data for K, Ca, and Mg. All these elements showed similar trends as soil EC. Chang et al. (1991)

observed an immediate impact on soil EC with increasing rate of manure application. This corresponds well to the immediate increase observed in the first month after application. This study did not find any increase in soil EC at 5-10 or 10-20 cm whereas Chang et al.(1991) found a response at 90 cm on plots that were amended with manure. The increase in soil EC at the beginning is relevant, but causes no concern as far as soluble salt damage is concerned. The correlation between this and K, Ca, and Mg helps to further clarify that an increase in these cations is the result feces deposition. Soil EC showed no change at the end of the winter season which corresponds to the findings of Eghball et al. (2004) who observed no residual effect of applied manure on soil EC.

Conclusions

This study determined that feces deposited from dairy cattle can have an influence on soil nutrients. Season was observed to affect removal of all nutrients from feces. Dry weight of feces decreased across time and was affected by season. The response in mineral forms of N indicates that mineralization occurs in feces. Decreases in P, Ca, Mg, Cu, and Zn in feces indicates that rainfall events immediately after deposition can cause leaching of these nutrients. The change in feces EC supports this statement since an immediate decrease was observed. This suggests that the mobility of these elements may be highest immediately after deposition.

Soil nutrient concentrations varied in their response during this study. Mineral N showed no change due to season at 0-5 cm while the 5-10 and 10-20 cm depths showed a treatment effect. The 0-5 cm depth showed the greatest response in NO_3-N+NH_4-N where the feces treatment increased NO_3-N+NH_4-N until day 26 then decreased until the end of the study. Soil extractable P showed a response at all depths but the greatest response was observed at 0-5 cm. Soil extractable K responses were greatest at 0-5 and 5-10 cm, where an increase in soil extractable K was observed until a certain day before there was a decrease. A treatment effect was observed for soil extractable Ca at all depths. Responses across time were only found at 5-10 and 10-20 cm, making it difficult to conclude whether increases at lower depths were the result of feces or environmental factors. Soil extractable Mg showed a treatment effect for all depths. At 0-5 cm, a noticeable response was observed across time in winter, where soil extractable Mg in the feces treatment increased to day 39 then decreased throughout that season; a linear decline was observed at 0-5 cm in summer. Soil extractable Cu showed no treatment effect, and response varied across time. Soil extractable Zn showed treatment effects at 0-5 and 5-10 cm, but only showed an increase in winter at 0-5 cm. Soil pH had varied responses across time and depth in feces treatments. Treatment effects were not found at the 10-20 cm depth. The change in soil pH is thought to be due to the liming effect of feces and then counteracted by the acidity produced from N mineralization. Soil EC was only affected by treatment at 0-5 cm where response varied due to season.

Feces and soil properties were generally affected by time and treatment. Increases in soil P, K, Ca, Mg, Zn, pH, and EC were found. This study suggests that cattle feces can increase the nutrient status of soils without causing damage to the environment or crops. In pasture situations these nutrient can be available for utilization by plants. Feeding and watering areas, where cattle tend to defecate the most, may be potential places where the effect of feces may be amplified. Future research should be focused toward the long-term effects of soil nutrients in pastures where cattle have been defecating over long periods. Interest should also be focused on the nutrient status of areas where cattle are frequently located such as feeding, watering, and milking areas.

Table 25. Sampling dates for feces and soil sampling at the Auburn University Swine Research Unit from 2008 to 2009.

Days after application	Winter	Summer
0	29-Oct-08	6-Apr-09
1	30-Oct-08	7-Apr-09
3	1-Nov-08	9-Apr-09
7	5-Nov-08	14-Apr-09
14	12-Nov-08	20-Apr-09
21	19-Nov-08	27-Apr-09
28	24-Nov-08	11-May-09
56	17-Dec-08	1-Jun-09
84	21-Jan-09	30-Jun-09
112	18-Feb-09	27-Jul-09
140	11-Mar-09	26-Aug-09
168	15-Apr-09	21-Sep-09
196	12-May-09	19-Oct-09

Table 26. Nutrient concentration of AU EVSRC Dairy Protein-Mineral Mix 11/08/07 provided to the dairy cattle at E. V. Smith Research Center Dairy Unit, Shorter, AL.

Nutrient	Concentration
Crude Protein, %	> 41
Calcium, %	>3.0
Phosphorus, %	>0.9
Magnesium, %	>0.9
Sodium, %	>0.60
Chlorine, %	>1.0
Sulfur, %	~0.85
Cobalt, mg kg^{-1}	>0.50
Copper, mg kg^{-1}	30 - 45
Iodine, mg kg^{-1}	>3.5
Manganese, mg kg^{-1}	>100
Selenium, mg kg^{-1}	~1.5
Zinc, mg kg^{-1}	>130
Vitamin A, IU kg^{-1}	>16000
Vitamin D, IU kg^{-1}	>4000
Vitamin E, IU kg^{-1}	>40

Table 27. Initial least square means of mass remaining in feces for all properties. Feces collected on day 0 was used for these estimates.

	Dry Weight	N	P	K	Ca	Mg	Cu	Zn	pH	EC	NO_3-N + NH_4-N
	----------------g----------------									--S m^{-1}--	-mg kg^{-1}-
					Winter						
Mean	126.1	3.09	2.20	0.94	8.01	2.39	0.0096	0.0664	8.21	0.265	43.6
SE	8.2	0.20	0.17	0.05	0.62	0.18	0.0008	0.0059	0.07	0.006	14.0
					Summer						
Mean	139.6	3.40	2.15	0.81	7.23	2.16	0.0085	0.0663	8.00	0.192	14.7
SE	8.2	0.20	0.17	0.05	0.62	0.18	0.0008	0.0059	0.07	0.006	14.0

Table 28. Initial least square means for all soil properties. Soil collected on day 0 in control plots was used for these estimates.

	N	P	K	Ca	Mg	Cu	Zn	NO_3-N+ NH_4-N	pH	EC
	-g kg^{-1}-	--------------------------mg kg^{-1}--------------------------								--S m^{-1}--
Winter										
0-5 cm										
Mean	2.5	13.1	146	1027	204	0.26	4.7	32.6	5.6	0.019
SE	0.2	5.3	18	99	23	0.12	1.1	4.8	0.1	0.005
5-10 cm										
Mean	1.4	9.3	90	521	108	0.35	2.2	18.2	5.4	0.012
SE	0.2	5.3	18	99	23	0.12	1.1	4.8	0.1	0.005
10-20 cm										
Mean	0.8	4.8	43	232	40	0.36	1.1	12.6	5.4	0.009
SE	0.2	5.3	18	99	23	0.12	1.1	4.8	0.1	0.005
Summer										
0-5 cm										
Mean	2.5	13.2	118	1314	253	0.35	11.1	29.6	5.6	0.017
SE	0.2	5.3	18	99	23	0.12	1.1	4.8	0.1	0.005
5-10 cm										
Mean	1.2	6.8	67	633	88	0.31	9.8	16.3	5.6	0.011
SE	0.2	5.3	18	99	23	0.12	1.1	4.8	0.1	0.005
10-20 cm										
Mean	0.7	3.9	45	402	47	0.40	8.9	8.6	5.8	0.005
SE	0.2	5.3	18	99	23	0.12	1.1	4.8	0.1	0.005

Table 29. Analysis of variance probability greater than F (Pr > F) for all elements in feces during both seasons.

Source	Dry Weight	N remaining	P remaining	K remaining	Ca remaining	Mg remaining	Zn remaining	Cu remaining	EC	pH	NO_3-N + NH_4-N
	------------------------------------Pr > F------------------------------------										
Season	0.0499	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Day(Season)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 30. Regression analysis probability greater than F (Pr > F) for feces dry weight during both seasons.

Source	Season	Pr > F
Day(Season)	Winter	0.0001
Day(Season)	Summer	<0.0001

Table 31. Regression coefficients for linear models of dry weight, nitrogen remaining, NO_3-N+NH_4-N, zinc remaining, and pH in feces during both seasons.

Season	Intercept	Standard Error	Linear	Standard Error	Quadratic	Standard Error
	----------	----------	-----g-----	----------	----------	----------
			Dry Weight			
Winter	129.7	3.8	-0.359	0.089	†	†
Summer	155.0	3.5	-0.432	0.039	†	†
			Nitrogen			
Winter	3.10	0.08	-0.0191	0.0020	†	†
Summer	3.37	0.08	-0.0091	0.0008	†	†
			Zinc			
Winter	0.069	0.003	-0.00025	0.00006	†	†
Summer	0.053	0.002	-0.00011	0.00003	†	†
			NO_3-N+NH_4-N			
	----------	----------	-----mg kg^{-1}-----	----------	----------	----------
Winter	23.0	8.1	4.41	0.52	-0.005	0.001
Summer	20.5	7.1	1.16	0.25	-0.030	0.005
			pH			
Winter	8.32	0.04	-0.0110	0.0009	†	†
Summer	7.65	0.04	-0.0028	0.0004	†	†

† Quadratic regression was not done for these elements.

Table 32. Percent moisture least square means and analysis of variance probability greater than F (Pr > F) during both seasons.

Day	Winter	Summer
	Least Square Means	
	--% moisture--	
0	85.6	84.1
1	84.2	81.9
3	81.5	74.5
7	70.9	73.3
14	63.2	59.2
21	63.5	19.5
28	59.1	55.7
56	70.4	34.3
84	48.5	9.8
112	65.3	32.4
140	†	5.0
168	†	42.4
196	†	35.3
	ANOVA	
Source	Pr > F	
Season	<0.0001	
Day(Season)	<0.0001	

† No feces was remaining on these dates.

Table 33. Regression analysis probability greater than F (Pr > F) for nitrogen remaining and NO_3-N+NH_4-N-N in feces during both seasons.

Source	Season	Pr > F
	Nitrogen Remaining	
Day(Season)	Winter	<0.0001
Day(Season)	Summer	<0.0001
	NO_3-N+NH_4-N	
Day(Season)	Winter	<0.0001
Day(Season)	Summer	<0.0001
Day*Day(Season)	Winter	<0.0001
Day*Day(Season)	Summer	0.0017

Table 34. Analysis of variance probability greater than F (Pr > F) for elements in soil at three depths.

Source	N	P	K	Ca	Mg	Cu	Zn	pH	EC	NO_3-N + NH_4-N
	----------	----------	----------	----------	----------	Pr > F	----------	----------	----------	----------
						0 - 5 cm				
Season	0.0004	<0.0001	<0.0001	0.6009	0.0002	0.0010	0.0484	0.0023	<0.0001	0.2804
Season*TRT	0.0442	0.0001	0.3343	0.2606	0.1469	0.4728	0.6423	0.0008	0.7141	0.2811
TRT	0.2530	<0.0001	<0.0001	<0.0001	<0.0001	0.0750	<0.0001	<0.0001	<0.0001	<0.0001
Day(Season)	0.0008	<0.0001	<0.0001	0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001
TRT*Day(Season)	0.0180	<0.0001	0.0357	0.1135	<0.0001	0.6784	0.7423	<0.0001	0.1721	0.0126
						5 - 10 cm				
Season	0.0704	<0.0001	<0.0001	0.0303	0.3416	0.8614	0.5280	0.0086	0.6778	<0.0001
Season*TRT	0.1998	0.8692	0.8965	0.4211	0.4471	0.5349	0.9391	0.1572	0.7807	0.9897
TRT	0.7339	<0.0001	0.0506	0.0061	0.0040	0.3202	0.0024	0.0006	0.1571	0.0003
Day(Season)	0.1028	<0.0001	<0.0001	0.0557	0.3164	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
TRT*Day(Season)	0.5395	0.0042	0.9408	0.3398	0.2904	0.7066	0.0035	0.3284	0.0908	0.3545
						10 - 20 cm				
Season	0.0081	<0.0001	0.1997	0.0010	0.0029	0.6303	0.1118	<0.0001	0.2786	<0.0001
Season*TRT	0.8477	0.2576	0.5300	0.7646	0.9466	0.9552	0.3641	0.6256	0.3553	0.2757
TRT	0.9556	<0.0001	0.7550	0.0294	0.0026	0.6924	0.9006	0.5154	0.4309	0.8757
Day(Season)	0.0019	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001
TRT*Day(Season)	0.8038	0.1948	0.5779	0.2106	0.1842	0.3506	0.9992	0.2116	0.0679	0.0058

Table 35. Soil total nitrogen least square means for the beginning and the end of each season for each treatment.

	Winter		Summer	
Day	Control	Feces	Control	Feces
	-------------------------g kg^{-1}-------------------------			
		0 - 5 cm		
0	2.48	3.67	2.48	2.23
196	2.38	2.22	1.77	1.72
		5 - 10 cm		
0	1.44	1.75	1.22	1.24
196	1.22	1.28	1.32	1.09
		10 - 20 cm		
0	0.83	0.87	0.70	0.67
196	0.65	0.63	0.56	0.57

Table 36. Analysis of variance probability greater than F (Pr>F) of soil total N across time at three depths for two seasons and two treatments.

	Winter		Summer	
Source	Control	Feces	Control	Feces
	--------------------Pr > F--------------------			
		0 - 5 cm		
Day(Season)	0.7720	0.0001	0.0313	0.1158
		5 - 10 cm		
Day(Season)	0.3230	0.0419	0.6551	0.5170
		10 - 20 cm		
Day(Season)	0.0500	0.0082	0.1066	0.2347

Table 37. Regression analysis probability greater than F (Pr>F) of soil NO_3-N + NH_4-N across time at three depths for two seasons and two treatments.

	Control		Feces	
Source	Winter	Summer	Winter	Summer
	------------------------Pr > F------------------------			
	0 - 5 cm			
Segment 1	0.0495		0.0080	
Segment 2	0.0237		0.0049	
	5 - 10 cm			
Linear	0.0053	0.1377	0.0307	0.0304
Quadratic	0.0002	†	0.0021	†
Cubic	0.0001	†	0.0006	†
	10 - 20 cm‡			
Linear			0.0015	0.6361
Quadratic			<0.0001	‡
Cubic			<0.0001	‡

† Only linear models were fit for these treatments and seasons.

‡ This depth was analyzed across treatments. Values do not correspond to the feces treatment but only to the season.

Table 38. Regression coefficients for soil NO_3-N + NH_4-N across time 0 - 5 cm applied with feces and a control across seasons.

			Segment 1		Segment 2		
Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Joint Point
	----------	----------	----------	mg kg^{-1}	----------	----------	
Control	38.83	3.28	0.6919	0.3050	-0.1017	0.0374	21
Feces	47.66	4.09	1.0064	0.2965	-0.2265	0.0612	26

Table 39. Regression coefficients for soil NO_3-N + NH_4-N across time for two depths applied with feces and a control within two seasons.

				Linear		Quadratic		Cubic	
Season	Treatment	Intercept	Std Error	Estimate	Std Error	Estimate	Std Error	Estimate	Std Error
		----------	----------	----------	mg kg^{-1}	----------	----------	----------	----------
					5 - 10 cm				
Winter	Control	26.74	2.30	0.4725	0.1674	-0.0084	0.0022	0.0000307	0.0000075
Winter	Feces	29.67	2.30	0.3645	0.1674	-0.0069	0.0022	0.0000263	0.0000075
Summer	Control	22.52	1.79	-0.0290	0.0194	†	†	†	†
Summer	Feces	26.70	1.79	-0.0424	0.0194	†	†	†	†
					10 -20 cm				
Summer	‡	12.54	1.05	0.0054	0.0114	†	†	†	†
Winter		19.44	1.34	0.3072	0.0953	-0.0057	0.0013	0.0000204	0.0000043

† Linear models were fit for these treatments and seasons.

‡ Analysis was conducted across treatments for these seasons.

Table 40. Pearson correlation coefficients and of nutrient remaining in feces to soil nutrient concentration.

	0 - 5 cm		5 - 10 cm		10 - 20 cm	
	Winter	Summer	Winter	Summer	Winter	Summer
			NO_3-N+NH_4-N			
Coefficient	0.47	-0.25	0.16	-0.06	-0.17	0.34
P > r	0.1709	0.4183	0.6572	0.8376	0.6485	0.2627
			P			
Coefficient	-0.77	-0.81	-0.45	-0.59	-0.22	-0.40
P > r	0.0098	0.0008	0.1929	0.0326	0.5484	0.1758
			K			
Coefficient	-0.48	0.29	-0.40	-0.29	-0.49	-0.09
P > r	0.1642	0.3298	0.1481	0.7724	0.2556	0.3324
			Ca			
Coefficient	-0.67	-0.31	-0.26	-0.18	-0.58	-0.04
P > r	0.0355	0.2949	0.0783	0.8910	0.4733	0.5641
			Mg			
Coefficient	-0.79	-0.22	-0.49	-0.46	-0.63	-0.22
P > r	0.0069	0.4690	0.1513	0.1163	0.0510	0.4663
			Cu			
Coefficient	-0.21	-0.30	-0.45	-0.40	-0.93	-0.27
P > r	0.5510	0.3259	0.1928	0.1727	0.0001	0.3792
			Zn			
Coefficient	-0.65	0.36	-0.33	0.66	-0.28	0.58
P > r	0.0399	0.2281	0.3460	0.0149	0.4369	0.0358
			pH			
Coefficient	-0.80	0.10	-0.72	0.17	-0.72	-0.01
P > r	0.0056	0.7475	0.0193	0.5704	0.0188	0.9714
			EC			
Coefficient	0.09	-0.43	0.35	-0.48	-0.20	-0.50
P > r	0.8055	0.1450	0.3193	0.0980	0.5810	0.0793

Table 41. Regression analysis probability greater than F (Pr >F) for phosphorus remaining in feces during both seasons.

Source	Season	Pr > F	Joint Point
		Linear Slope	
Segment 1	Winter	0.0390	46
Segment 2	Winter	0.1488	
Segment 1	Summer	0.0793	3
Segment 2	Summer	0.0006	
		Linear Plateau	
Segment 1	Winter	0.0703	73

Table 42. Regression coefficients for segmented linear models of phosphorus, potassium, calcium, magnesium, and copper remaining in feces during both seasons.

			Segment 1		Segment 2		
Season	Intercept	Standard Error	Linear	Standard Error	Linear	Standard Error	Joint Point
	--------------------	--------------------	--------------------	g	--------------------	--------------------	--------------------
				Phosphorus			
Winter	2.37	0.09	-0.018	0.004	†	†	73
Summer	2.29	0.15	-0.233	0.032	-0.0040	0.0008	3
				Potassium			
Winter	1.03	0.04	-0.026	0.003	†	†	31
Summer	0.69	0.04	-0.025	0.003	†	†	22
				Calcium			
Winter	8.67	0.38	-0.065	0.018	†	†	69
Summer	7.70	0.41	-1.038	0.276	-0.0089	0.0023	3
				Magnesium			
Winter	2.61	0.11	-0.047	0.010	†	†	45
Summer	2.30	0.10	-0.384	0.053	-0.0030	0.0006	3
				Copper			
Winter	0.0105	0.0006	-0.00011	0.00004	†	†	42
Summer	0.0090	0.0005	-0.00170	0.00025	†	†	3

† Quadratic regression was not done for these elements.

Table 43. Regression analysis probability greater than F (Pr>F) of Mehlich-1 soil phosphorus across time at three depths for two seasons and two treatments.

	0 - 5 cm		5 - 10 cm		10 - 20 cm	
Source	Control	Feces	Control	Feces	Control	Feces
	---------------------------------------Pr > F---------------------------------------					
			Winter			
Segment 1	0.0163	<0.0001	0.0015	0.0019	0.0617	0.0448
Segment 2	0.0002	0.0005	0.0001	0.0017	0.0002	0.0003
			Summer			
Day	0.3499	0.0007	0.1397	0.0011	0.8915	0.2316

Table 44. Regression coefficients for Mehlich - 1 soil phosphorus across time at three depths applied with feces and a control within two seasons.

				Segment 1		Segment 2		
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Joint Point
		----------------------------------mg kg^{-1}-------------------------------------						
				0 - 5 cm				
Winter	Control	17.67	3.20	2.4527	0.8322	-0.1423	0.0233	8
Winter	Feces	27.63	6.34	2.3258	0.2910	-0.7730	0.1452	52
Summer	Control	20.58	2.30	-0.0484	0.0249	†	†	†
Summer	Feces	30.55	3.05	0.1779	0.0330	†	†	†
				5 - 10 cm				
Winter	Control	9.75	1.85	1.5177	0.3381	-0.0897	0.0127	7
Winter	Feces	14.06	1.31	0.4055	0.0939	-0.0900	0.0205	30
Summer	Control	9.23	0.72	-0.0171	0.0078	†	†	†
Summer	Feces	10.64	1.05	0.0384	0.0114	†	†	†
				10 -20 cm				
Winter	Control	4.98	1.01	0.6485	0.3040	-0.0417	0.0071	7
Winter	Feces	6.46	0.98	0.3088	0.1326	-0.0551	0.0095	21
Summer	Control	4.42	0.57	-0.0009	0.0061	†	†	†
Summer	Feces	5.17	0.47	0.0076	0.0051	†	†	†

† There was no segmented model conducted on this season and treatment.

Table 45. Regression analysis probability greater than F (Pr>F) for potassium remaining in feces during both seasons.

Source	Season	Pr > F	Joint Point
Segment 1	Winter	0.0390	31
Segment 1	Summer	0.0793	22

Table 46. Regression analysis probability greater than F (Pr>F) of Mehlich-1 soil potassium across time at three depths for two seasons and two treatments.

	Winter		Summer	
Source	Control	Feces	Control	Feces
	--------------------Pr > F-------------------			
	0 - 5 cm			
Segment 1	0.2340	0.0001	0.0275	0.0001
Segment 2	0.0347	<0.0001	†	†
	5 - 10 cm			
Segment 1	0.0059	0.0080	0.1494	0.1848
Segment 2	0.0094	0.0058	†	†
	10 - 20 cm			
Day	0.0928‡			

† There was no segmented model conducted on this season and treatment.

‡ Analysis for this depth was conducted across seasons and treatments

Table 47. Regression coefficients for Mehlich - 1 soil potassium across time at three depths applied with feces and a control within two seasons.

				Segment 1		Segment 2		
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Inflection Point
		----------------------------------	----------------------------------	---mg kg^{-1}---	----------------------------------	----------------------------------		
				0 - 5 cm				
Winter	Control	133.5	20.7	1.8169	1.4242	-0.7878	0.3170	49
Winter	Feces	159.7	14.4	5.6844	0.8808	-1.2997	0.1549	26
Summer	Control	125.3	5.6	-0.2773	0.0612	†	†	†
Summer	Feces	169.2	5.9	-0.4956	0.0649	†	†	†
				5 - 10 cm				
Winter	Control	50.4	12.4	1.8280	0.5103	-0.6768	0.2059	49
Winter	Feces	58.3	9.5	1.8957	0.5591	-0.6794	0.1891	49
Summer	Control	67.0	4.2	-0.1220	0.0464	†	†	†
Summer	Feces	74.1	4.5	-0.1122	0.0498	†	†	†
				10 -20 cm				
	‡	41.1	2.6	0.0488	0.0289	†	†	†

† There was no segmented model conducted on this season and treatment.

‡ Analysis for this depth was conducted across seasons and treatments

Table 48. Regression analysis probability greater than F (Pr>F) for calcium and magnesium remaining in feces during both seasons.

Source	Season	Pr > F	Inflection Point
		<u>Calcium</u>	
Linear Slope			
Segment 1	Winter	0.0308	34
Segment 2	Winter	0.1926	
Segment 1	Summer	0.0045	3
Segment 2	Summer	0.0041	
Linear Plateau			
Segment 1	Winter	0.0052	69
		<u>Magnesium</u>	
Linear Slope			
Segment 1	Winter	0.0019	43
Segment 2	Winter	0.6855	
Segment 1	Summer	0.0001	3
Segment 2	Summer	0.0005	
Linear Plateau			
Segment 1	Winter	0.0020	45

Table 49. Regression analysis probability greater than F (Pr>F) of Mehlich-1 soil calcium across time at three depths for two seasons and two treatments.

	Control		Feces	
Source	Winter	Summer	Winter	Summer
	------------------------Pr > F-----------------------			
	0 - 5 cm†			
Day	0.4085		0.3839	
	5 - 10 cm			
Segment 1	0.9162	0.0893	0.0477	0.8387
Segment 2	†	†	0.0835	†
	10 - 20 cm			
Segment 1	0.4991	0.7827	0.0027	0.7374
Segment 2	†	†	0.0025	†

† There was no segmented model conducted on this season and treatment.

Table 50. Regression coefficients for Mehlich - 1 soil calcium across time at three depths applied with feces and a control within two seasons.

				Segment 1		Segment 2		
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Inflection Point
		------------------------------------mg kg^{-1}------------------------------------						
				0 - 5 cm				
‡	Control	1219.2	44.9	-0.4036	0.4873	†	†	†
	Feces	1400.6	44.9	0.4252	0.4873	†	†	†
				5 - 10 cm				
Winter	Control	431.5	32.2	0.0368	0.3491	†	†	†
Winter	Feces	460.4	35.5	3.3276	1.4524	-1.1404	0.5859	49
Summer	Control	540.7	32.1	-0.5948	0.3483	†	†	†
Summer	Feces	551.6	32.1	-0.0710	0.3483	†	†	†
				10 -20 cm				
Winter	Control	233.1	16.6	0.1222	0.1804	†	†	†
Winter	Feces	232.7	16.3	1.6594	0.4057	-1.6357	0.3947	84
Summer	Control	275.5	16.6	0.0498	0.1801	†	†	†
Summer	Feces	294.5	16.6	0.0605	0.1801	†	†	†

† There was no segmented model conducted on this season and treatment.

‡ Analysis for this depth was conducted across seasons.

Table 51. Regression analysis probability greater than F (Pr>F) of Mehlich-1 soil magnesium across time at three depths for two seasons and two treatments.

	Winter		Summer	
Source	Control	Feces	Control	Feces
	-------------------------Pr > F-------------------------			
	0 - 5 cm			
Segment 1	0.5343	0.0031	0.0020	0.0413
Segment 2	†	0.0002	‡	‡
	10 - 20 cm			
Segment 1	0.7833	0.0063	0.7759	0.1225
Segment 2	‡	0.0141	‡	‡

† A linear plateau model was used for this season and treatment.

‡ There was no segmented model conducted on this season and treatment.

Table 52. Regression coefficients for Mehlich - 1 soil magnesium across time at two depths applied with feces and a control within two seasons.

				Segment 1		Segment 2		
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Inflection Point
		---------------------------------------mg kg^{-1}---------------------------------------						
				0 - 5 cm				
Winter	Control	239.30	17.13	0.1163	0.1868	†	†	26
Winter	Feces	274.37	17.64	5.1011	1.2717	-1.5596	0.2647	39
Summer	Control	259.78	17.21	-0.5836	0.1864	†	†	†
Summer	Feces	330.20	17.21	-0.3828	0.1864	†	†	†
				10 -20 cm				
Winter	Control	35.35	2.73	0.0082	0.0297	†	†	†
Winter	Feces	35.43	2.87	0.2530	0.0714	-0.2110	0.0695	84
Summer	Control	40.83	2.74	0.0085	0.0297	†	†	†
Summer	Feces	43.76	2.74	0.0460	0.0297	†	†	†

† There was no segmented model conducted on this season and treatment.

Table 53. Regression analysis probability greater than F (Pr > F) for copper remaining in feces during both seasons.

Source	Season	Estimate	Pr > F	Inflection Point
		---g---		
Segment 1	Winter	-0.0001	0.0267	42
Segment 1	Summer	-0.0017	<0.0001	3

Table 54. Regression analysis probability greater than F (Pr >F) for zinc remaining and pH in feces during both seasons.

Source	Season	Pr > F
Zinc		
Day(Season)	Winter	0.0001
Day(Season)	Summer	0.0002
pH		
Day(Season)	Winter	<0.0001
Day(Season)	Summer	<0.0001

Table 55. Regression analysis probability greater than F (Pr>F) of Mehlich-1 soil copper at three depths and for two seasons.

Source	Winter	Summer
	-----------Pr > F-----------	
	0 -5 cm	
Day	0.1176	0.0009
	5 - 10 cm	
Day	0.0239	
	10 - 20 cm	
Day	<0.0001	

Table 56. Regression coefficients for Mehlich - 1 soil copper across time at three depths applied with feces and a control within two seasons.

Season	Intercept	Std Error	Slope	Std Error
	---------------------------mg kg^{-1}---------------------------			
		0 - 5 cm		
Winter	0.3177	0.0279	-0.0005	0.0003
Summer	0.3121	0.0280	0.0010	0.0003
		5 - 10 cm		
†	0.4745	0.0297	0.0007	0.0003
		10 - 20 cm		
†	0.5202	0.0289	0.0018	0.0003

† Analysis for this depth was conducted across seasons and treatments.

Table 57. Regression analysis probability greater than F (Pr>F) of Mehlich-1 soil zinc across time across time at three depths for two seasons and two treatments.

	Control		Feces	
Source	Winter	Summer	Winter	Summer
	-------------------------Pr > F------------------------			
	0 - 5 cm			
Segment 1	0.1068	0.3499	0.0219	0.0007
Segment 2			0.0833	
	5 - 10 cm			
Day	0.0687		0.1556	
	10 - 20 cm			
Day	0.3671			

Table 58. Regression coefficients for Mehlich - 1 soil zinc across time at three depths applied with feces and a control within two seasons.

				Segment 1		Segment 2		
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Inflection Point
		-------------------------------------		mg kg^{-1}	-------------------------------------			
				0 - 5 cm				
Winter	Control	7.4	0.5	0.0145	0.0052	†	†	†
Winter	Feces	8.0	0.3	0.0924	0.0334	-0.0323	0.0166	70
Summer	Control	9.1	0.5	-0.0217	0.0051	†	†	†
Summer	Feces	10.4	0.6	-0.0134	0.0070	†	†	†
				5 - 10 cm				
‡	Control	5.1	0.4	-0.0078	0.0042	†	†	†
	Feces	5.7	0.4	-0.0060	0.0042	†	†	†
				10 -20 cm				
‡		3.7	0.3	-0.0031	0.0035	†	†	†

† There was no segmented model conducted on this season and treatment.

‡ Analysis for this depth was conducted across seasons and/or treatments.

Table 59. Regression analysis probability greater than F (Pr>F) of soil pH across time across time at three depths for two seasons and two treatments.

	Winter		Summer	
Source	Control	Feces	Control	Feces
	--------------------Pr > F--------------------			
		0 - 5 cm		
Segment 1	0.0005	<0.0001	<0.0001	0.0307
Segment 2	†	0.0296	†	†
		5 - 10 cm		
Segment 1	<0.0001‡	<0.0001‡	0.0013	0.1296
		10 - 20 cm		
Segment 1	<0.0001		0.0012	

† There was no segmented model conducted on this season and treatment.

‡ A linear plateau model was used for this season and treatment.

Table 60. Regression coefficients for soil pH across time at three depths applied with feces and a control within two seasons.

				Segment 1		Segment 2		
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Inflection Point
0 - 5 cm								
Winter	Control	5.358	0.053	0.0020	0.0006	†	†	†
Winter	Feces	5.490	0.051	0.0106	0.0015	-0.0045	0.0018	84
Summer	Control	5.706	0.053	-0.0033	0.0006	†	†	†
Summer	Feces	5.726	0.053	-0.0013	0.0006	†	†	†
5 - 10 cm								
Winter	Control	5.103	0.043	0.0039	0.0013	†	†	111
Winter	Feces	5.136	0.046	0.0067	0.0008	†	†	84
Summer	Control	5.489	0.043	-0.0015	0.0005	†	†	†
Summer	Feces	5.488	0.043	-0.0007	0.0005	†	†	†
10 -20 cm								
Winter	§	5.230	0.026	0.00258	0.00028	†	†	†
Summer		5.553	0.026	-0.00093	0.00028	†	†	†

† There was no segmented model conducted on this season and treatment.

‡ A linear plateau model was used for this season and treatment.

§ This depth was analyzed across treatments.

Table 61. Regression equations for electrical conductivity in feces during both seasons.

Season	Equation
Winter	$y = 0.261e^{-0.0357x} + 0.017e^{0.0068x}$
Summer	$y = 0.147e^{-0.1344x} + 0.066e^{-0.0021x}$

Table 62. Regression analysis probability greater than F (Pr>F) of soil electrical conductivity across time across time at three depths for two seasons and two treatments.

	Winter		Summer	
Source	Control	Feces	Control	Feces
	--------------------Pr > F--------------------			
		0 - 5 cm		
Segment 1	0.0017	0.0005	0.2771	0.1969
Segment 2	†	0.0005	‡	‡
		5 - 10 cm		
Day		0.6035		
		10 - 20 cm		
Day		0.6111		

† A linear plateau model was used for this season and treatment combination.

‡ There was no segmented model conducted on this season and treatment.

Table 63. Regression coefficients for soil electrical conductivity across time at three depths applied with feces and a control within two seasons.

				Segment 1		Segment 2			
Season	Treatment	Intercept	Std Error	Slope	Std Error	Slope	Std Error	Inflection Point	Inflection Point 2
		------------------------------------	------------------	--S m^{-1}--	------------------	------------------------------------			
				0 - 5 cm					
Winter	Control	0.0366	0.0026	-0.00017	0.00004	†	†	111	†
Winter	Feces	0.0319	0.0021	0.00104	0.00020	-0.00046	0.00009	23	101
Summer	Control	0.0194	0.0022	0.00003	0.00002	‡	‡	‡	‡
Summer	Feces	0.0257	0.0022	0.00003	0.00002	‡	‡	‡	‡
				5 - 10 cm					
§		0.0165	0.0012	-0.000007	0.000013	‡	‡	‡	‡
				10 -20 cm					
§		0.0110	0.0008	-0.000005	0.000009	‡	‡	‡	‡

† A linear plateau model was used for this season and treatment combination.

‡ There was no segmented model conducted on this season and treatment.

§ Analysis for this depth was conducted across seasons and/or treatments.

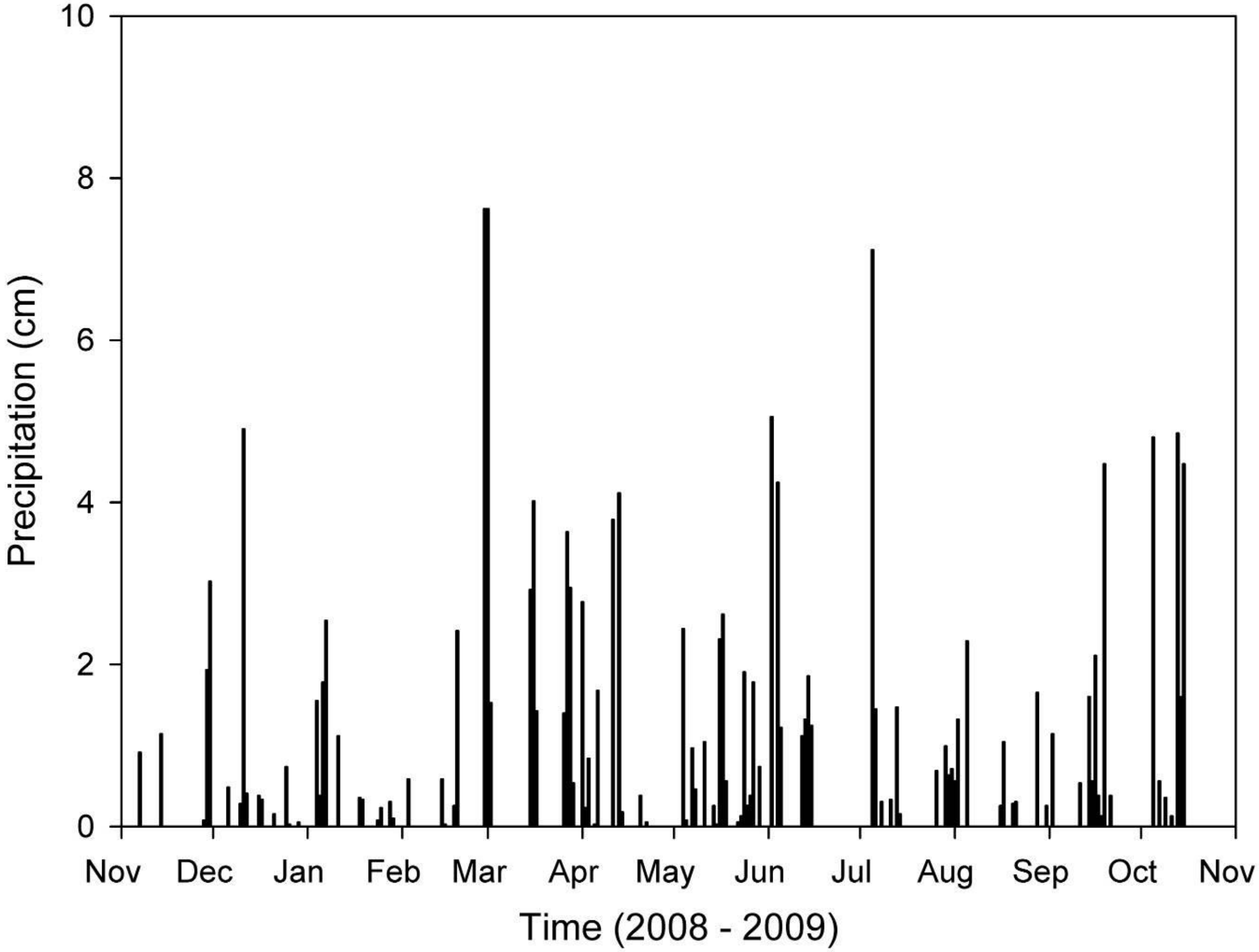

Figure 18. Precipitation from November 2008 to November 2009 at the Auburn University Swine Research Unit.

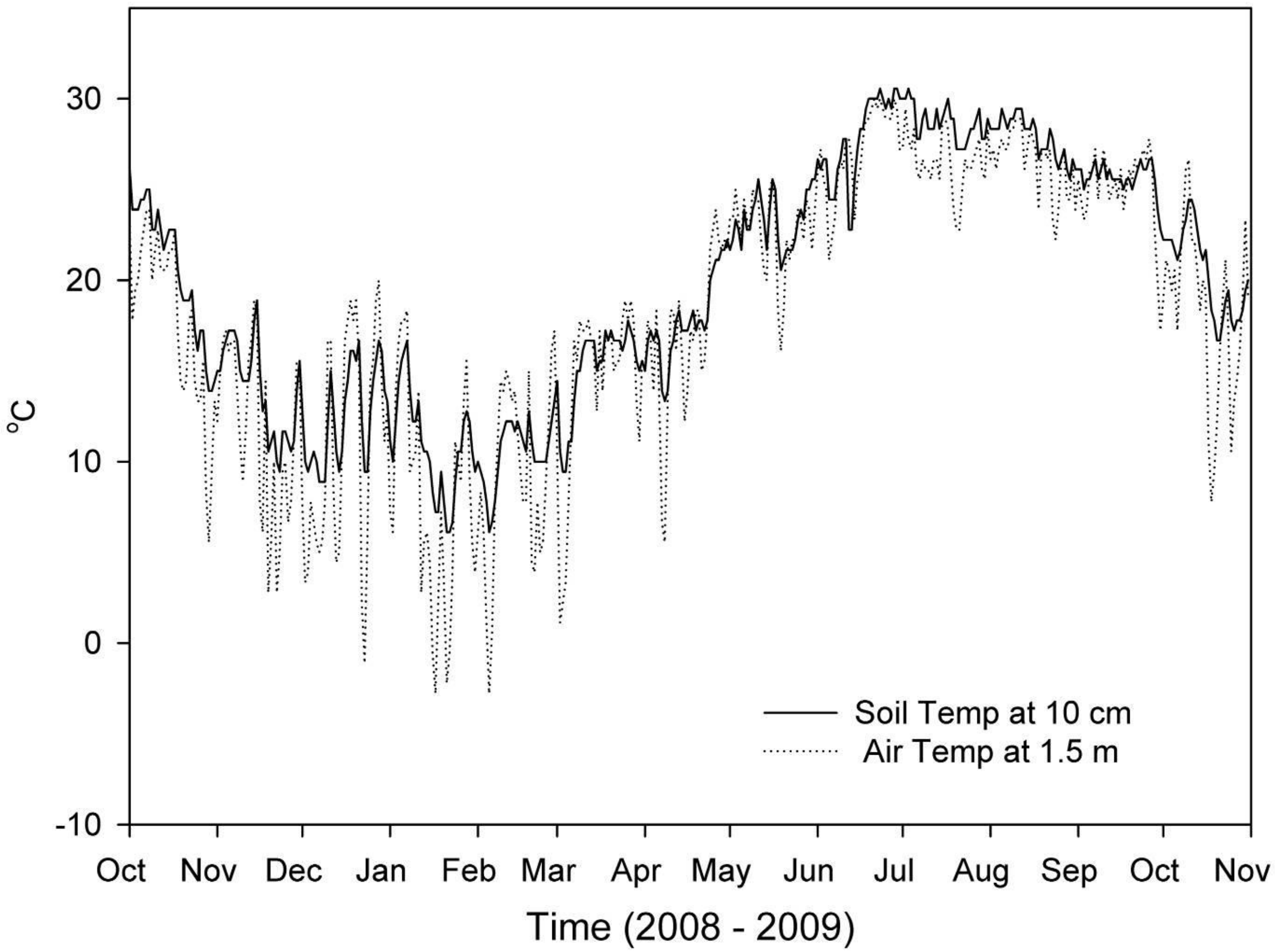

Figure 19. Soil and air temperatures from November 2008 to November 2009 at the Auburn University Swine Research Unit.

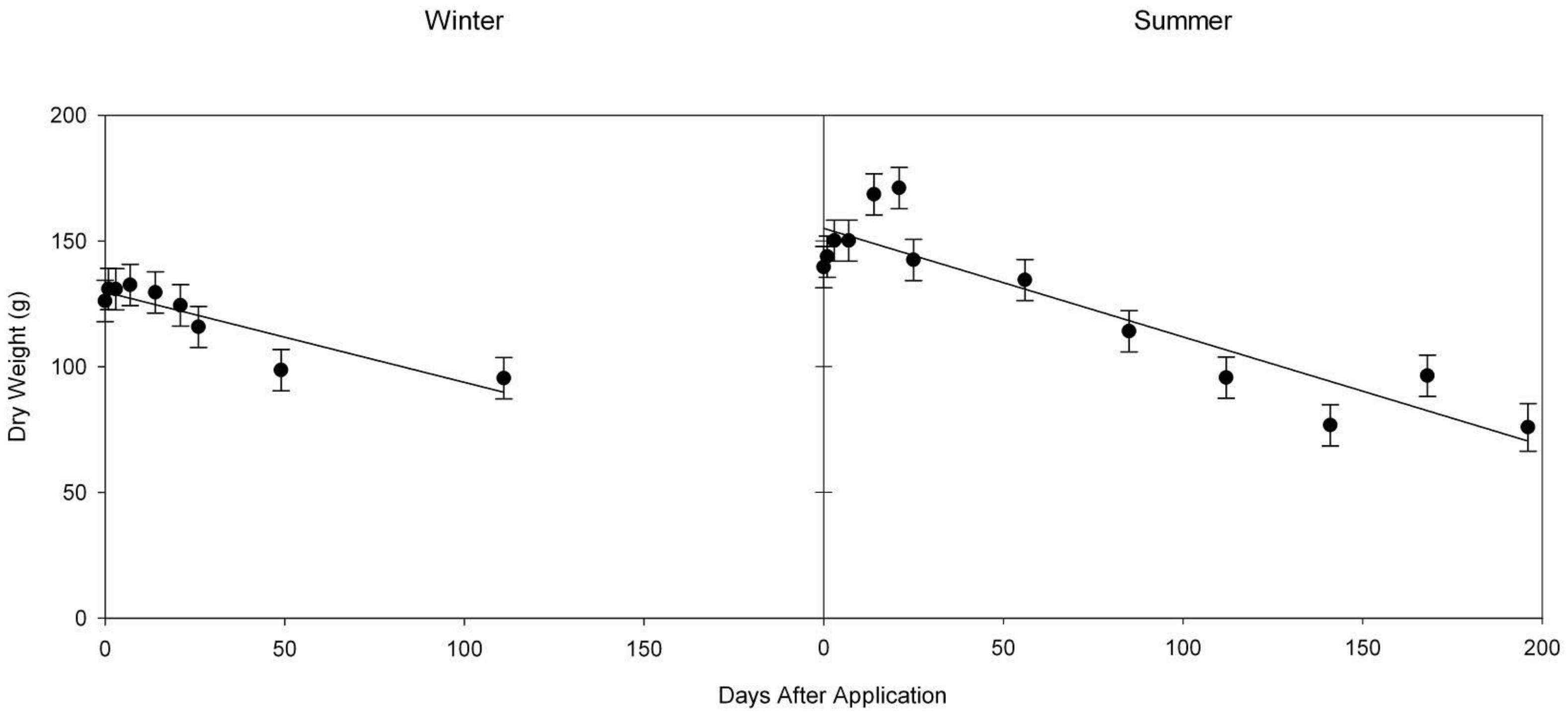

Figure 20. Dry weight of feces across time during both seasons. Error bars represent standard errors of the least square means.

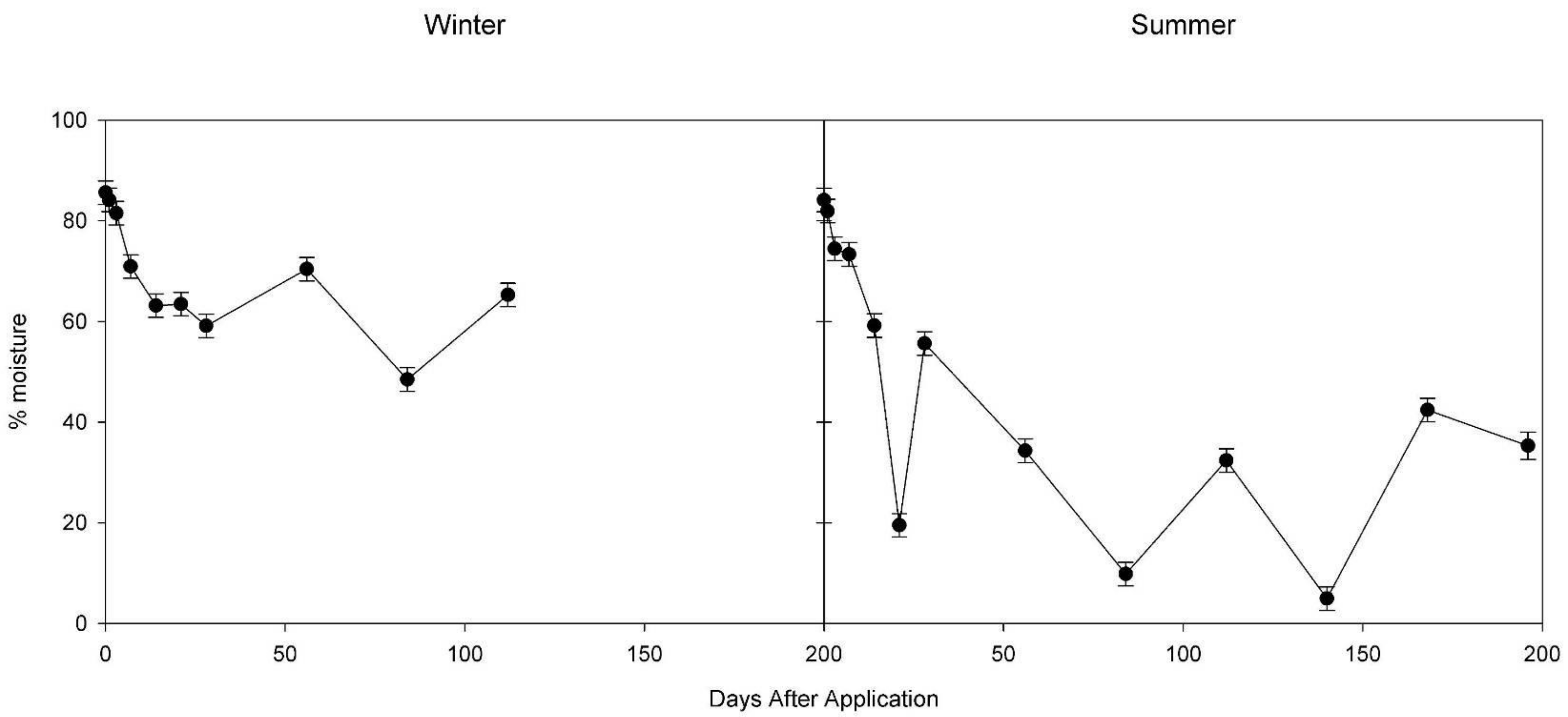

Figure 21. Percent moisture of feces across time during both seasons. Error bars represent standard errors of the least square means.

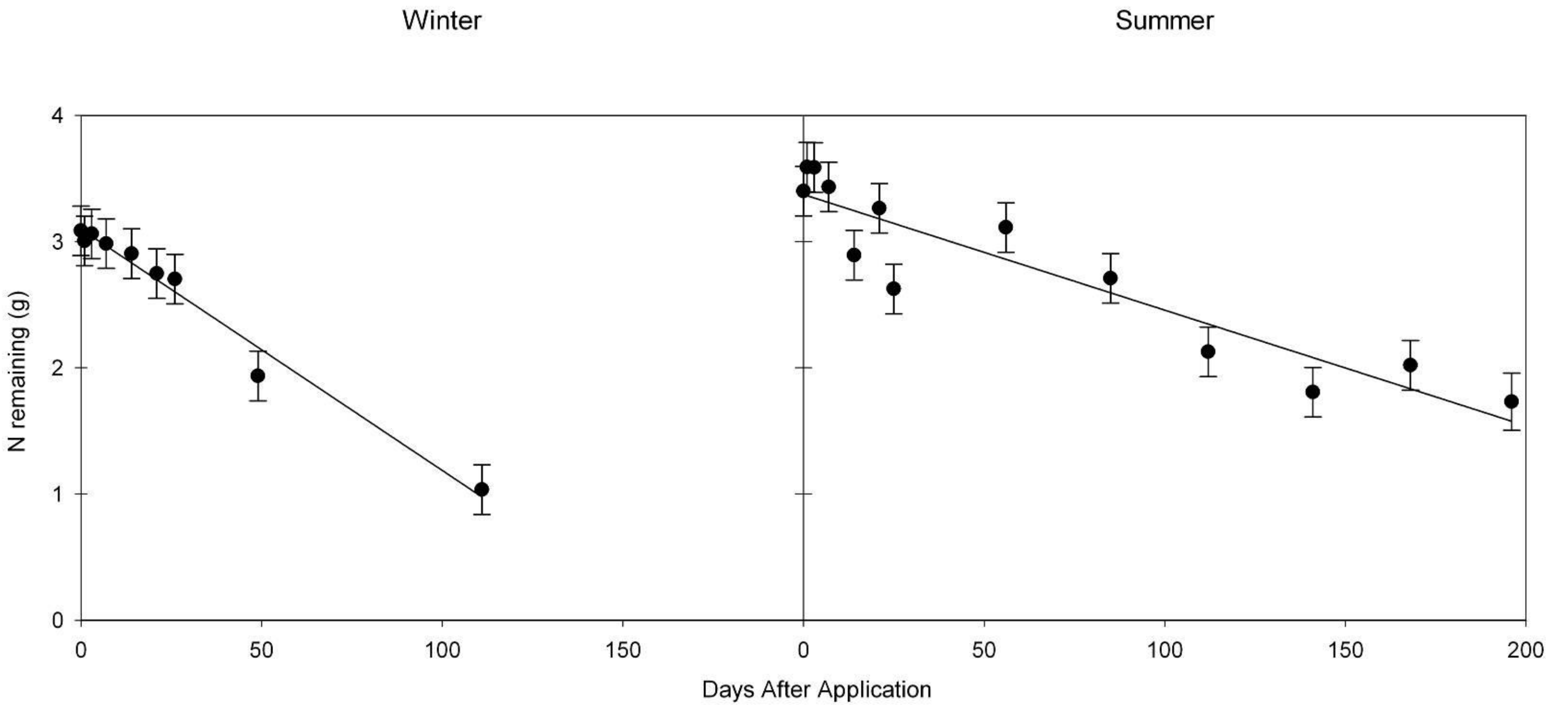

Figure 22. Nitrogen remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

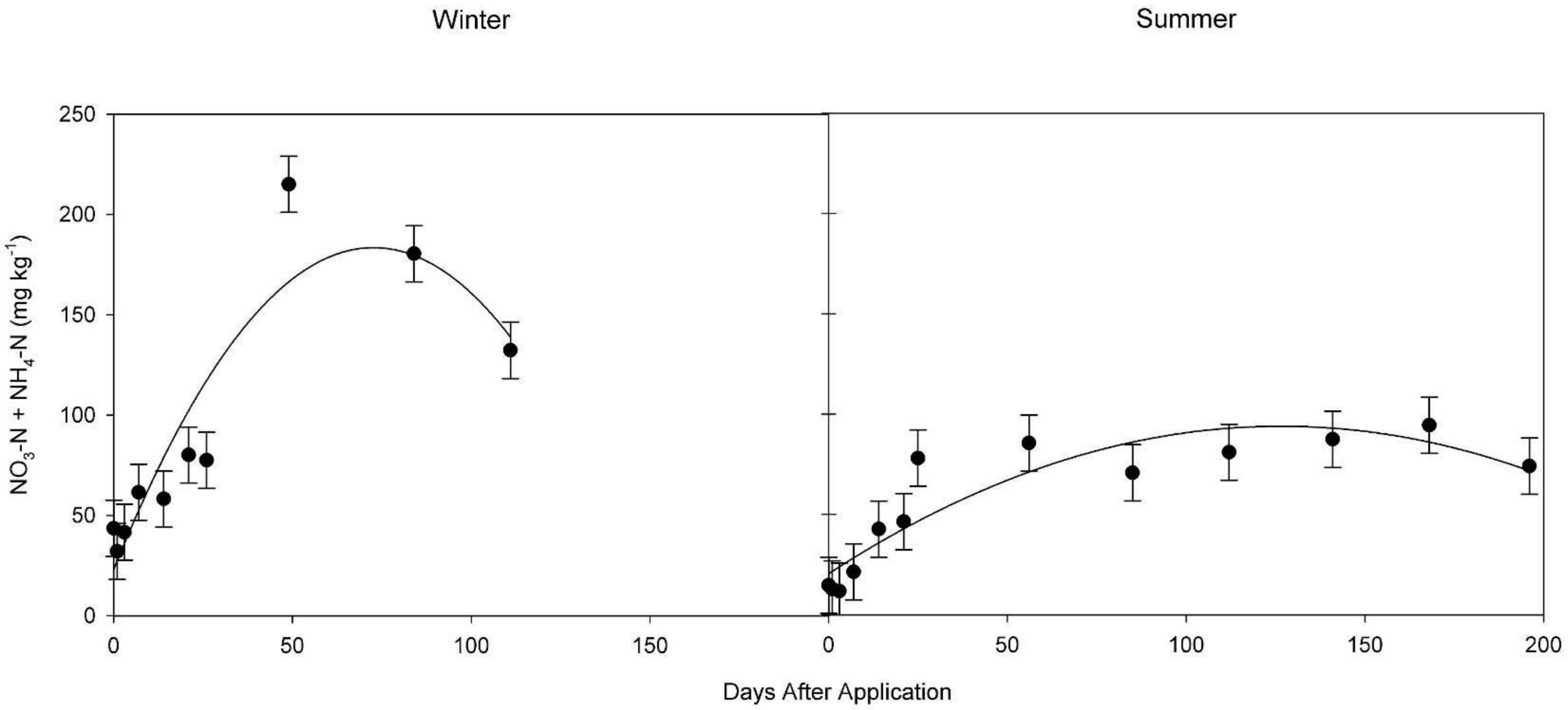

Figure 23. NO_3-N+NH_4-N concentration in feces across time during both seasons. Error bars represent standard errors of the least square means.

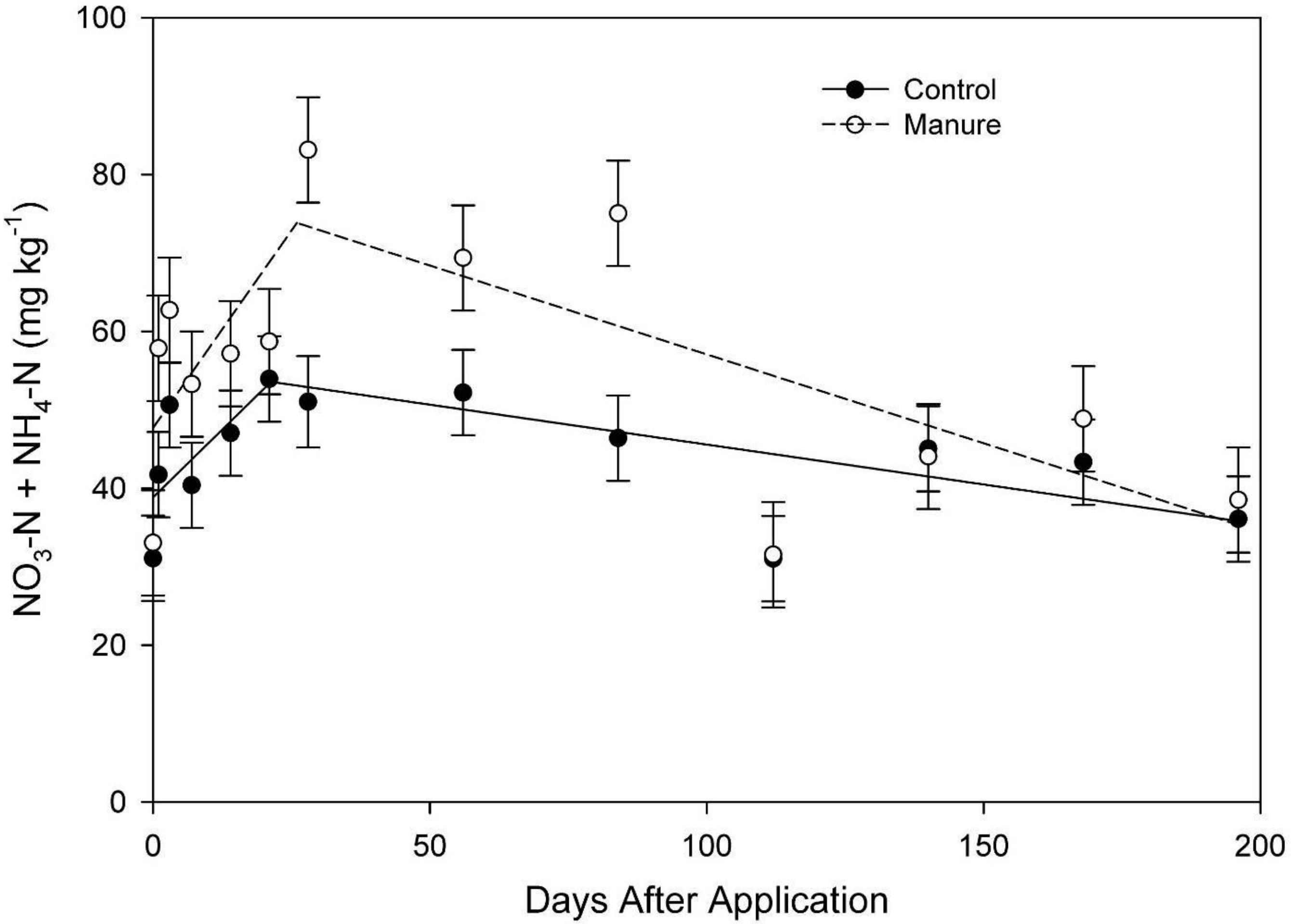

Figure 24. NO_3-N+NH_4-N concentration in soil over time at 0-5 cm across seasons. Error bars represent standard errors of the least square means.

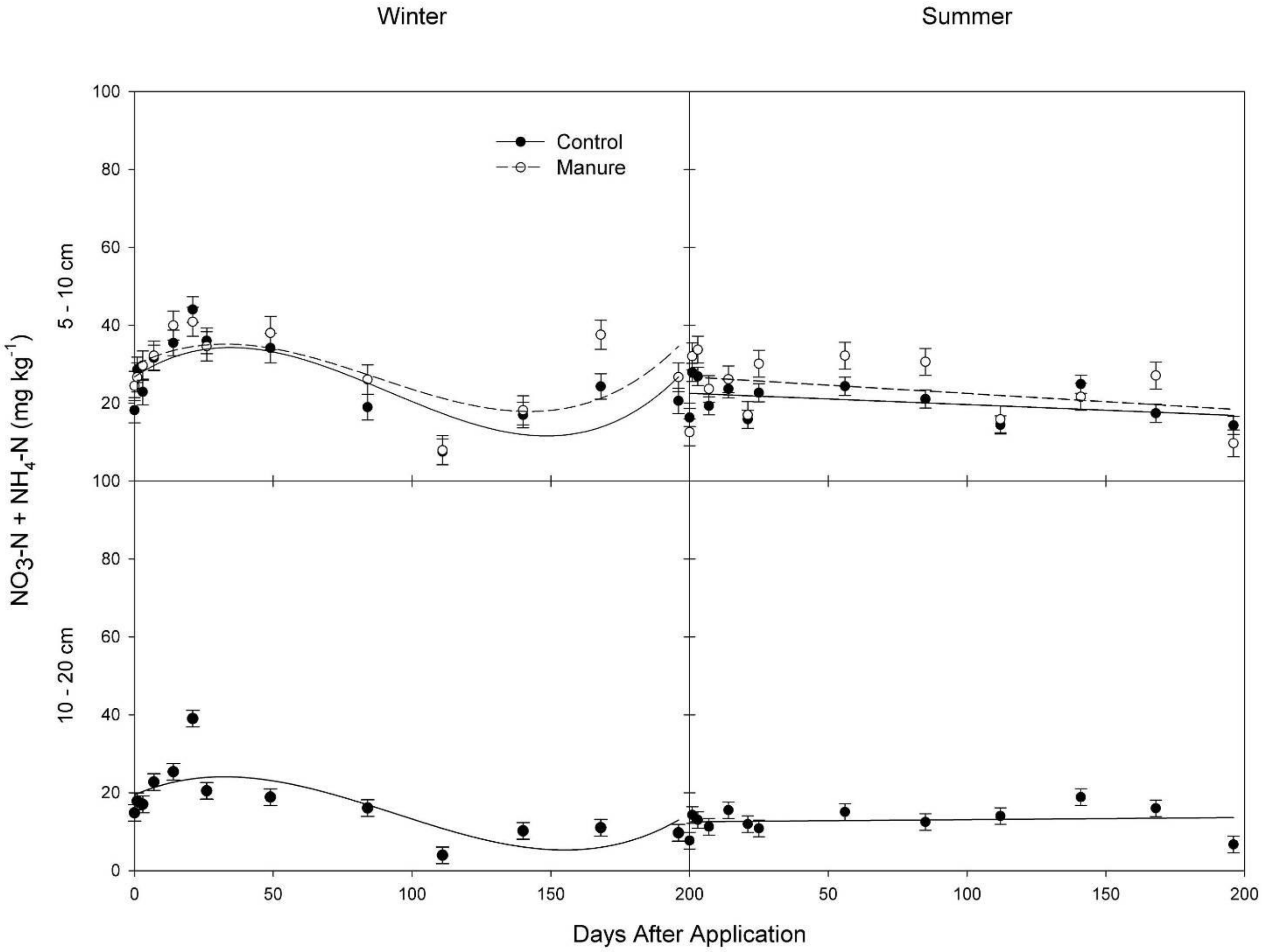

Figure 25. NO_3-N+NH_4-N concentration in soil over time at 5-10 and 10-20 cm during both seasons. Error bars represent standard errors of the least square means.

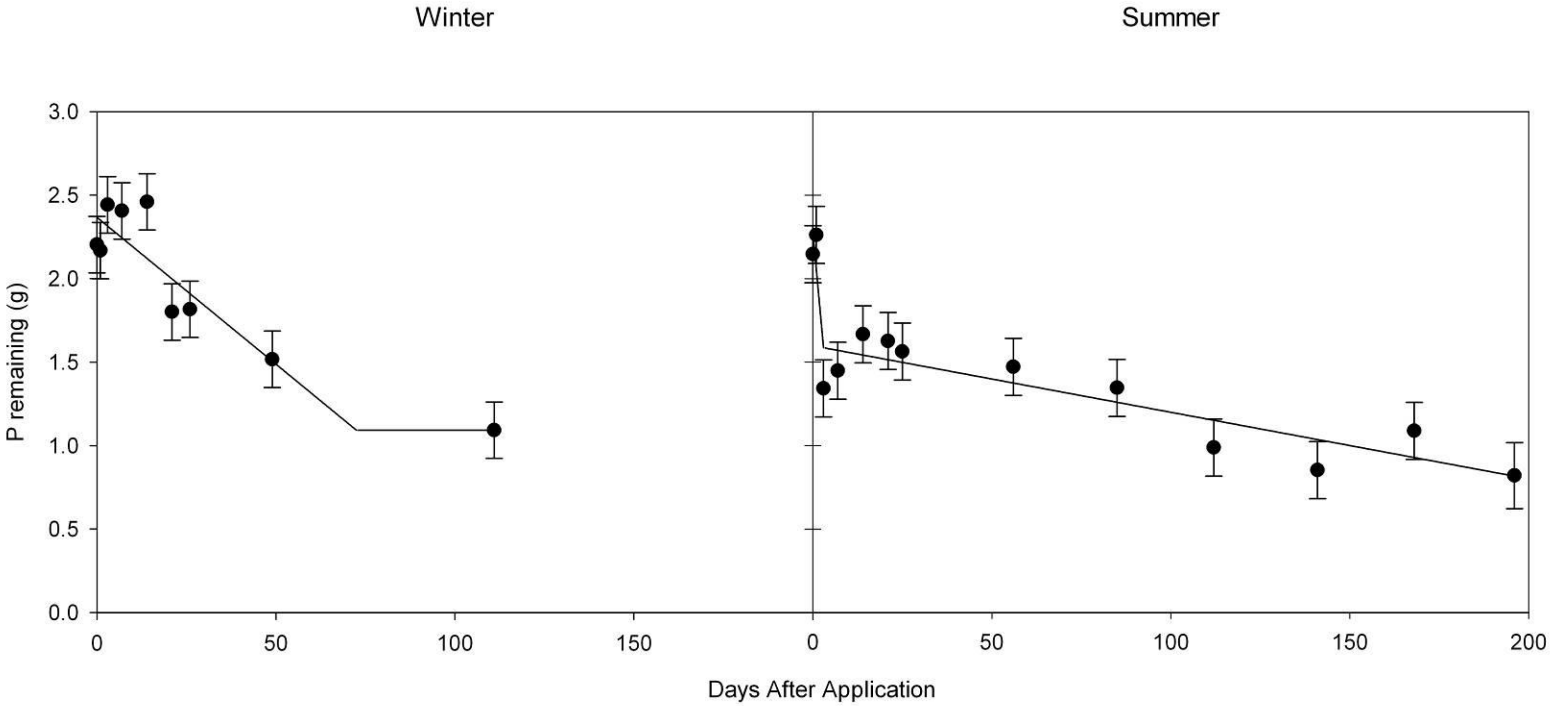

Figure 26. Phosphorus remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

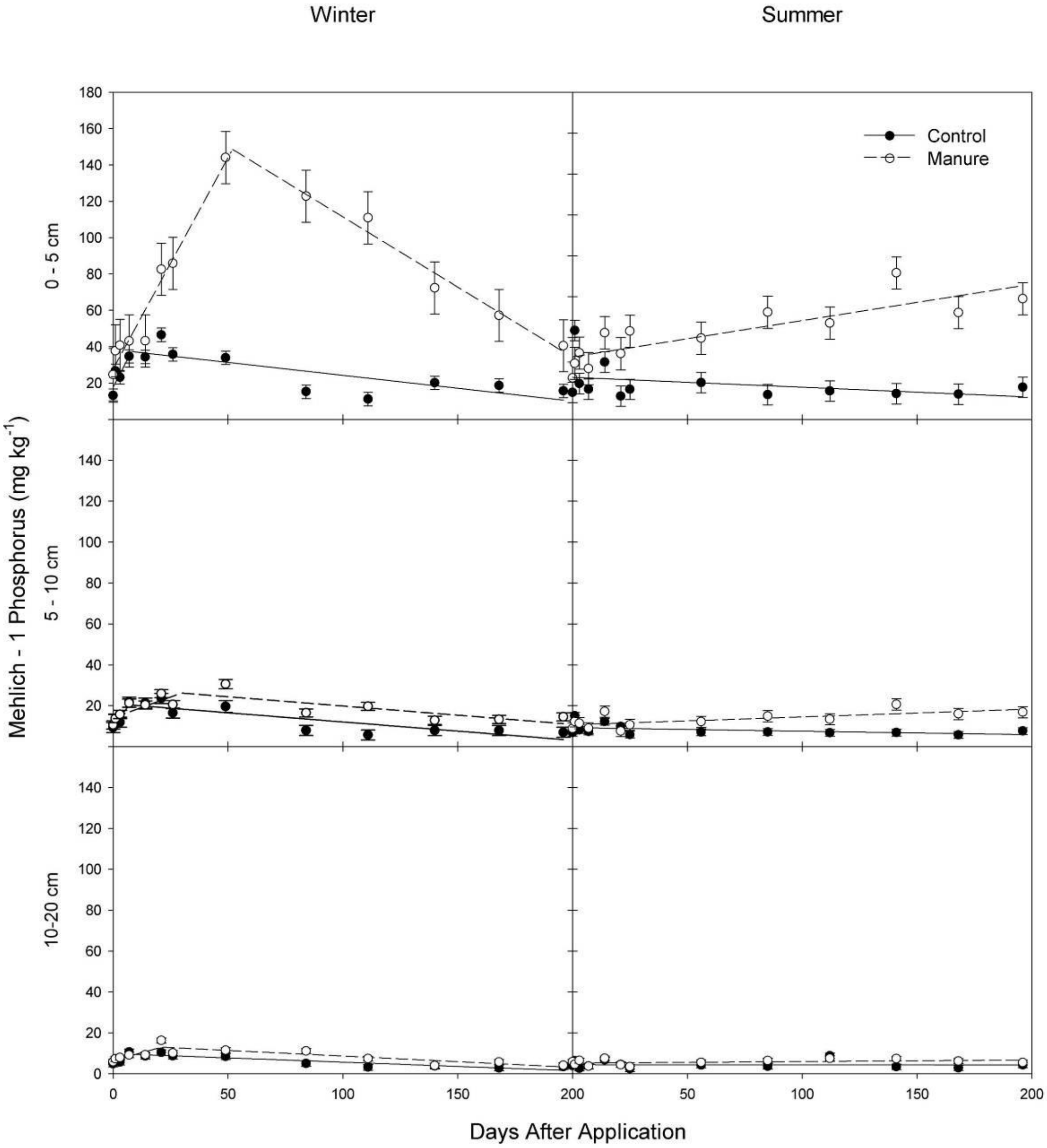

Figure 27. Mehlich-1 soil phosphorus across time at three depths during both seasons. Error bars represent standard errors of the least square mean.

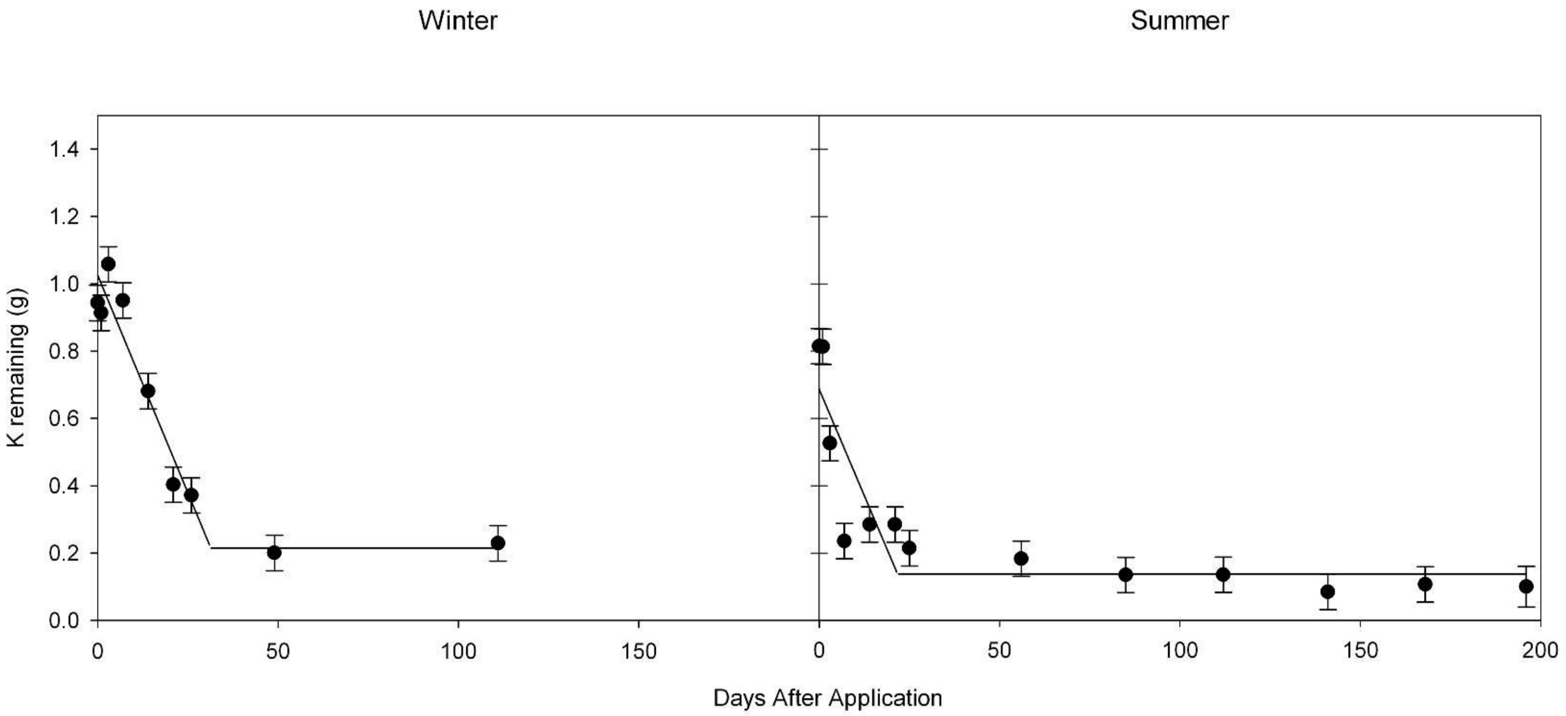

Figure 28. Potassium remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

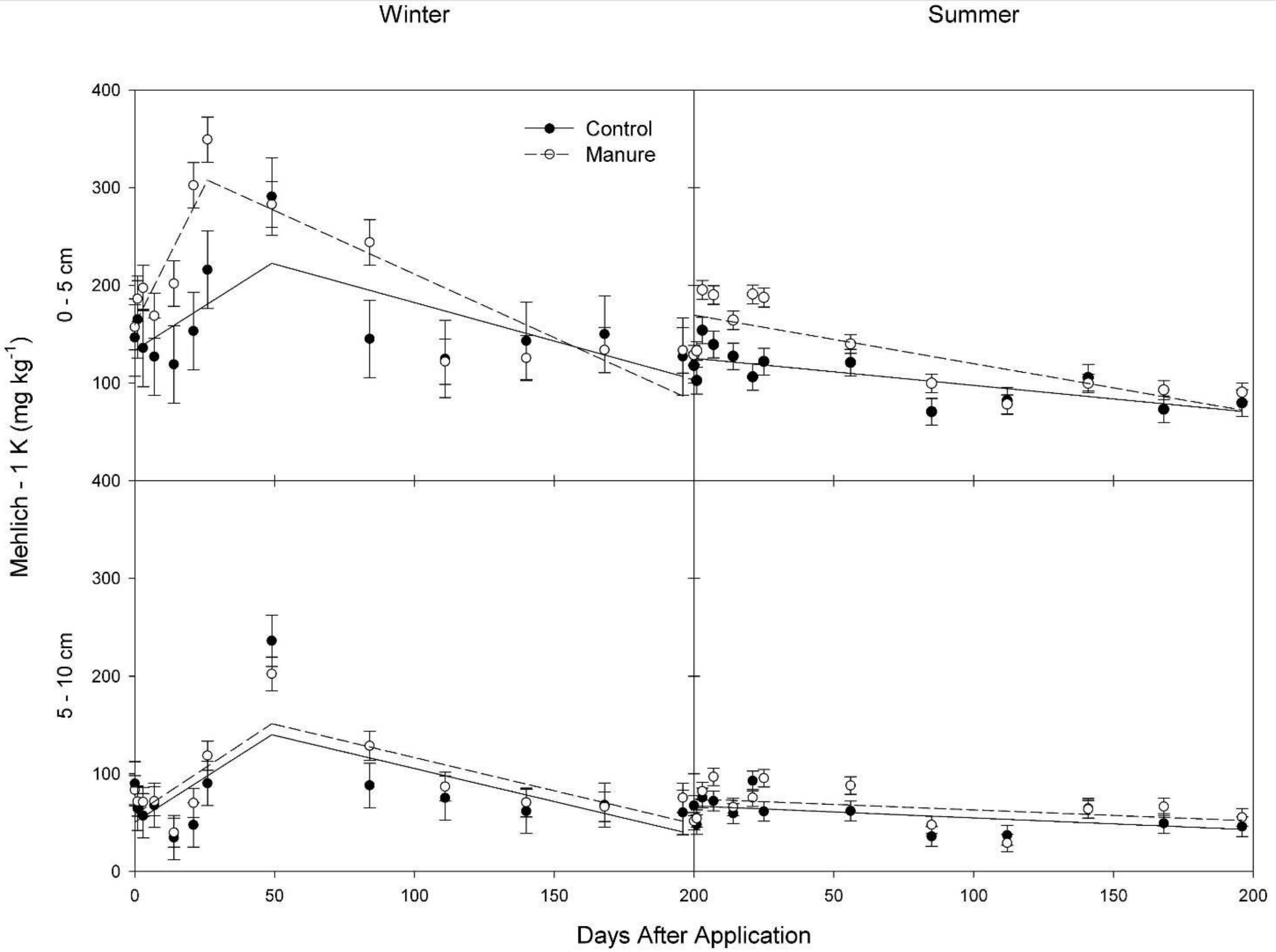

Figure 29. Mehlich-1 soil potassium across time at 0-5 and 5-10 cm during both seasons. Error bars represent standard errors of the least square means.

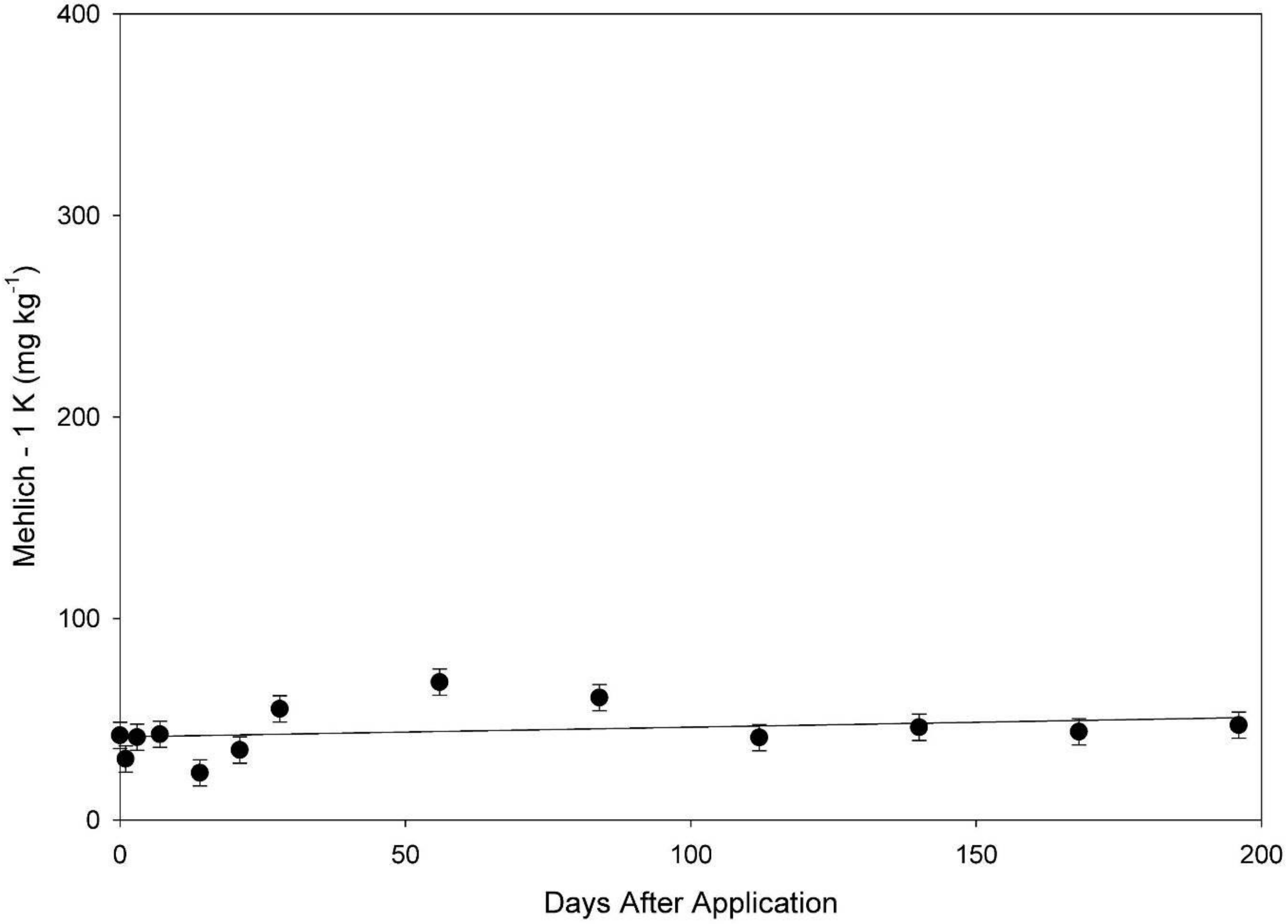

Figure 30. Mehlich-1 soil potassium across time at 10-20 cm across both seasons. Error bars represent standard errors of the least square means.

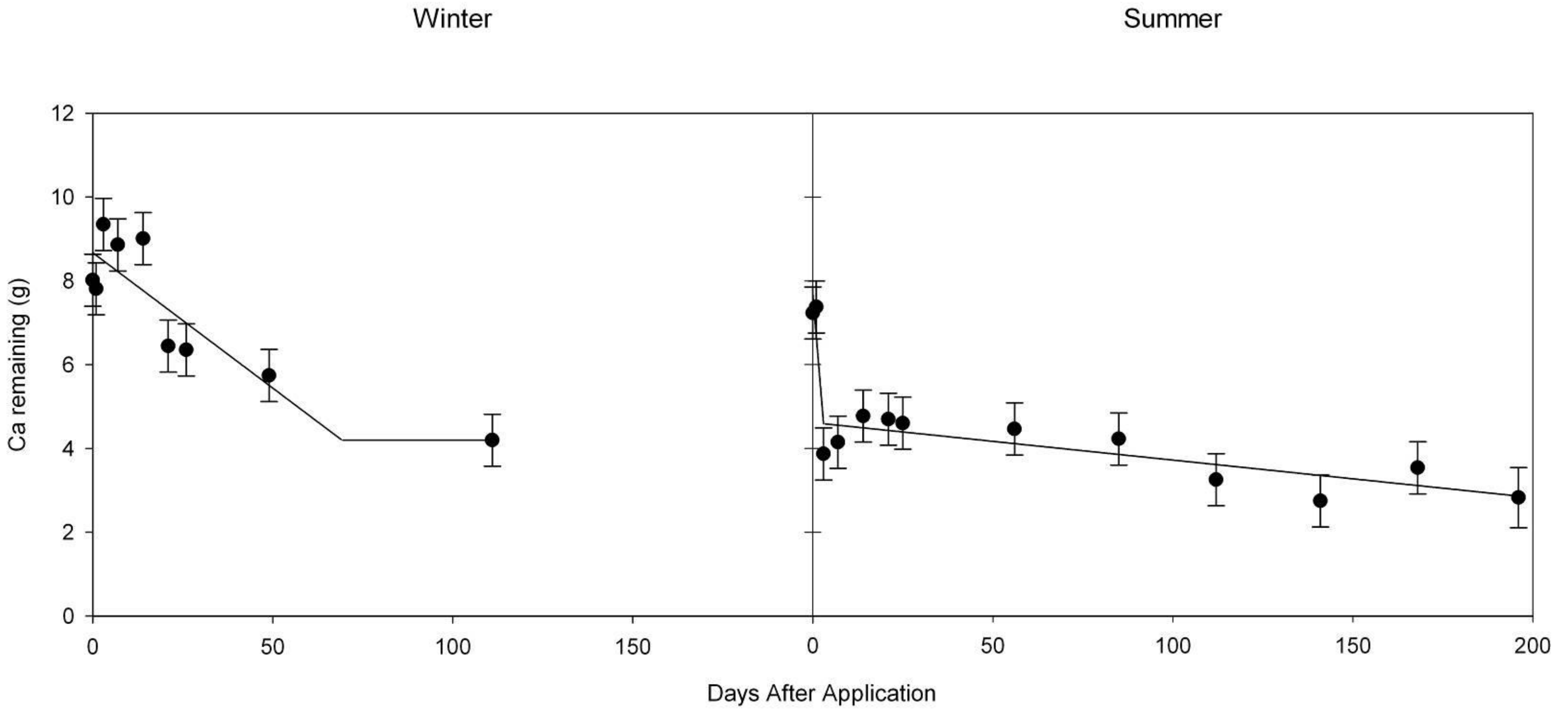

Figure 31. Calcium remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

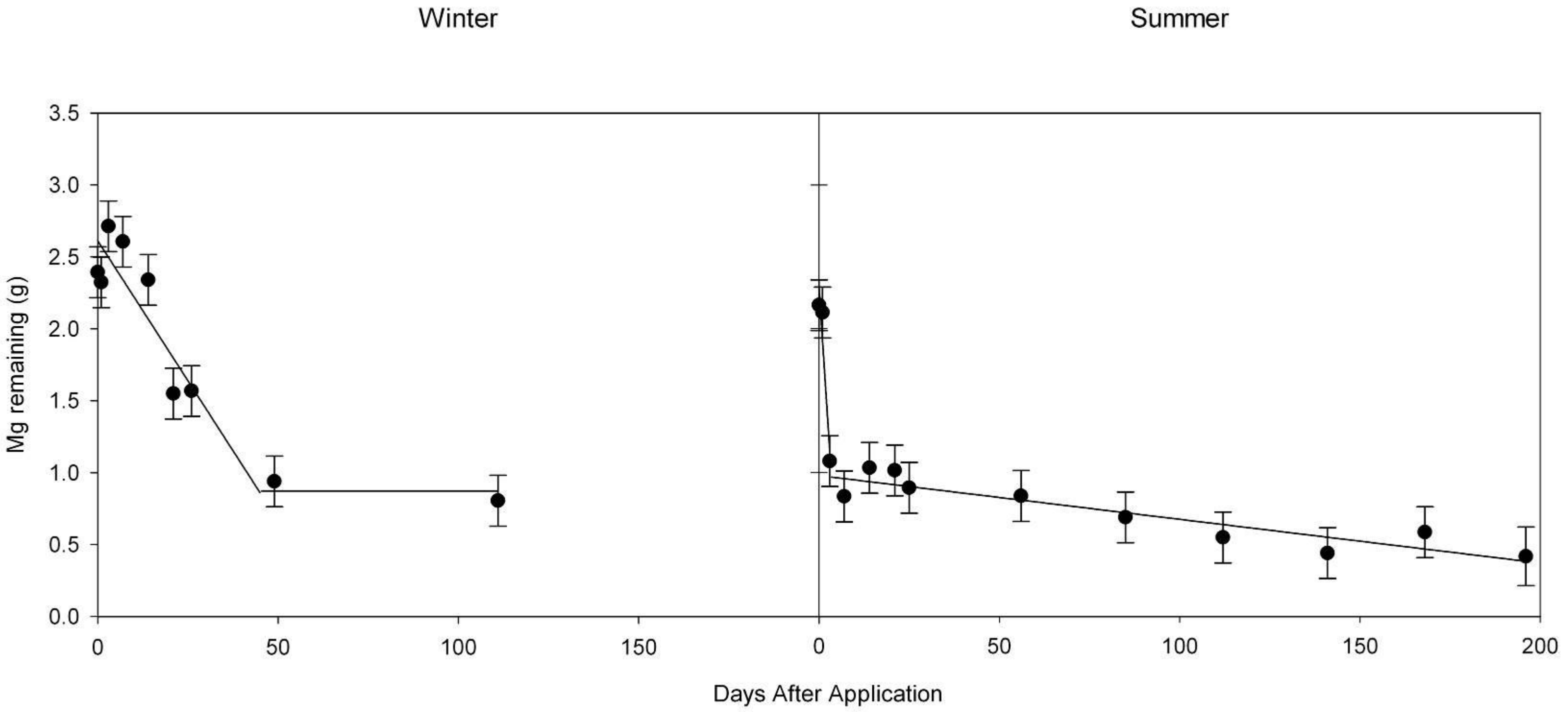

Figure 32. Magnesium remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

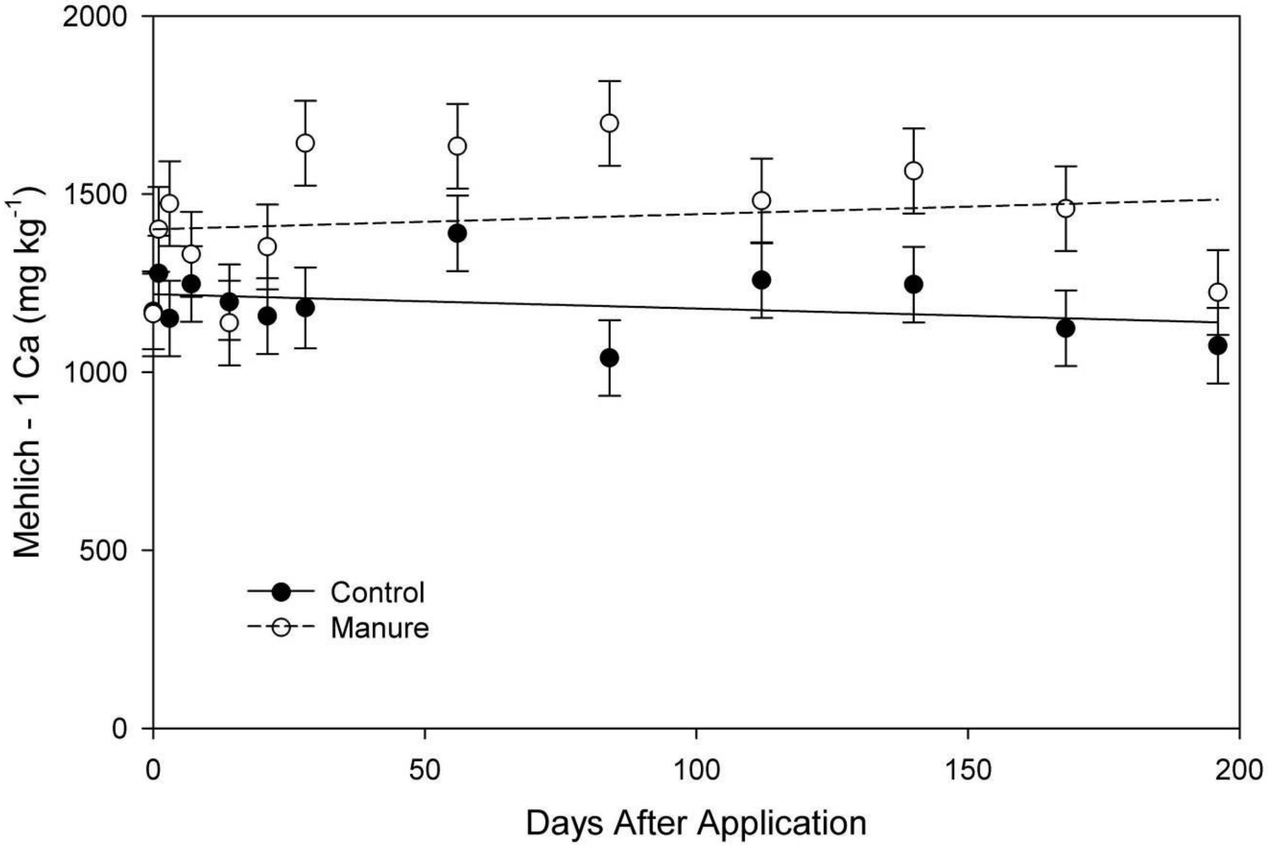

Figure 33. Mehlich-1 soil calcium across time at 0-5 cm across both seasons. Error bars represent standard errors of the least square means.

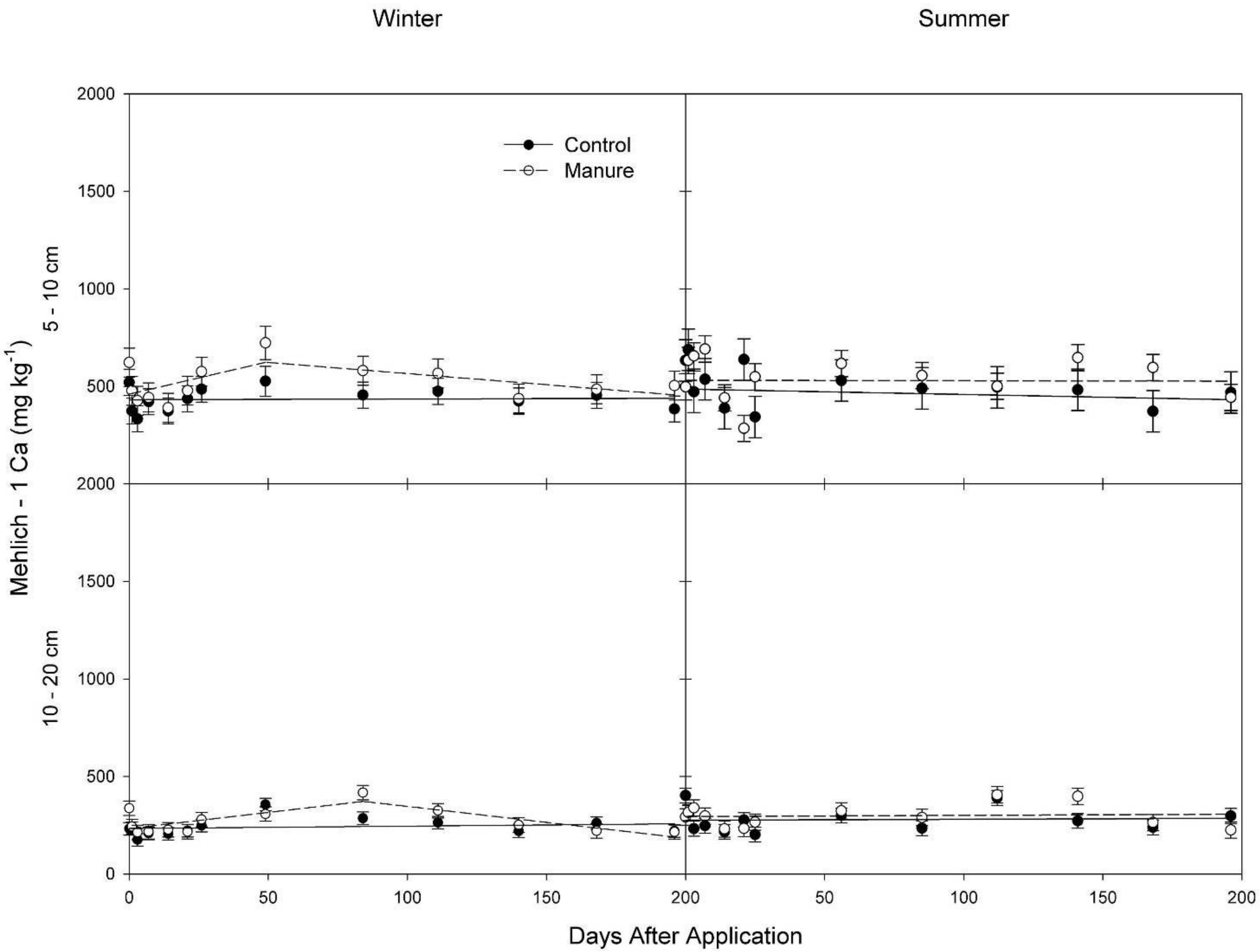

Figure 34. Mehlich-1 soil calcium across time at 5-10 and 10-20 cm during both seasons. Error bars represent standard errors of the least square means.

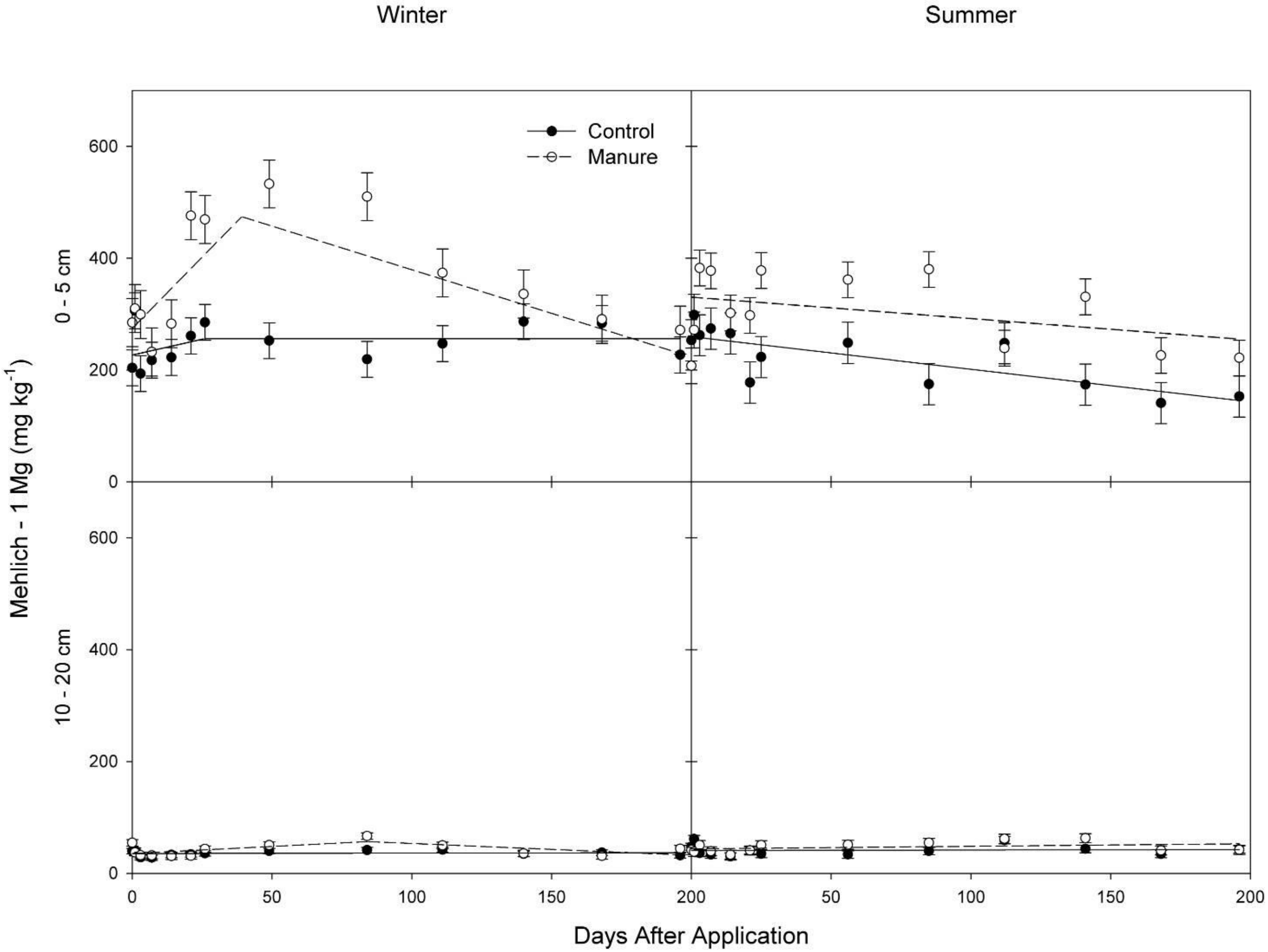

Figure 35. Mehlich-1 soil magnesium across time at 0-5 and 10-20 cm during both seasons. Error bars represent standard errors of the least square mean.

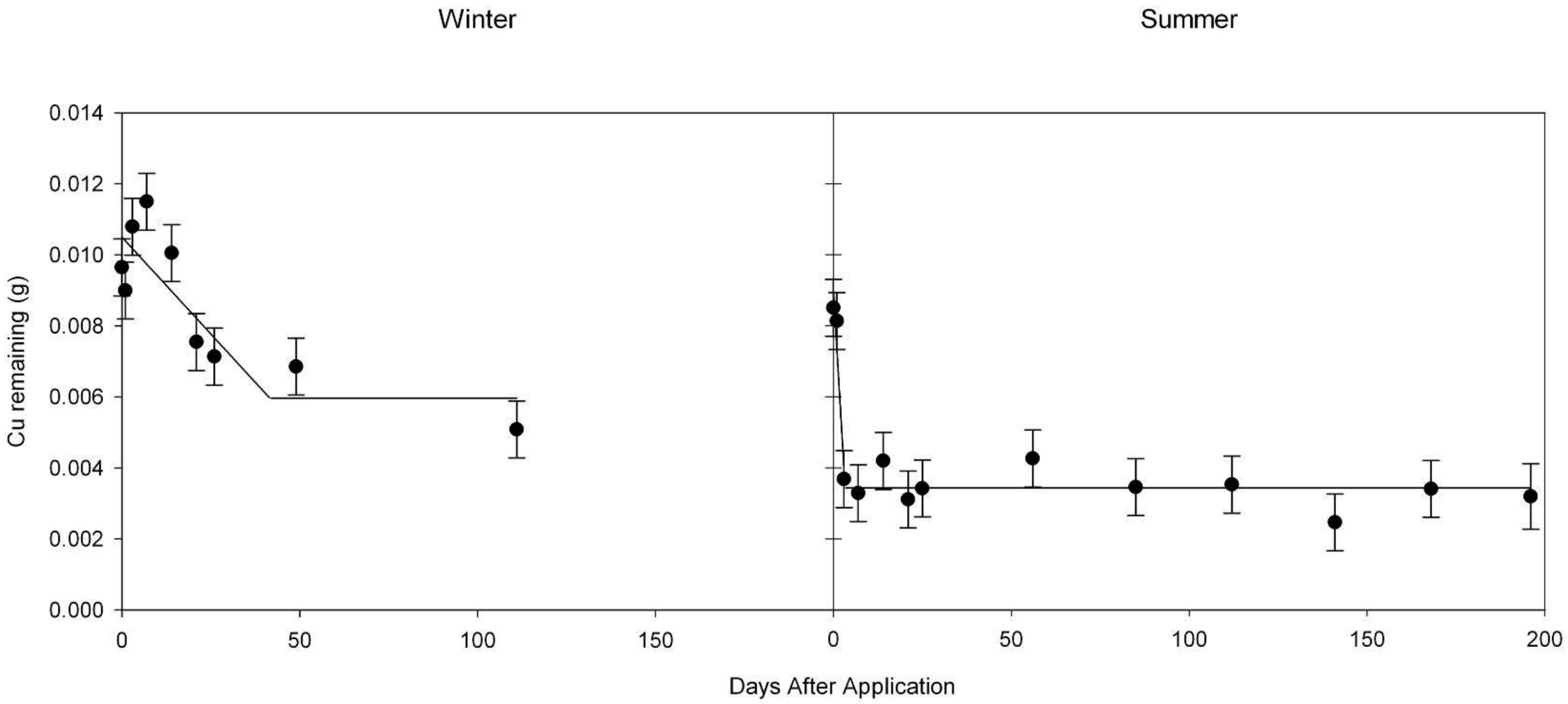

Figure 36. Copper remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

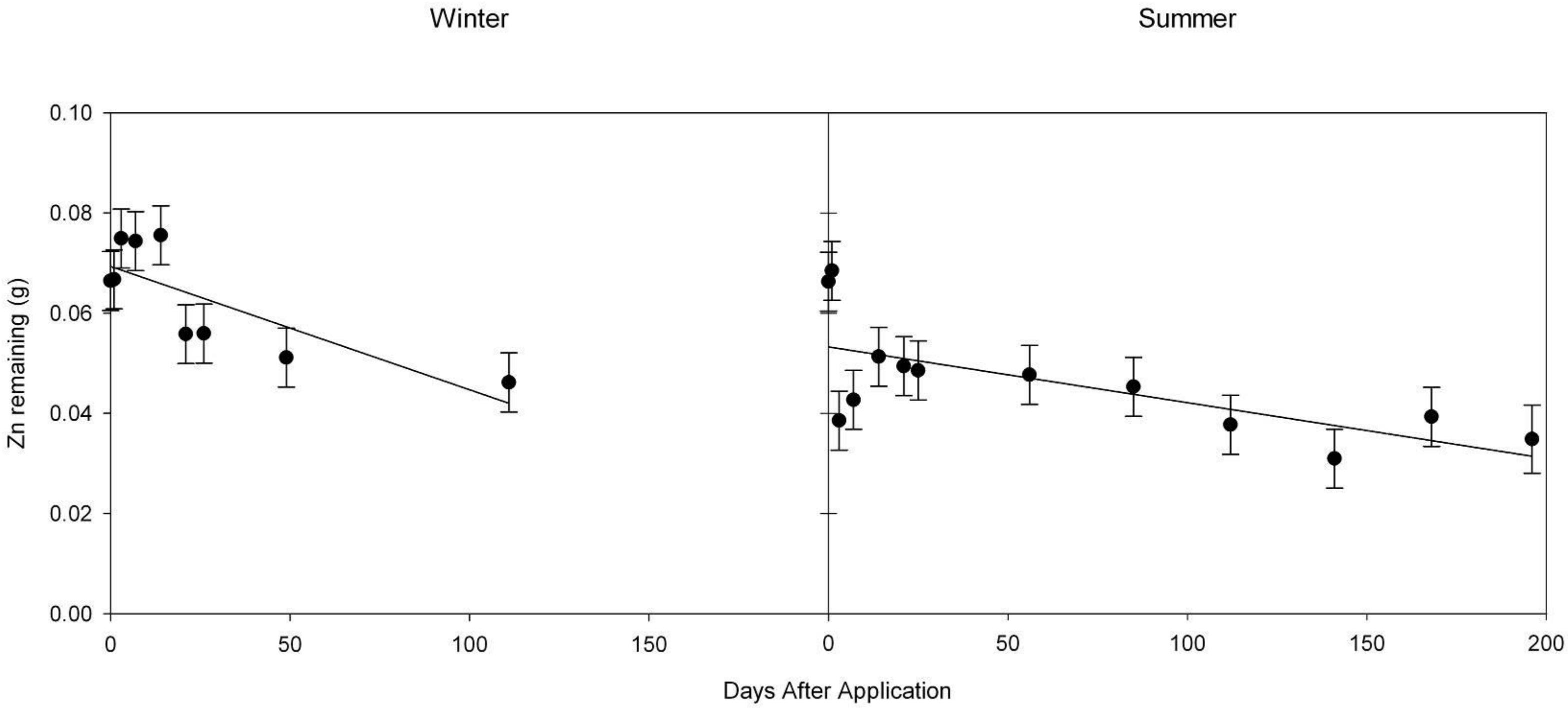

Figure 37. Zinc remaining in feces across time during both seasons. Error bars represent standard errors of the least square means.

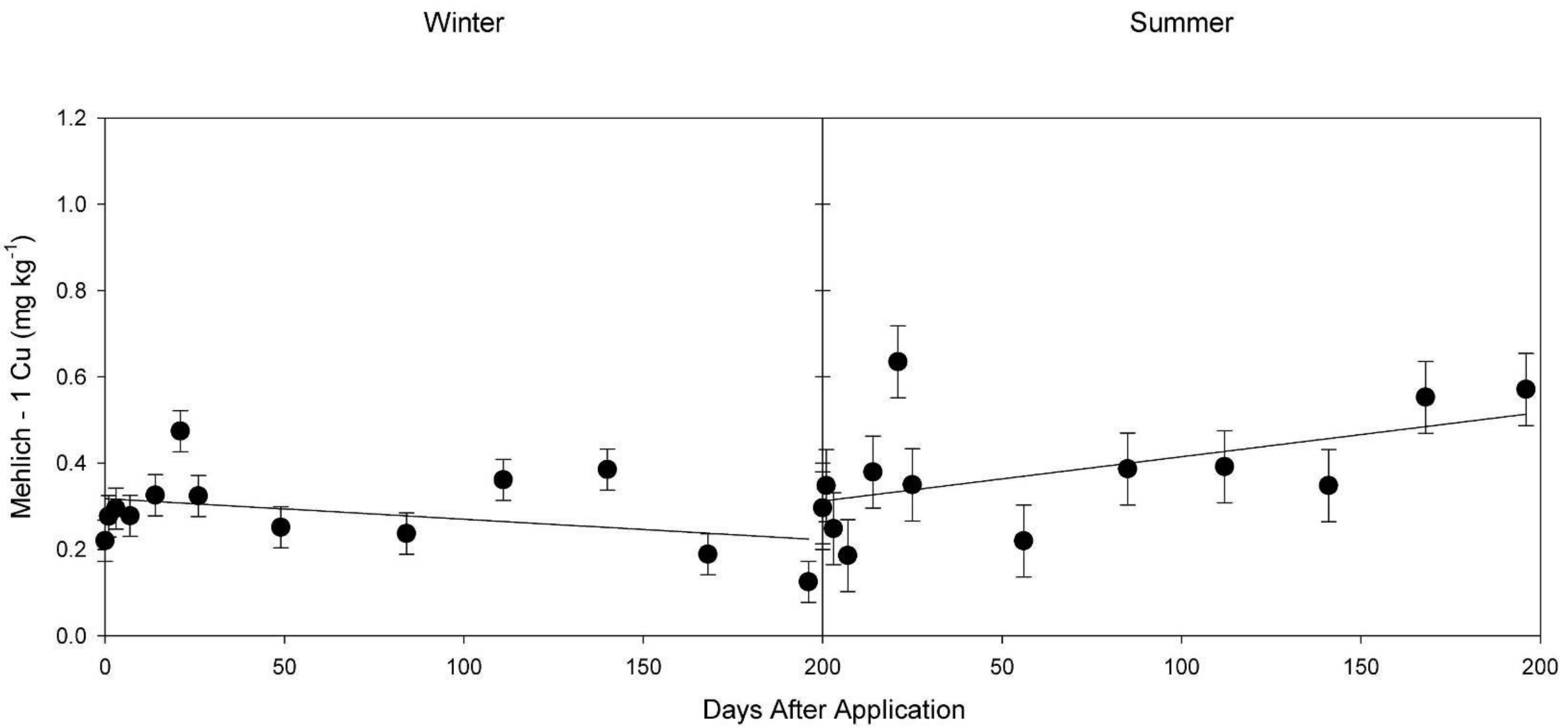

Figure 38. Mehlich-1 soil copper across time at 0-5 in both seasons. Error bars represent standard errors of the least square means.

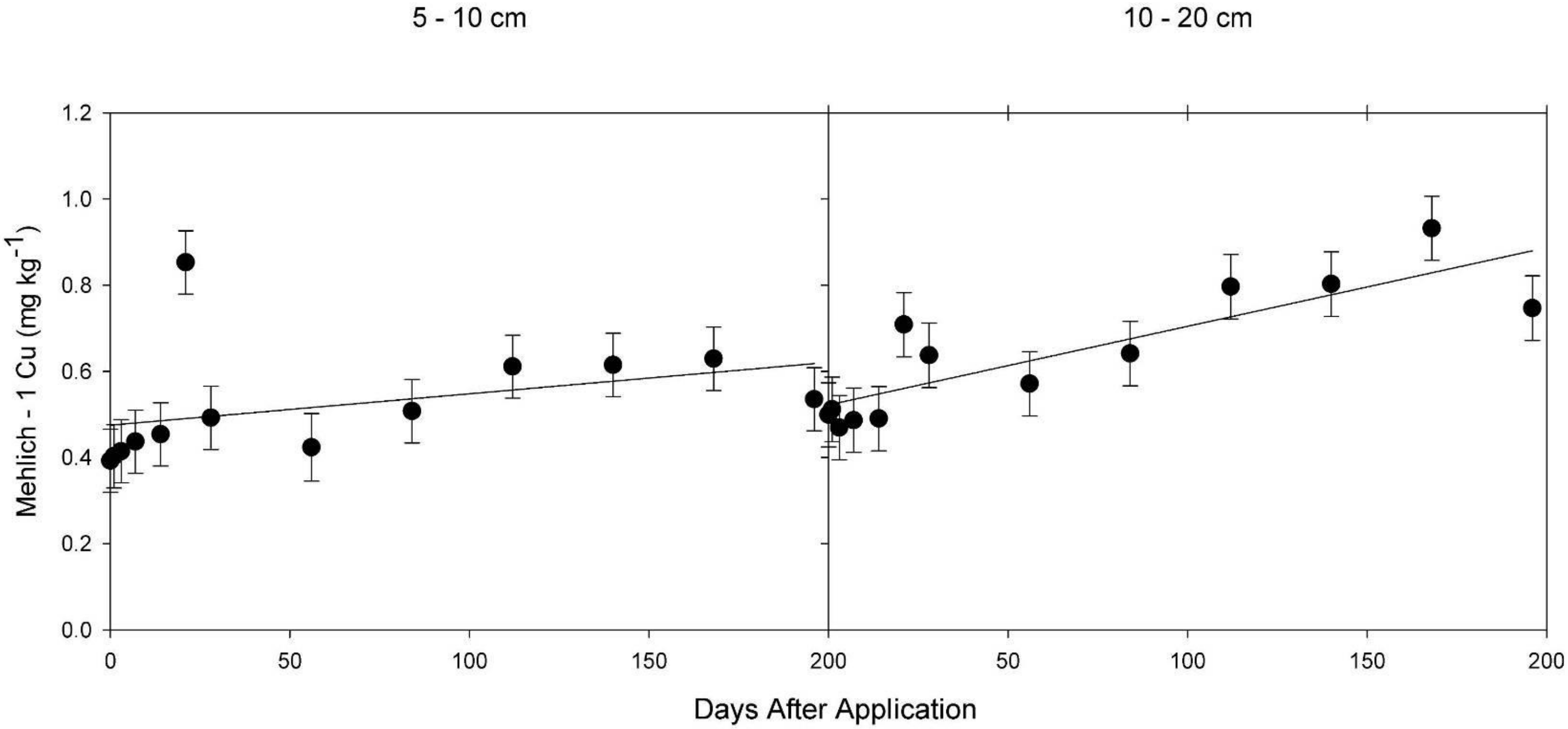

Figure 39. Mehlich-1 soil copper across time at 5-10 and 10-20 cm across both seasons. Error bars represent standard errors of the least square means.

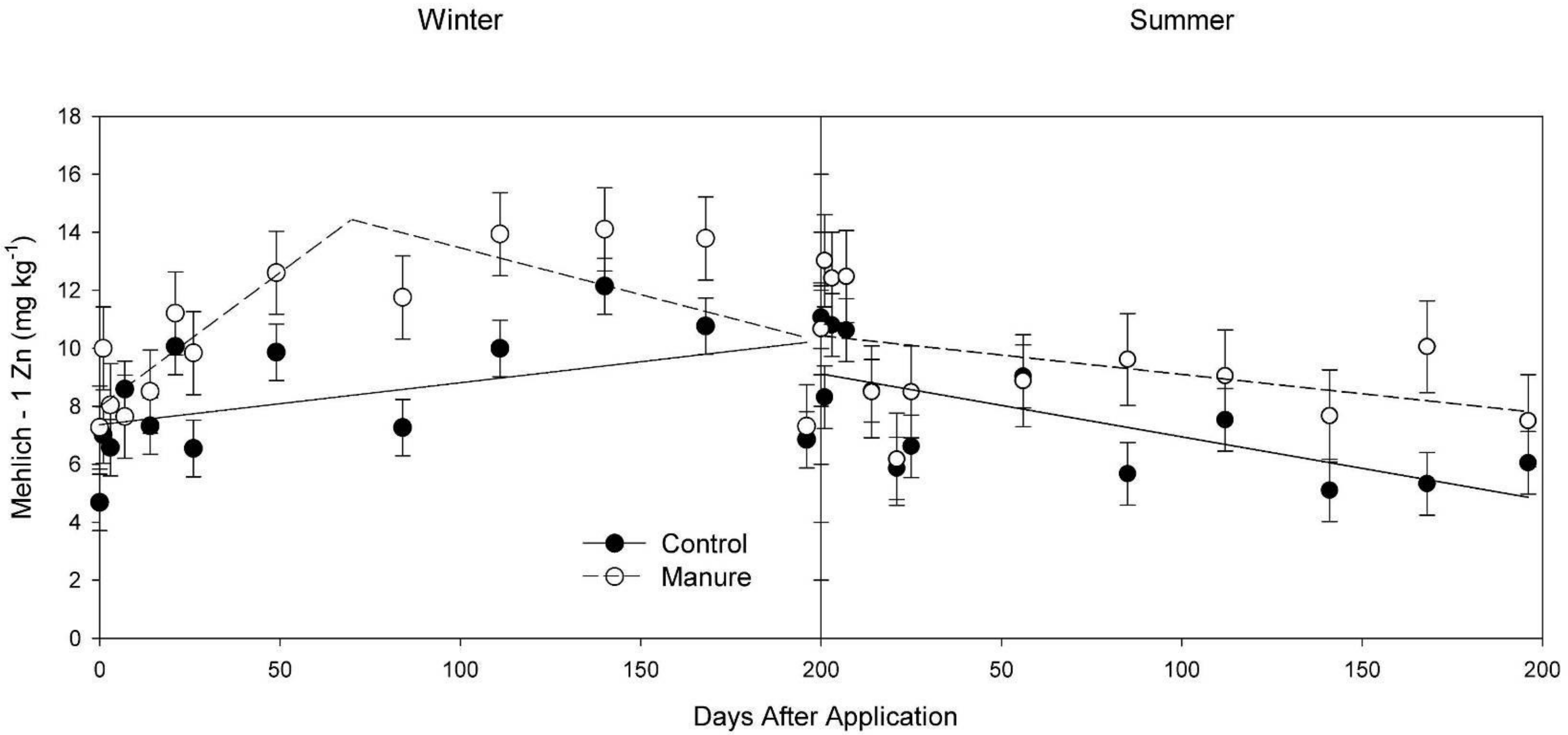

Figure 40. Mehlich-1 soil zinc across time at 0-5 cm in both seasons. Error bars represent standard errors of the least square means.

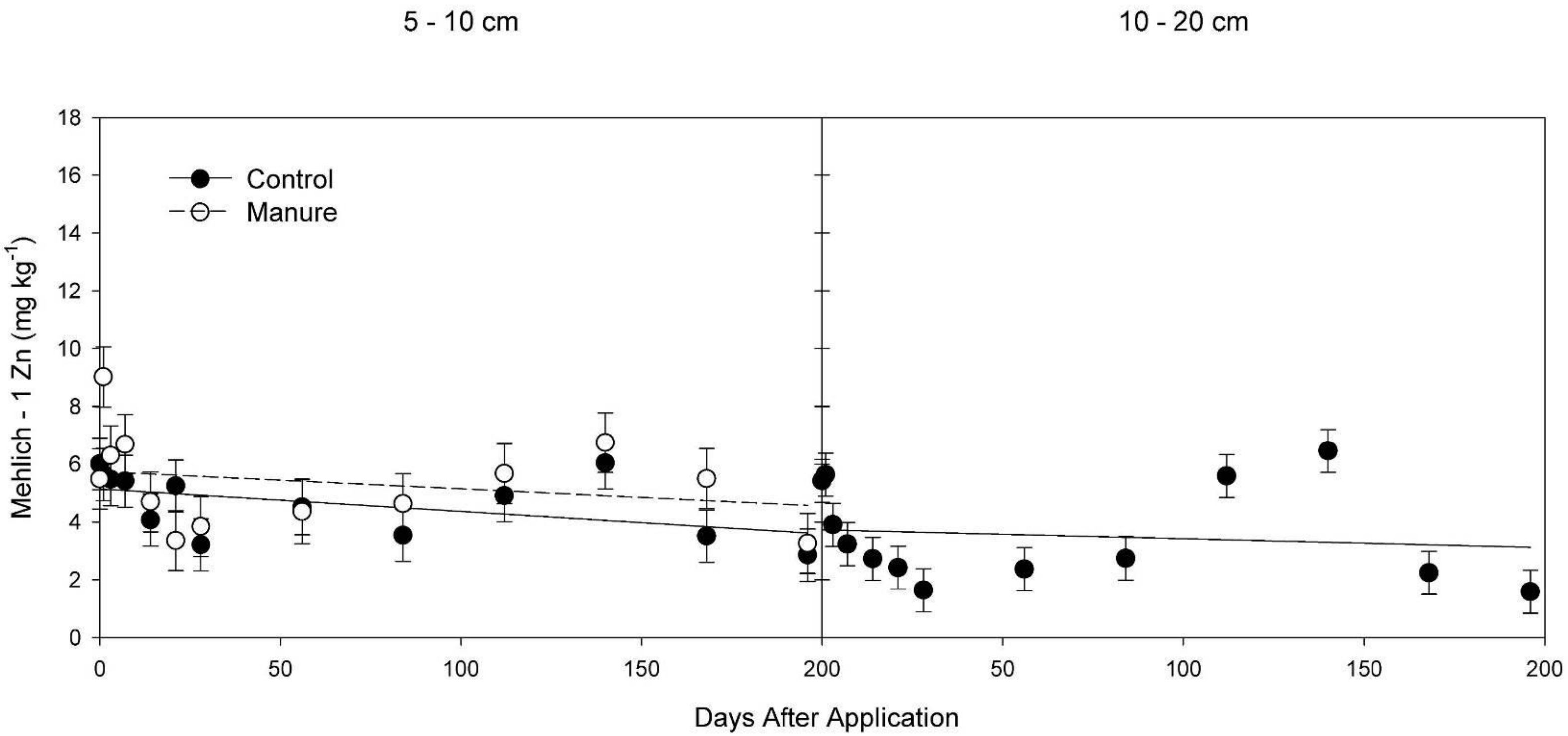

Figure 41. Mehlich-1 soil zinc across time at 5-10 and 10-20 cm across both seasons. Error bars represent standard errors of the least square means.

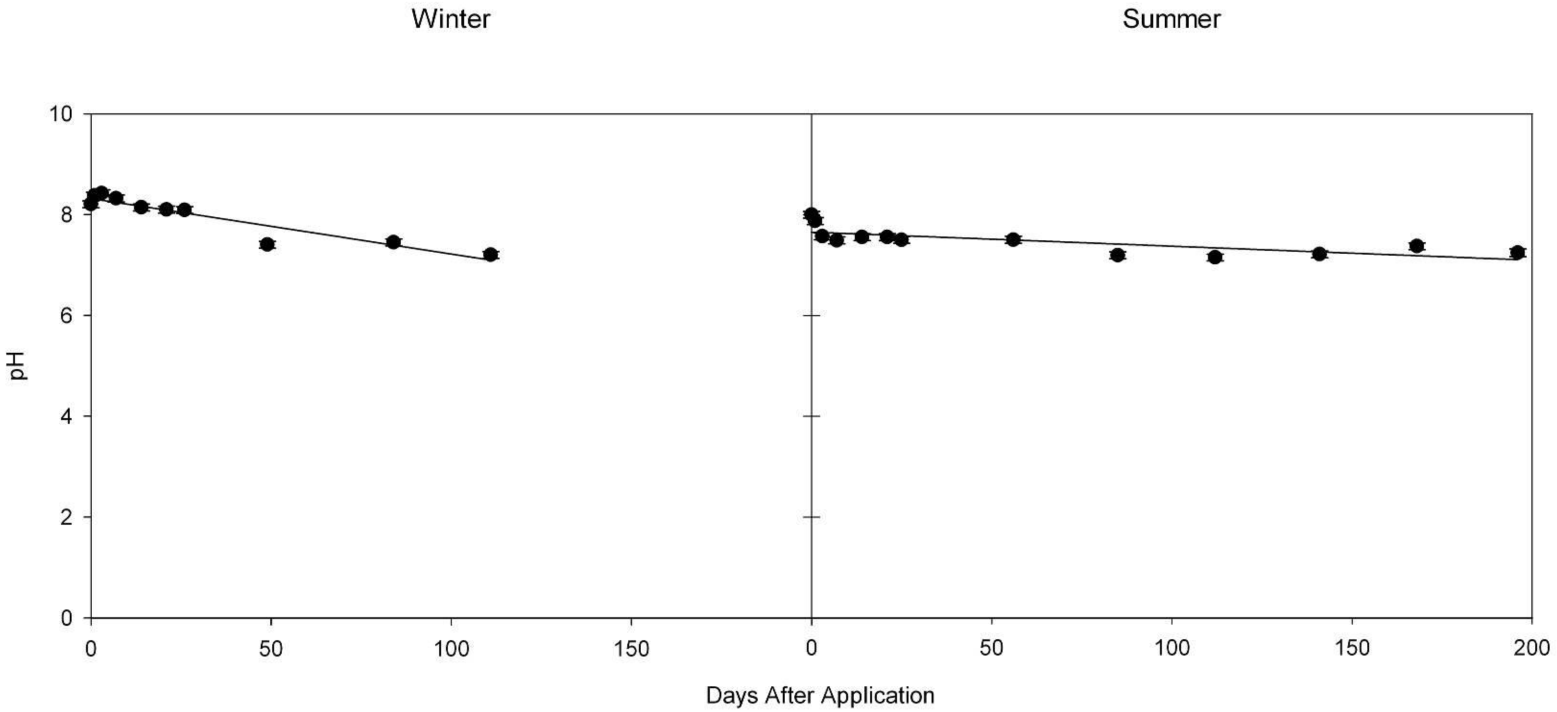

Figure 42. Feces pH across time during both seasons. Error bars represent standard errors of the least square means.

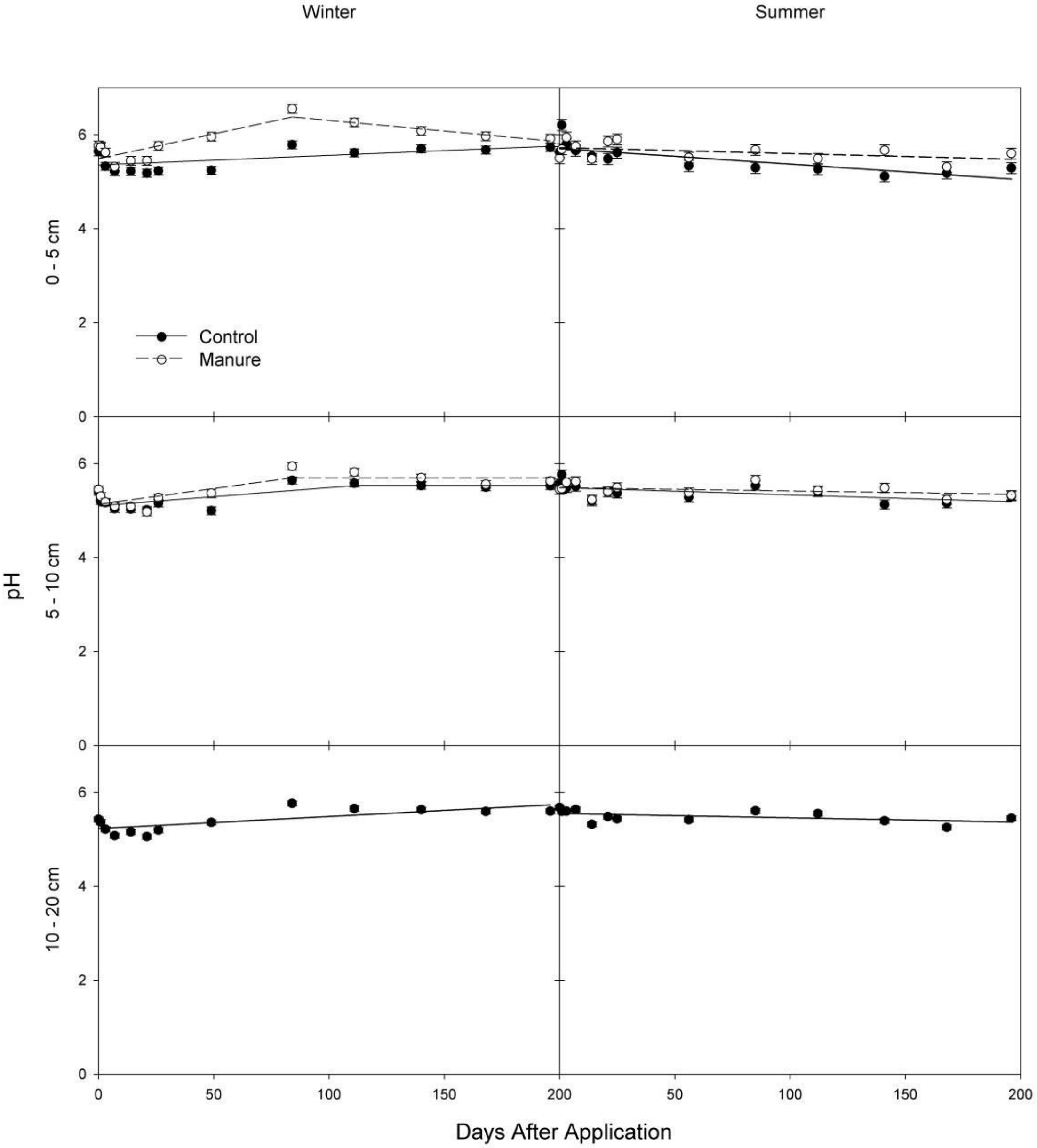

Figure 43. Soil pH at three depths across time during both seasons. Error bars represent standard errors of the least square means.

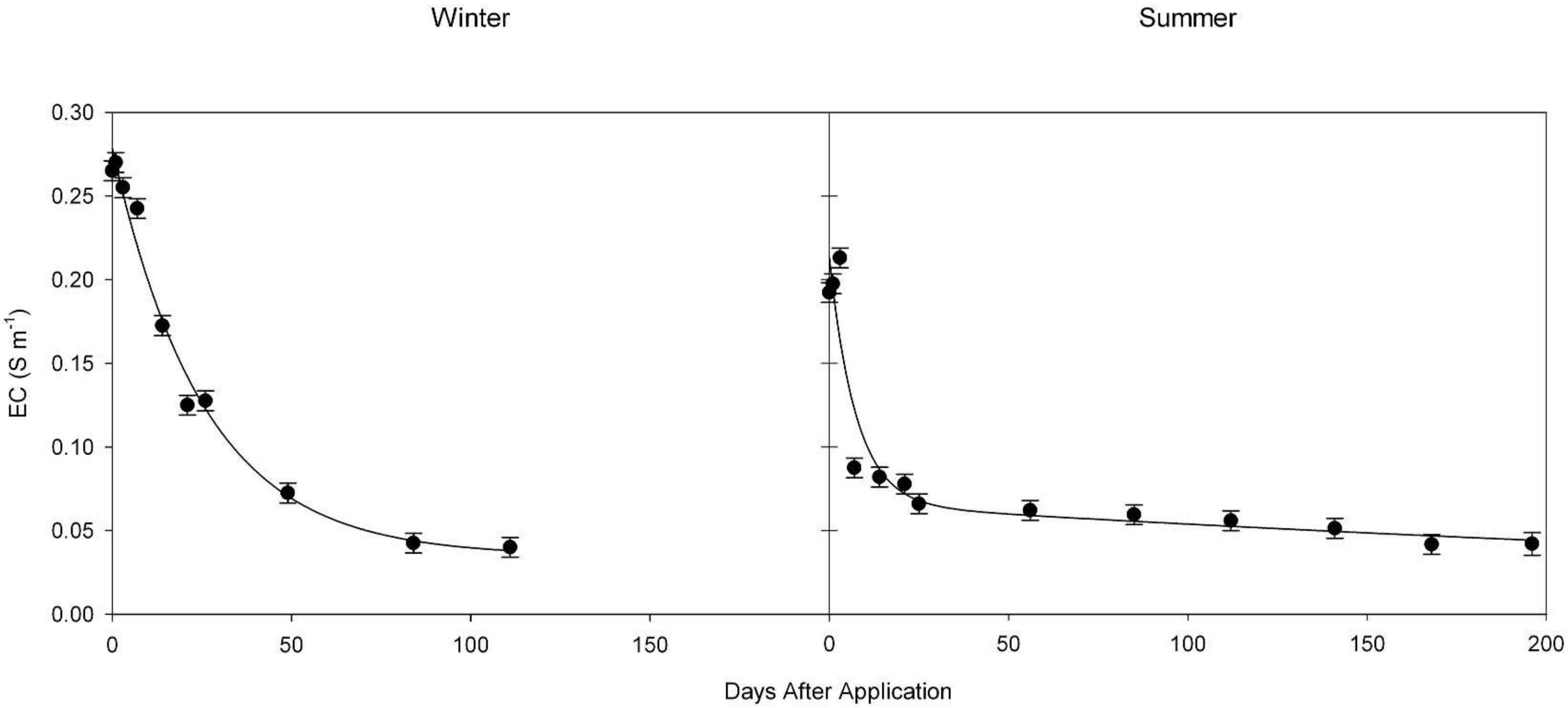

Figure 44. Electrical conductivity in feces across time during both seasons. Error bars represent standard errors of the least square means.

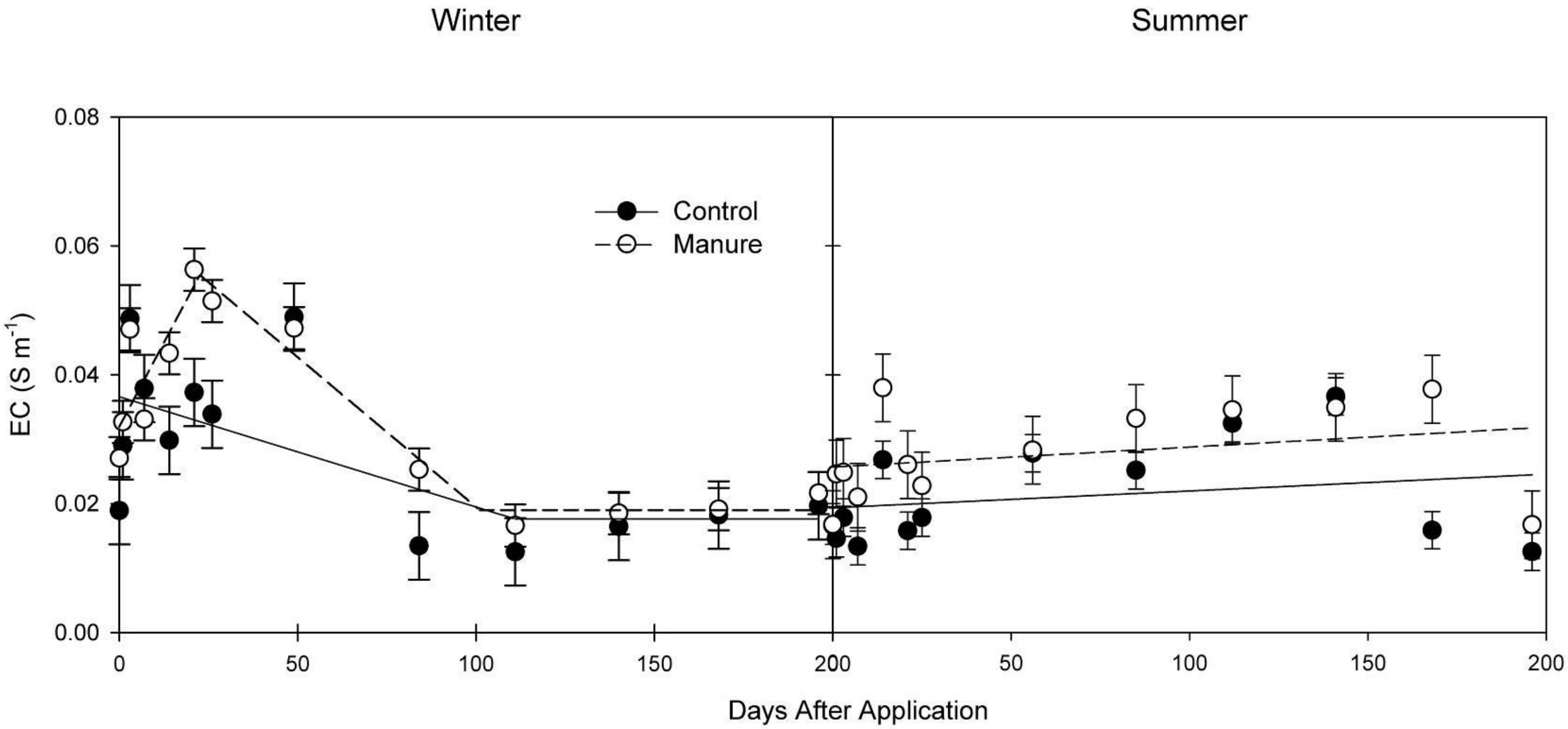

Figure 45. Soil electrical conductivity across time at 0-5 cm during both seasons. Error bars represent standard errors of the least square means.

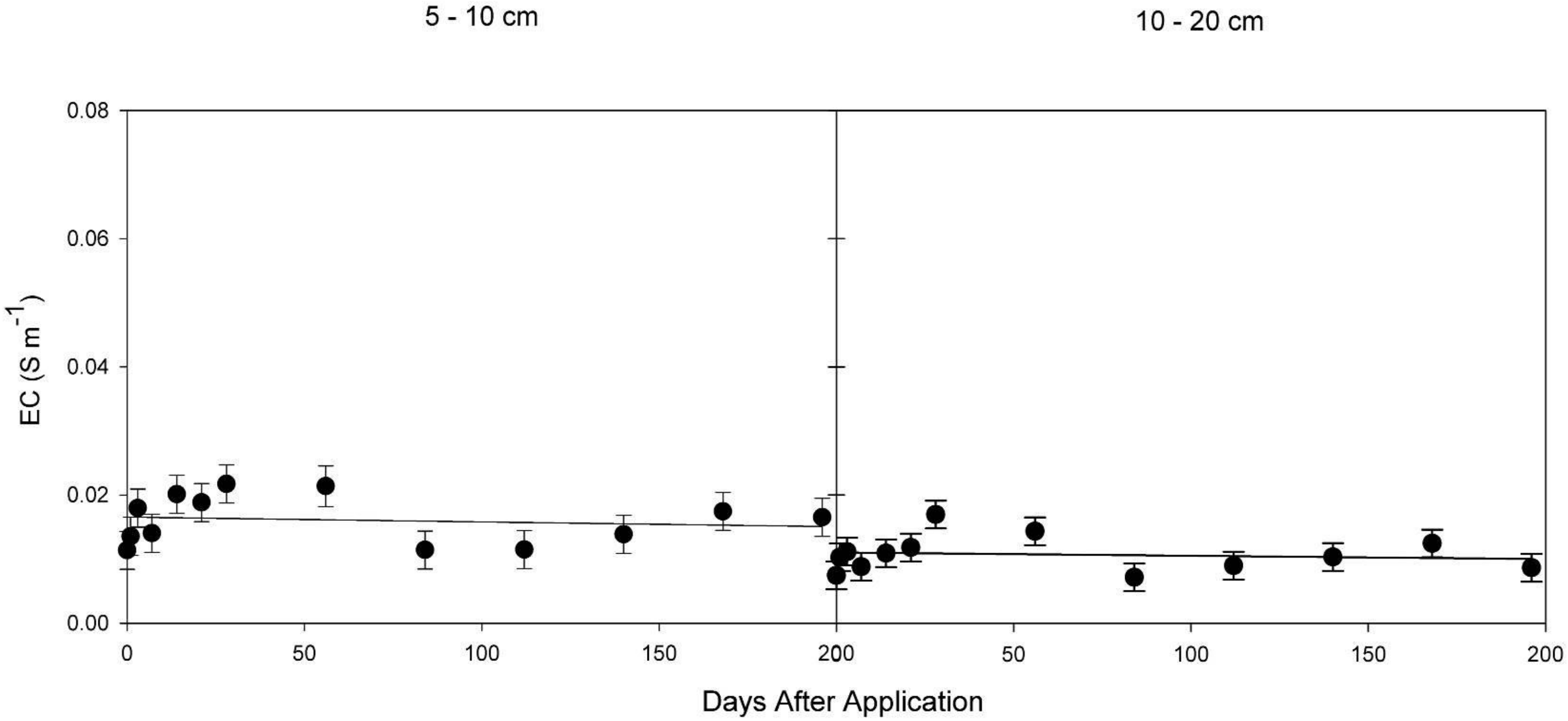

Figure 46. Soil electrical conductivity across time at 5-10 and 10-20 cm across both seasons. Error bars represent standard errors of the least square means.

IV. Conclusions

Judicious nutrient management for perennial grass species utilized in biomass production is essential for producing optimal yield. This research has shown that in the southeastern U.S. coastal plains, N is the only nutrient addition needed for biomass production of switchgrass and big bluestem. A rate of 150 kg N ha^{-1} would be appropriate for producing optimal yield. Biomass and fertilizer prices will be the determinants on how much N should be applied. Switchgrass showed the best net return on fertilizer application, whereas big bluestem was more dependent on the price of biomass in order to show an increase in net return. Phosphorus and K fertilizer applications are not recommended, since they are not shown to increase yield.

The decision to apply supplemental nutrients during the growing season can be a daunting task for producers. Deficiency of nutrients may not be visible to growers until it is too late and the result may be a substantial loss in yield. This study suggests for switchgrass and big bluestem, tissue samples, when taken early in the growing season, can detect N deficiency.

The results of this research can aid producers in nutrient management decisions when growing big bluestem and switchgrass for biomass production. Initial fertilizer applications should be based on expected biomass price and supplemental additions should utilize tissue testing to determine whether there is a need during the growing season.

The second half of this work dealt with nutrients released from cattle feces and changes in soil nutrient status. The effects of applying manure to soils is well documented, however limited information is available on the correlation of feces deposition in pastures and the nutrients they provide. This research suggests that N, P, K, Ca, Mg, and Zn are added to the soil by cattle feces. The availability of these nutrients can be dependent on season since their release from feces relies on environmental conditions. Not all nutrients will be added in large amounts, but their influence should be taken into account. Soil N and P are impacted the greatest since their concentrations in manure are the highest. The implications nutrient loss from cattle defecation has on the environment may be limited only to areas where cattle tend to spend the most time and defecate the most.

References

Abassi, M. K., M. Hina, A. Khalique, and S. R. Khan. 2007. Mineralization of Three Organic Manures Used as Nitrogen Source in a Soil Incubated under Laboratory Conditions. Comm. Soil Sci. and Plant Anal. 38:1691-1711.

Adler, P. R., S. J. Del Grosso, and W. J. Parton. 2007. Life-cycle assessment of net greenhouse-gas flux or bioenergy cropping systems. Ecol. Appl. 17:675-691.

Aland, A., L. Lidfors, and I. Ekesbo. 2002. Diurnal distribution of dairy cow defecation and urination. Appl. Anim. Behav. Sci. 78:43-54.

ASAE Standards. 2005. Manure production and characteristics. D384.2. St. Josephs,MI. ASABE.

Barnett, G. M. 1994. Phosphorus forms in animal manure. Bioresources Technol. 19:139-148.

Benke, M. B., S. P. Indrarante, X. Hao, C. Chang, and T. B. Goh. 2008. Trace Elements Changes in Soil after Long-Term Cattle Manure Applications. J. Environ. Qual. 37:798-807.

Bock, B. R. 1984. Efficient use of nitrogen in cropping systems. p 273-294. *In* R. C. Dinauer et al. (ed.) Nitrogen in crop production. ASA, CSSA, SSSA, Madison, WI.

Bransby, D. I., S. B. McLaughlin, and D. J. Parrish. 1997. A review of carbon and nitrogen balances in switchgrass grown for energy. Biomass and Bioenergy. 14:379-384.

Bransby, D. I., S. Sladden, T. Morrison, S. Durbin, and B. Durbin. 2002. Extraordinary response of switchgrass to nitrogen fertilization. p 320-322. *In* Cassida, K., (ed.) Proc. Forage and Grassl. Conf., Bloomington, MN, July 14-17, 2002. Georgetown, TX: Am. Forage and Grassl. Coun.

Brejda J. J., D. H. Yocom, L. E. Moser, and S. S. Waller. 1993. Dependence of 3 Nebraska Sandhills warm-season grasses on vesicular-arbuscular mycorrhizae. J. Range Manage. 46:14-20.

Brock, E. H., Q. M. Ketterings, and M. McBride. 2006. Copper and zinc accumulation in poultry and dairy manure-amended fields. Soil Sci. 171:388-399.

Cassman, K. G. and D. N. Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. Am. J. 44:1233-1237.

Calderon, F. J., McCarty, G. W., and J. B. Reeves. 2005. Analysis of manure and nitrogen mineralization during incubation. Biol. Fert. Soils. 41:328-336.

Castle, M.E., A. S. Foot, and R. J. Halley. 1950. Some observation on the behavior of dairy cattle with particular reference to grazing. J. Dairy Res. 17:215-230.

Chang, C., T. G. Sommerfeldt, and T. Entz. 1991. Soil chemistry after eleven annual applications of cattle feedlot manure. J. Environ. Qual. 20:475-480.

Chapuis-Lardy, L., J. Fiorini, J. Toth, and Z. Dou. 2004. Phosphorus Concentration and Solubility in Dairy Feces: Variabiliy and Affecting Factors. J. Dairy Sci. 87:4334-4341.

Colemen, S. W., C. M. Taliaferro, and R. J. Tyrl. 2004. Old World Bluestems. p 909-936. *In* L. E. Moser et al. (ed.) Warm-Season (C_4) Grasses. ASA, CSSA, SSSA, Madison, Wisconsin.

Cope, J. T. 1970. Response of cotton, corn, and bermudagrass to rates of N, P, and K. Bulletin 181. Alabama Agric. Exp. Stn.

Cope, J. T. 1984. Long-term fertility experiments on cotton, corn, soybeans, sorghum, and peanuts. Bulletin 561. Alabama Agric. Exp. Stn.

Economic Research Service. 2010. Ferilizer Prices. U. S. Dep. of Ag.

Eghball, B. 2000. Nitrogen Mineralization from Field-Applied Beef Cattle Feedlot Manure or Compost. Soil Sci. Soc. Am. J. 64:2024-2030.

Eghball, B. and J. F. Powers. 1994. Beef cattle feedlot manure management. J. of Soil and Water Conserv. 39:114-122.

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

Eghball, B., D. Ginting, and J. E. Gilley. 2004. Residual effects of manure and compost applications on corn production and soil properties. Agron. J. 96:442-447.

Eneji, A. E., M. Irshad, T. Honna, S. Yamamoto, T. Endo, and T. Masuda. 2003. Potassium, Calcium, and Magnesium Mineralization in Manure-Treated Soils. Comm. Soil Sci. Plant Anal. 34:1669-1679.

Esse, P. C., A. Buerker, P Hiernaux, and A. Assa. 2001. Decomposition of and nutrient release from ruminant manure on acid sandy soils in the Sahelian zone of Niger, West Africa. Agric. Ecosyst. Environ. 83:55-63.

Energy Information Administration. 2010a. Annual Energy Review 2009. U. S. Dep. of Energy.

Fletcher, P. and P. H. T. Beckett. 1987. The chemistry of heavy metals in digested sewage sludge-II. Heavy metal complexation with soluble organic matter. Wat. Res. 21:1163-1172.

Friedrich, J. W., D. Smith, and L. E. Schrader. 1977. Herbage yield and chemical composition of switchgrass as affected by N, S, and K Ferilization. Agron. J. 69:30-33.

Franzluebber, A. J., J. A. Stuedemann, and H. H. Schomberg. 2000. Spatial distribution of soil carbon and nitrogen pools under grazed tall fescue. Soil Sci. Soc. Am. J. 64:635-639.

Giampietro, M., S. Ulgiati, and D. Pimentel. 1997. Feasibility of Large-Scale Biofuel Production. Bioscience. 47:587-600.

Haque, M., F. M. Epplin, and C. M. Taliaferro. 2009. Nitrogen and harvest frequency effect on yield and cost for four perennial grasses. Agron. J. 101:1463-1469.

Hall, K. E., J. R. George, and R. R. Riedl. 1982. Herbage Dry Matter Yields of Switchgrass, Big Bluestem and Indiangrass with N Fertilization. Agron. J. 74:47-51.

He, Z., T. S. Griffin, and C. W. Honeycutt. 2004. Phosphorus Distribution in Dairy Manure. Journ. Environ. Qual. 33:1528-1534.

Heckathorn, S. A. and H. Delucia. 1996. Retranslocation of shoot nitrogen to rhizomes and roots in prairie grasses may limit loss of N to grazing and fire during drought. Funct. Ecol. 10:396-400.

Hetrick, B. A. D., D. G. Kitt, and G. T. Wilson. 1988. Mycorrhizal dependence and growth habit of warm-season and cool-season tallgrass prairie plants. Can. J. Botany. 66:1376-1380.

Heggenstaller, A. H., K. J. Moore, M. Liebman, and R. P. Anex. 2009. Nitrogen influences biomass on nutrient partitioning by perennial, warm-season grasses. Agron. J. 101:1363-1371.

IPCC. 2001**.** Summary for Policy Makers. *In* J T Houghton et al. (ed.) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Eds. Cambridge, UK, and New York, USA: Cambridge University Press. Available at http://www.ipcc.ch.

Klausner, S. D., V. R. Kanneganti, and D. R. Bouldin. 1995. An Approach for Estimating Decay Series of Organic Nitrogen in Animal Manure. Agron. J. 86:897-903.

Kramer M. 2005. R^2 statistics for mixed models. 2005 Proceedings of the Conference on Applied Statistics in Agriculture, Manhattan, KS.

Lemus, R., E. C. Brummer, C. L. Burras, K. J. Moore, M. F. Baker, and N. E. Molstad. 2008a. Effects of nitrogen fertilization on biomass yield and quality in large fields of established switchgrass in southern Iowa, USA. Biomass and Bioenergy. 32:1187-1194.

Lemus, R., D. J. Parrish, and O. Abaye. 2008b. Nitrogen-use dynamics in switchgrass grown for biomass. Bioenergy Res. 1:153-162.

Lupwayi, N. Z. and Haque, I. (1999). Leucana hedgerow intercropping and cattle manure application in the Ethiopian highlands I. Decomposition and nutrient release. Biol Fertil. Soils. 28:182-195.

Marschner, H. 1995. Minerals Nutrition of Higher Plants. 2nd ed. London: Academic Press.

McBride, M. B. and G. Spiers. 2001. Trace elements content of selected fertilizers and dairy manures as determine by ICP-MS. Comm. Soil Sci. Plant Anal. 32:139-156.

McLaughlin, S. B. and M. E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy. 14:317-324.

McLaughlin S. B., J. H. Bouton, D. I. Bransby, B. V. Conger, W. R. Ocumpaugh, D. J. Parrish, C. M. Taliaferro, K. P. Vogel, and S. D. Wullschleger. 1999. Developing switchgrass as a bioenergy crop. p. 282–99. *In* Janick, J J, (ed.) Proc. of the Fourth National New Crops Symposium. Alexandria, VA: ASHS Press.

McLaughlin, S. B. and L. A. Kszos. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. Biomass and Bioenergy. 28:515-535.

McMurphy, W. E., C. E. Denman, and B. B. Tucker. 1975. Fertilization of Native Grass and Weeping Lovegrass. Agron. J. 67:233-236.

Mitchell, R., J. Fritz, K. Moore, L. Moser, K. Vogel, D. Redfearn, and D. Wester. 2001. Predicting Forage Quality in Switchgrass and Big Bluestem. Agron. J. 93:118-124.

Morse, D., R. A. Nordstedt, H. H. Head, and H. H. Van Horn. 1994. Production and characteristics of manure from lactating dairy cows in Florida. Trans. ASAE. 37:275-279.

Moser, L. E., and K. P. Vogel. 1995. Switchgrass, big bluestem, and indiangrass. p 409-420. *In* R. F. Barnes et al. (ed.) Forages. Vol. 1. An Introduction to Grassland Agriculture. 5th Ed. Iowa State Univ. Press, Ames, Iowa.

Motavalli, P. P., K. A. Kelling, and J. C. Converse. 1989. First-Year Nutrient Availability from Injected Dairy Manure. J. Environ. Qual. 18:180-185.

Muir, J. P., M. A. Sanderson, W. P. Ocumpaugh, R. M. Jones, and R. L. Reed. 2001. Biomass Production of 'Alamo' Switchgrass in Response to Nitrogen, Phosphorus, and Row Spacing. Agron. J. 93:896-901.

Mulkey, V. R., V. N. Owens, and D. K. Lee. 2006. Management of Switchgrass-Dominated Conservation Reserve Program Lands for Biomass Production in South Dakota. Crop Sci. 46:712-720.

Mulkey, V. R., V. N. Owens, and D. K. Lee. 2008. Management of warm-season grass mixtures for biomass production in South Dakota USA. Bioresource Technol. 99:609-617.

Mundus, S., R. S. C. Menezes, A. Neergaard, M. S. Garrido. 2008. Maize growth and soil nitrogen availability after fertilization with cattle manure and/or gliricidia in semi-arid NE Brazil. Nutr. Cycl. Agroecosyst. 82:61-73.

National Research Council (U.S.). 2001. Nutrient Requirements of Dairy Cattle. 7th ed. National Academy Press, Washington DC.

Nennich, T. D., J. H. Harrison, L. M. VanWieringen, D. Meyer, A. J. Heinrichs, W. P. Weiss, N. R. St-Pierre, R. L. Kincaid, D. L. Davidson, and E. Block. 2005. Prediction of Manure and Nutrient Excretion from Dairy Cattle. J. Dairy Sci. 88:3721-3733.

Oudshoorn, F. W., T. Kristensen, and E. S. Nadimi. 2008. Dairy cow defecation and urination frequency and spatial distribution in relation to time-limited grazing. Livestock Sci. 113:62-73.

Parrish, D. J. and J. H. Fike. 2005. The Biology and Agronomy of Switchgrass for Biofuels. Crit. Rev. Plant Sci. 24:423-459.

Paustian, K., O. Andrén, H. H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Van Noordwijk, and P. L. Woomer. 1997. Agricultural soils as a sink to mitigate CO_2 emissions. Soil Use Manage. 13:230-244.

Perlack, R. D., L. L. Wright, A. F. Turhollow, R. L. Graham, B. J. Stokes, and D. C. Erbach. 2005. Biomass as a Feedstock for Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. Oak Ridge National Laboratory. (http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf).

Rehm, G. W. 1984. Yield and Quality of a Warm-Season Grass Mixture Treated with N, P, and Atrazine. Agron. J. 76:731-734.

Reijs, J. W., M. P. W. Sonneveld, P. Sorensen, R. L. M. Schils, J. C. J. Groot, and E. A. Lantinga. 2005. Effects of different diets on utilization of nitrogen from cattle slurry applied to grassland on a sandy soil in The Netherlands. Agric., Ecosyst. Environ. 118:65-79.

Reynolds, J. H., C. L. Walker, and M. J. Kirchner. 2000. Nitrogen removal in switchgrass biomass under two harvest systems. Biomass and Bioenergy. 19:281-286.

Safley, L. M., P. W. Weserman, and J. C. Barker. 1985. Fresh dairy manure characteristics and barnlot nutrient losses. p 191-199. *In* Agricultural Waste Utilization and Management. Proc. of the Fifth International Symposium on Agricultural Wastes. Chicago, Illinois, December 16-17, 1985. St. Joseph MI: Am. Soc. Agric. Eng.

Sanderson, M. A., P. R. Adler, A. A. Boateng, M. D. Casler, and G. Sarath. 2006. Switchgrass as a biofuels feedstock in the USA. Can. J. Plant Sci. 86:1315-1325.

Sanderson, M. A. and P. R. Adler. 2008. Perennial Forages as Second Generation Bioenergy Crops. Int. J. Mol. Sci. 9:768-788.

Schmer, M. R., K. P. Vogel, R. B. Mitchell, and R. K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. Proc. of the National Academy of Sci. 105:464-469.

Sharpley, A. N., R. W. McDowell, P., and J. A. Kleinman. 2004. Amounts, Forms, and Solubility of Phosphorus in Soils Receiving Manure. Soil Sci. Soc. Am. J. 68:2048-2057.

Sharpley, A. and B. Moyer. 2000. Phosphorus forms in manure and compost and their release during simulated rainfall. J. Environ. Qual. 29:1462-1469.

Smart, A. J., L. E. Moser, and K. P. Vogel. 2003. Establishment and Seedling Growth of Big Bluestem and Switchgrass Populations Divergently Selected for Seedling Tiller Number. Crop Sci. 43:1434-1440.

Smith, D. 1979. Fertilization of switchgrass in the greenhouse with various levels of N and K. Agron. J. 71:149-150.

Sorensen, P., M. R. Weisbjerg, and P. Lund. 2003. Dietary effects on the composition and plant utilization of nitrogen in dairy cattle manure. J. Agric Sci. 141:79-91.

Staley, T. E., W. L. Stout, and G. A. Jung. 1991. Nitrogen use by tall fescue and switchgrass on acidic soils of varying water holding capacity. Agron. J. 83:732-738.

Thomason, W. E., W. R. Raun, G. V. Johnson, C. M. Taliaferro, K. W. Freeman, K. J. Wynn, and R. W. Mullen. 2004. Switchgrass Response to Harvest Frequency and Time and Rate of Applied Nitrogen. J. Plant Nutr. 27:1199-1226.

Vogel, K. P. 1996. Energy production from forages (or American agriculture - back to the future). J. Soil Water Conserv. 51:137-139.

Vogel, K. P., J. J. Brejda, D. T. Walters, and D. R. Buxton. 2002. Switchgrass biomass production in the Midwest USA: harvest and nitrogen management. Agron. J. 94:413-420.

Watts, D. B., H. A. Torbert, and S. A. Prior. 2007. Mineralization of Nitrogen in Soils Amended with Dairy Manure as Affected by Wetting/Drying Cycles. Comm. Soil Sci. Plant Anal. 38:2103-2116.

West, C. P., A. P. Mallarino, W. F. Wedin, and D. B. Marx. 1989. Spatial variability of soil chemical properties in grazed pastures. Soil Sci. Soc. Am. J. 53:784-789.

Whalen, J. K., C. Chang, G. W. Clayton, and J. P. Carefoot. 2000. Cattle Manure Amendments Can Increase the pH of Acid Soils. Soil Sci. Soc. Am. J. 64:962-966.

Whalen, J. K., C. Chang, and B. M. Olson. 2001. Nitrogen and phosphorus mineralization potential of soils receiving repeated annual cattle manure application. Biol. Fert. Soils. 34:334-341.

Wilkerson, V. A., D. R. Mertens, and D. P. Casper. 1997. Prediction of Excretion of Manure and Nitrogen by Holstein Dairy Cattle. J. Dairy Sci. 80:3193-3204.