NUTRIENT CYCLING AT CATTLE FEEDLOTS
FIELD & LABORATORY STUDY

by

GRACE C. VAILLANT

B.S., Virginia Tech, 2004

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Approved by:

Major Professor
Dr. Gary Pierzynski

Copyright

Abstract

Soil chemical and physical properties beneath cattle feedlot pens are largely unstudied. This project was conducted to survey select soil chemical and physical properties of soil beneath active open air cattle feedlots. At four cattle feedlots in Kansas, the concentrations of NH_4-N, organic-N, organic-C, Cl^-, and P were high at the surface and rapidly decreased within 1.00 m. At three of the four feedlots, NO_3-N was generally below background concentration (4.1 mg kg^{-1}) while one feedlot had a >75 mg kg^{-1} increase in the top 1.00 m. Based on feeding data, only a small percent (7.9 to 1.2) of the total N deposited on the surface was found in the top 1.00 m below the pen surface for a range of 25 to 60 years of operation. While in use, these feedlots do not appear to have a high potential for groundwater pollution from NO_3-N leaching. However, if they were to become inactive they may pose a severe threat to groundwater quality from organic-N mineralization and NH_4-N nitrification. If feedlots were closed and the land could be largely remediated by removing a layer of soil, these feedlots would have an average 48% profile N removed in a 0.25 m thick layer. .

A chamber, a modified vacuum desiccator, was tested for the investigation of NH_3 volatilization from soil in the laboratory. Ammonia volatilization at the soil surface is dependent on air flow, soil and air temperatures, soil water content, pH, the concentrations of NH_3 and NH_4^+ in the air and soil solution, and factors affecting soil temperature including humidity. This chamber was built to control and/or quantify as many of these variables as possible. A technique for quantifying and predicting NH_3 volatilization is important because AFOs are one of the largest contributors of NH_3 to the atmosphere, which can cause acid precipitation and particulate matter deposition downwind from the operation. The chambers created allowed for repeated measurements with little error and appear to be a feasible, inexpensive apparatus to investigate NH_3 volatilization mechanisms. Using synthetic urine as an N source, NH_3 volatilization was affected by initial soil moisture content and soil texture and may be affected by initial soil pH. This chamber has promise to provide excellent data to assist the efforts being made to understand and model NH_3 volatilization from feedlot pens.

Table of Contents

List of Figures

List of Tables

Acknowledgements

There is a long list of people who have all helped shape and guide my experiences here at Kansas State University, and I would like to thank every one of you because I have had a wonderful time and love being here in Manhattan. I would like to thank my committee, Dr. Gary Pierzynski, Dr. Jay Ham, and Dr. Ronaldo Maghirang and other faculty for their guidance and assistance in completing my research projects and thesis writing. I would also like to give a special mention to Kathy Lowe and the Soil Testing Lab for putting up with all of my samples, and for entertaining my many study breaks. In addition, I must thank all of the graduate and undergraduate students who helped me in the field and in the lab.

I would also like to thank my parents and family for working so hard to prepare me for the world and encouraging me to always strive for my dreams and to keep moving forward every day whether its cloudy or sunny. And, for putting up with my numerous calls home for advice and moral support. Lastly, I have to thank my friends especially Kathryn Schmitt McCain and Kristy Hajny who have kept me sane and for participating in all the fun and mayhem we have had or created.

CHAPTER 1 - Introduction

The United States Department of Agriculture (USDA) has been collecting data on cattle production in the United States since 1964. The number of cattle on feed in the United States has fluctuated over time, increasing from 9 million in 1964 to 14 million in 1973 (Figure 1-1). In 1974, there was a sharp decline to 10 million head with a rapid recovery to 12-million in 1975. Since 1975, cattle on feed have ranged from 13 to 10 million. In Kansas, the number of cattle in confined feeding operations has been on an upward trend since 1964, having 2.4 million cattle on feed in 2006, and is ranked second to Texas for number of cattle on feed at 1000+ head capacity feedlots. However, the number of feedlots in Kansas has declined from 145 000 to 1900 while the number of cattle per feedlot has increased (USDA, 2006). Most cattle feedlots in the United States are located on the western High Plains including western Nebraska and Kansas, and the Texas and Oklahoma panhandles. Stocking rates for cattle vary by region in correlation with seasonal precipitation and temperature and range from 7 to 37 m^2 hd^{-1} in the Great Plains (Sweeten, 2000). Stocking rates in Kansas are often between 17 and 20 m^2 hd^{-1}. Cattle finishing periods are typically 150 days and the cattle generally range in live-weight from 272 to 544 kg with an average of 408 kg (Sweeten, 2000).

An animal feeding operation (AFO) is described as a facility where animals are stabled or confined and fed for a total of 45 days or more within any 12 month period and where crops, vegetation, forage growth, or post harvest residues are not sustained in the normal growing season over any portion of the facility (USEPA, 2003b). A concentrated animal feeding operation (CAFO) is a AFO exceeding a certain number of animals, specific by animal. For cattle, a medium CAFO is any AFO having 300 to 999 head and a large CAFO is any AFO having over 1000 head. According to the National Pollution Discharge Elimination System (NPDES), medium and large CAFOs are required to obtain a permit for discharges or potential discharges, or qualify for the “no potential discharge” designation because a CAFO is considered a pollution point source. To obtain a permit for a CAFO the operator must report information; including 1) location, 2) topographic map of location, 3) information about number and type of animal, 4)

information about the type of confinement, 5) type of containment, storage, and total capacity for manure, litter, and process wastewater, 6) available acreage available for land application of wastes, 7) estimated amount of manure, litter, and process wastewater per year, 8) amount of waste transferred to other operations per year, and 9) a nutrient management plan (USEPA, 2003a). At AFOs the common mechanisms of loss for nutrients, volatile organic compounds, or other contaminants are volatilization, runoff, leaching, and mechanical transport.

There were two objectives of this thesis. The first was to survey select soil physical and chemical properties beneath pens at four beef cattle feedlots in Kansas. The results presented will address the following questions: 1) how have the nutrients accumulated in the soil profile? 2) is there high variability in subsurface nutrients within and among feedlots? 3) does the total amount of a nutrient represent a significant fraction of the material initially deposited on the pen surface as manure? and 4) could the quantity of nutrients accumulated beneath feedlots have the potential to impact local ground water quality? It is important to understand if a significant amount of the nutrients deposited on the pen surface at open cattle feedlots presents a potential groundwater quality threat by leaching. The data will help society understand how nutrients move underneath pen surfaces and is important for manure management strategies and pen cleaning procedures. This research also contributes to the efforts of creating a nutrient balance for the feedlot system. In addition, there have been some suggestions that it is necessary to install a liner at feedlots before operation, similar to lagoon fabrication, to prevent groundwater contamination. This requirement would pose a huge financial and logistical burden on the operator and may not be necessary because the cattle create a liner on their own from hoof action.

The second objective was to develop and test a laboratory chamber method that would allow for a variety of different experiments to be implemented to investigate the mechanisms of NH_3 volatilization in the laboratory. Ammonia volatilization at the soil surface is dependent on air flow, soil and air temperatures, soil water content, pH, and the concentrations of NH_3 and NH_4^+ in both the air and soil solution. Furthermore, given soil temperature is dependent on the soil energy balance, flux is also influenced by anything that impacts convective and latent heat fluxes which would add humidity of the air and

solar radiation to the list of governing variables. This chamber system was built to control or quantify as many of these variables as possible so the process in question could be evaluated. This endeavor is important because a simple, reproducible apparatus and technique is needed to measure NH_3 volatilization in the laboratory in order to identify, study, and model the controlling mechanisms. Once the mechanisms are better understood, it may be possible to create and implement economical management practices to reduce the amount and rate of NH_3 volatilization into the atmosphere from AFOs. A technique for quantifying and predicting NH_3 volatilization is also important because AFOs are one of the largest contributors of NH_3 to the atmosphere which can cause N enrichment in unwanted areas, increased acid precipitation, and particulate matter deposition (Steinfeld et al., 2006; Fen et al., 2003).

References

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, and D. W. Johnson. 2003. Ecological effects of nitrogen deposition in the western United States. BioScience. 53:404-420.

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. deHaan. 2006. Livestock's long shadow: environmental issues and options. FAO. Rome. 390 pp.

Sweeten, J. M. 2000. Manure and wastewater management for cattle feedlots. Rev. Environ Contam. Toxicol. 167: 121-153.

United States Department of Agriculture. 2006. National Agricultural Statistics Service. Cattle on Feed. www.usda.gov. [accessed 9 October 2006].

United States Environmental Protection Agency. 2003a. Title 40 Protection of Environment, Chapter 1 Environmental Protection Agency, Part 122 EPA Administered Permit Programs: The National Pollutant Discharge Elimination System (CFR 122.21). National Archives and Records Administration. Code of Federal Regulations. [available online] http://www.access.gpo.gov/nara/cfr/waisidx_03/40cfr122_03.html (accessed on 21 March 2007).

United States Environmental Protection Agency. 2003b. Title 40 Protection of Environment, Chapter 1 Environmental Protection Agency, Part 122 EPA Administered Permit Programs: The National Pollutant Discharge Elimination System (CFR 122.23). National Archives and Records Administration. Code of Federal Regulations. [available online] http://www.access.gpo.gov/nara/cfr/waisidx_03/40cfr122_03.html (accessed on 21 March 2007).

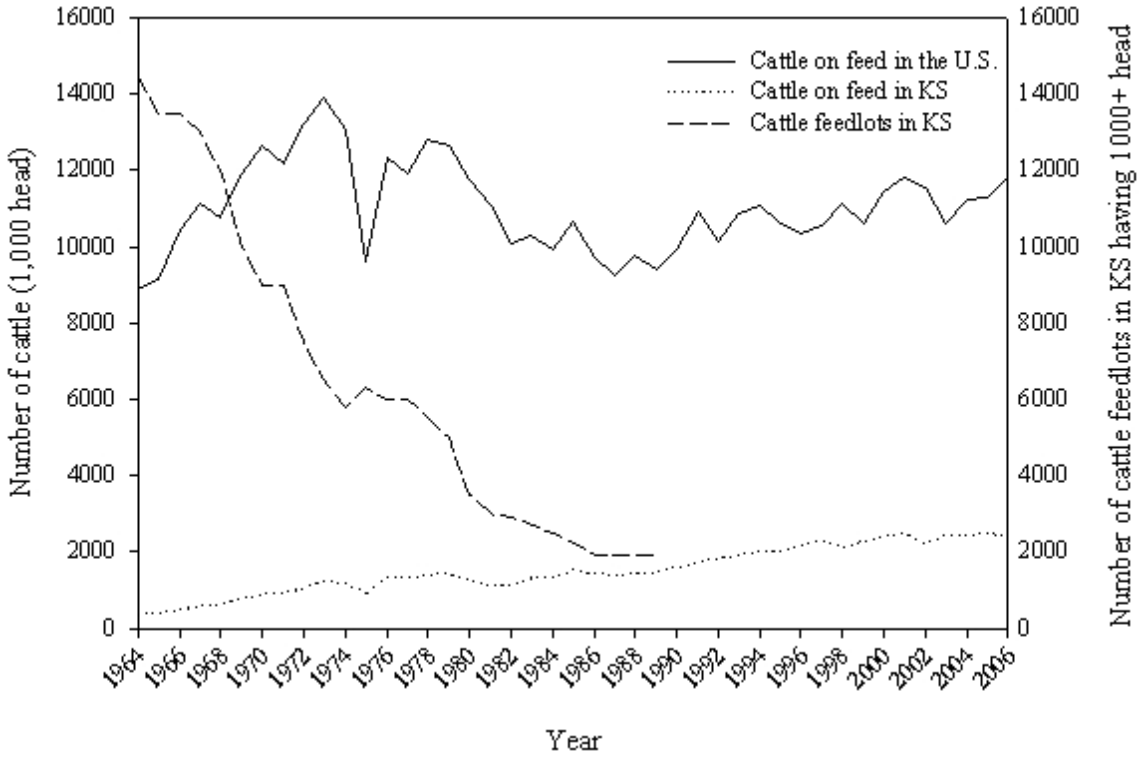

Figure 1-1. Trends of number of cattle on feed in the United States and Kansas and number of feedlots in Kansas (USDA, 2006).

CHAPTER 2 - Literature Review

The impact of livestock on the environment is substantial, and growing. Global demand for meat, milk, and eggs is rising, driven by rising incomes, growing populations, and urbanization. Steinfeld et al. (2006) summarized that one of the most significant contributors to serious environmental problems was the livestock sector. In addition, livestock production, including feedcrop production, is the largest anthropogenic user of land and utilizes 70% of all agricultural land, which represents approximately 30% of the planet's land surface (Steinfeld et al., 2006). During the past 30 years, animal production in the United States has become more specialized and concentrated. In 2003, the nations 238 000 animal feeding operations (AFOs) produced 500 million tons of manure with concentrated animal feeding operations (CAFOs), representing operations with over 1000 animal units, accounting for more than half of the manure (Steinfeld et al., 2006). The livestock sector is associated with many different pollutants, especially manure related discharges including antibiotics, pathogens, nutrients, pesticides, hormones, solids, and trace elements (CDC, 2004). Better policies are required to protect and preserve the environment as well as a social and health necessity.

Many factors have shaped the livestock sector. The world population has grown to 6.5 billion with most of the growth in developing countries and steady population in developed countries (UN, 2005). In 2005, 49% of the population was living in cities (FAO, 2006). Changes in population, economics, diets, technology, and land use drive the global livestock sector (Steinfeld et al., 2006). As demands for livestock derived items have increased, innovations in biology, chemistry, and machinery have worked to satisfy the demand. The common solution has been intensification instead of expansion. Historically, AFOs had to remain close to the location of demand, to chilling and processing plants, and feed sources. As time passed, changes have occurred allowing operations to shift further from demand centers, driven by land and labor prices, access to feed, lower environmental standards, tax incentives, or locations with fewer problems. As livestock production has grown and intensified, it depends less on locally available feed sources and increasingly on feed concentrates traded domestically and

internationally (Steinfeld et al., 2006). In 2002, 670 million tons of cereals were fed to livestock, approximately one-third of the global cereal harvest. Another 350 million tons of protein rich processing byproducts (brans, oil cakes, and fishmeal) were also used as feed (Steinfeld et al., 2006). In developed countries, livestock production increased 22% from 1980 to 2004 with ruminant production decreasing by 7% and poultry and pig production increasing by 42%. The distribution of ruminant AFOs has been dependent on initial locations with locally available feed sources and land areas perceived as having little economic value, such as natural prairie (Steinfeld et al., 2006). Increased demand has translated to large scale operations with the highest number of animals coming from Texas, Kansas, Nebraska, and Colorado for beef cattle (USDA, 2006a); Iowa, North Carolina, Minnesota, and Illinois for swine (USDA, 2006b); and Georgia, Arkansas, Mississippi, and North Carolina for poultry (USDA, 2005).

Animal Feeding Operations

An AFO is described as a facility where animals are stabled or confined and fed for a total of 45 days or more given any 12-month period, and where crops, vegetation, forage growth, or post harvest residues are not sustained in the normal growing season over any portion of the facility (USEPA, 2003b). A CAFO is an AFO exceeding a certain number of animals, specific by species. For cattle, a medium CAFO is any AFO having 300 to 999 head and a large CAFO is any AFO having over 1000 head. According to the National Pollution Discharge Elimination System (NPDES), medium and large CAFOs are required to obtain a permit for discharges or potential discharges, or qualify for the “no potential discharge” designation because a CAFO is considered a pollution point source. To obtain a permit for a CAFO the operator must report information; including 1) location, 2) topographic map of location, 3) information about number and type of animal, 4) information about confinement system, 5) type of containment, storage, and total capacity for manure, litter, and process wastewater, 6) available acreage available for land application of wastes, 7) estimated amount of manure, litter, and process wastewater per year, 8) amount of waste transferred to other operations per year, and 9) a nutrient management plan (USEPA, 2003a).

In many situations AFOs are a major cause of land use changes and subsequent loss of biodiversity. They are also a major source of land-based pollution, emitting nutrients and organic mater, pathogens, and drug residues into rivers, lakes, and coastal seas. Nutrient overloading can cause eutrophication and pollute drinking water while the solids can increase turbidity and inhibit aquatic plant growth. Microorganisms in waste can live for a few days up to a few weeks depending on conditions and different microorganisms and have different pollution tolerances. In the beef and swine industry, antibiotics are administered at sub-therapeutic rates and hormones are used to increase feed conversion efficiency. These drug residues and others can contaminate aquatic ecosystems (Morse and Jackson, 2003; Wallinga, 2002). When used properly hormones have been shown to have no negative effects to human health (FAO, 2003). Emissions into the atmosphere contribute to greenhouse gas concentrations, acid rain, and particulate matter deposition (NRC, 2003; Steinfeld et al., 2006; Holland and Lamarque, 1997; FAO, 2001). The livestock sector contributes 35 to 40%, 65%, and 66% of CH_4, N_2O, and NH_3, respectively, to total global anthropogenic emissions (NRC, 2003). Schwartz and Randall (2003) suggest global warming could prove to be a greater risk than terrorism and could lead to catastrophic droughts, famines, and riots.

Nitrogen Cycling

Large accumulations of N occur at AFOs and are an element of major concern because it is used in many biological processes. Nitrogen can easily undergo many transformations making it hard to control and contain in large. In general, N cycles through a cattle feedlot in the following manner. Cattle are fed a high N containing feed and have a low N retention of approximately 15% (Cole, 2006). The N deposited on the pen surface can then be lost by the mechanisms of volatilization, run off, leaching, or mechanical transport. The transformations of N are affected by direct and indirect factors. The chemistry of the cycle is affected by physical variables such as temperature and water, and by biological components including microorganisms and enzymes.

Nitrogen deposited on the pen surface is primarily in organic forms and as urea. The organic-N can be released by mineralization as NH_4-N. The NH_4^+-N can then be nitrified to NO_3-N which, is mobile in soil and can be leached through the soil profile.

Ammonium is not a very mobile constituent in soils because it participates in cation exchange, but upon exchange site saturation, NH_4-N can then leach. Ammonium has also been reported as a strong indicator of lagoon seepage (DeSutter et al., 2005; Huffman and Westerman, 1995). Nitrate leaching can threaten groundwater resources potentially causing health problems such as methemoglobinemia in humans and animals. In addition, the NO_3-N can also be denitrified under oxygen limiting conditions. At AFOs NO_3-N is not expected to be present in high concentrations because the main form of N deposition is urea and conditions are not optimum for nitrification. Ammonia has a high vapor pressure and can easily volatilize into the atmosphere.

The urea, from urine, quickly hydrolyzes and produces NH_4^+ that can then be converted to NH_3 (Jarvis and Pain, 1990). Fifty percent of urea-N has been estimated to volatilize as NH_3 (Cole, 2006). Urea in the soil undergoes hydrolysis catalyzed by the enzyme urease in a two step, kinetically very fast, process (Equation 2-1 and 2-2). In addition, urea hydrolysis produces OH^- and raises pH.

$$(NH_2)_2CO + 2H_2O \xrightarrow{urease} 2NH_4^+ + CO_3^{-2} \quad (2\text{-}1)$$

$$CO_3^{-2} + H_2O \leftrightarrow HCO_3^- + OH^- \quad (2\text{-}2)$$

Sherlock and Goh (1985) calculated the half-life of urine urea to be 3.0 and 4.7 hours under summer and autumn conditions, respectively. The autumn hydrolysis rate was attributed to lower soil temperatures. Hydrolysis of urine urea is more rapid than pure urea when added to soil under similar conditions because of the presence of hippuric acid, a minor constituent of animal urine, having a stimulatory effect on urea hydrolysis (Sherlock and Goh, 1985). Haynes and William (1993) found the urea in animal urine hydrolyzes extremely rapidly after leaving the animal, and suggest urease is already present in the urine.

Following urea hydrolysis, large amounts of NH_4-N concentrations are present in the soil (Haynes and William, 1993). Some studies have found NH_4-N accumulations to be as high as 100 to 250 mg kg^{-1} in the surface 10 cm (Ball et al., 1979; Carran et al., 1982; Sherlock and Goh, 1985) and from 500 to 1000 mg kg^{-1} in the surface 2.5 cm

(Vallis et al., 1985). Typically, NH_4-N concentrations in soil at a natural prairie are 5.6 mg kg^{-1} (McKinley, 2007; Norris, 2000). A prerequisite for NH_3 volatilization is a supply of free NH_4^+ near the soil surface (Haynes and William, 1993). The conversion of NH_4^+ to NH_3 is the major process regulating the potential loss of NH_3 from soils:

$$NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O \tag{2-3}$$

The equilibrium between NH_4^+ and NH_3 is controlled by many factors, but in general, the supply of NH_3 is favored by high soil pH, high temperatures, and evaporative loss of soil water (Haynes and Sherlock, 1986). The high concentration of NH_4^+ and high pH in urine patches favor NH_3 volatilization losses. The high pH of urine (8.6) is also the optimum pH for urease activity and the reactions result in localized areas of high pH during the first 24 hours after urination (Vallis et al., 1985; Sherlock and Goh, 1985). Vallis et al. (1985) and Sherlock and Goh (1985) observed a rapid rise in NH_3 flux during the first 24 hours followed by a gradual exponential decline with a diurnal pattern having increased volatilization during the daytime. Lockyer and Whitehead (1990) measured a positive correlation between soil temperature and volatilization at a 3 cm soil depth during the 3 days following urine application. Losses of NH_3 from urine patches generally represent 4 to 46% of urine N with 15 to 25% loss being most common. Hot, dry, summer conditions favor loss whereas cool, moist, winter conditions minimize loss (Haynes and William, 1993). Sherlock and Goh (1985) measured urine patch volatilization losses of 22% in summer, 25% in autumn, and 12% in winter. Rayden et al. (1985) measured losses of urine N of 22% at mean temperature of 16ºC and 10% losses at mean temperature of 8ºC. Vallis et al. (1985) observed losses as high as 46% in the tropical dry season.

At cattle feedlots, N is an important nutrient to manage. Ammonium in the soil is generally tied up by cation exchange and moves downward by diffusion and leaching. Nitrate is mobile and can move by diffusion, water movement, or be denitrified. Ammonia is one air pollutant of great concern to the owners, managers, and neighbors of open-lot AFOs (Auvermann, 2006). Studying the quantity, rate, and mechanisms of NH_3 volatilization is important because NH_3 may be carried away by air movement and

deposited elsewhere, often in close proximity to the AFO. These N inputs can cause changes in the ecosystem such as increased net primary productivity, eutrophication, and various unnatural chain reaction alterations.

Measuring Ammonia Volatilization

Scientifically credible estimates of air emissions from AFOs are complicated by numerous factors such as the kinds and numbers of animals, diets, housing, manure management, topography, environmental factors, and management actions to mitigate emissions and their effects. These factors all affect the amount and degree of dispersion in the atmosphere (NRC, 2003). In order to determine the potential adverse impacts to the environment accurate estimations of air emissions from AFOs are needed. In addition, these air emission estimates will be useful for developing methods to reduce NH_3 being released into the atmosphere. Therefore, the National Research Council (NRC) (2003) recommended research should continue to determine accurate and precise analytical techniques to measure and report NH_3 emissions, especially if there is a push for new legislation forcing operations to report this data. Under the Emergency Planning and Community Right-to-Know Act (EPCRA) industries are held to certain monitoring and reporting NH_3 regulations. Plaintiffs of recent lawsuits under EPCRA assert that the routine airborne emissions of NH_3 from many AFOs exceed the monitoring and reporting thresholds of 100 lb day^{-1} and that any such AFO, including those that have not been monitoring and reporting NH_3 emissions, should be penalized similarly to the industries covered under EPCRA.

Studies have been conducted to measure the amount of NH_3 volatilization from open-air AFOs, urea fertilizer studies, and manure amendments. Shah et al. (2006) wrote a thorough review on measuring NH_3 volatilization emissions. Measurement and collection techniques have included acid scrubbers, filter packs, denuders, or optical methods connected to enclosures or micrometeorological apparatus (Shah et al., 2006). Acid scrubbers include acid traps and bubblers in which air is forced through an acidic solution to form an NH_4^+ salt that can be measured by an ion-selective electrode, colorimetry, titrimetry, or ion chromatography. Scrubbers also have high a NH_3 trapping efficiency of >97% with acid concentrations of 0.001 to 0.1 M and airflow rates of 2 to 4

L min^{-1}(Shah et al., 2006). Filter packs typically consist of a holder having screened openings and acid coated filter paper placed between uncoated filters with spacers to trap the NH_3, aerosols, and particulates. Filter packs can be used with or without (passive) forced air. Rabaud et al. (2001) found no difference in performance among filters coated with citric acid, oxalic acid, tartaric acid, or H_2SO_4. Denuders are glass tubes coated on the inside with an acid or packed with an NH_3-sorbing media. When air passes through the tube NH_3 can be trapped by the media, forming an NH_4^+ salt or complex (Shah et al., 2006). Denuders coated with H_3PO_3 have >99% NH_3 trapping efficiency (Perrino and Gherardi, 1999). The NH_3 is later extracted by washing the denuder with an eluent. Several optical methods that have been employed in NH_3 quantification including chemiluminescence, spectroscopy (tunable diode laser, Fourier transform IR, photoacoustic, photothermal interferometer), and fluorescence, but these tools are expensive and require significant logistic support for long term deployment (Shah et al., 2006).

Shah et al. (2006) summarized that the choice of chamber materials, chamber dimensions, and airflow rates all affect the convective heat transfer and albedo of the system for outdoor chambers. Ammonia sorbs too many surfaces; therefore, the choice of material is important especially when making absolute measurements especially in small concentrations. Shah et al. (2006) noted that NH_3 sorption was affected by temperature, tubing length, and gas concentration. Tubing material of low density polyethylene and Teflon have the lowest sorption capacities and glass denuders should be rinsed. However, more data is required to compare different types of tubing material in a range of temperatures, lengths, and inlet concentrations. Enclosures left in the field during rainfall can over estimate NH_3 flux, and removal of enclosure between samplings can decrease the change in environment caused by the chamber (Keuken et al., 1989; Mannheim et al., 1995). Additionally, Shah et al. (2006) summarized chambers have small footprints and high spatial variability which are unsuitable for developing NH_3 emission factors but the chambers could be useful in comparing relative emissions when NH_3 sources are applied uniformly to the surface.

Numerous studies have discussed the mechanisms in soils and the factors affecting the magnitude of NH_3 loss from urea fertilizers and animal wastes. Among

these factors are soil type (texture, pH, $CaCO_3$ content, and urease activity), environmental conditions (temperature, soil water content, rainfall pattern, wind speed, and relative humidity), and fertilizer management (timing, placement, and irrigation regime). Although direct effects of these factors are fairly well understood, the interactions are complex and sometimes controversial. Losses of NH_3 vary widely between studies and appear to be influenced by water content and temperature. Researchers have determined several trends in NH_3 losses. First, moisture by rainfall can be highly effective in reducing NH_3 loss if applied within three hours of urea application, but if rain is delayed by more than 48 hours NH_3 volatilization is not reduced (Kissel et al., 2004; Black et al., 1987). Second, rainfall increases the water content of the soil surface, and all factors remaining the same, urea hydrolysis will increase (Kissel and Cabrera, 1988; Freney et al., 1992). Lastly, the faster the rate of hydrolysis at the soil surface, the greater the rate of NH_3 loss (Moe, 1967).

In field studies, lower NH_3 losses in different seasons or at different experimental sites were associated with periods of rainfall, often after many days rather than immediately following urea application (Harper et al., 1983). One systematic study by Carrier and Bernier (1971) showed the effectiveness of rainfall in reducing NH_3 loss decreased with time after urea application to the humus layer of a forest soil. Bouwmeester et al. (1985) demonstrated that 8 mm of water applied 3 days after spreading urea on a moist soil reduced loss from 25 to 19% of the N applied (Black et al., 1987). In a laboratory study, water applied to oven dry soil enhanced NH_3 loss while water applied to initially moist soil reduced loss (Fenn and Miyamoto, 1981). In a field study, 2 mm of water applied to a soil at 30% of field capacity resulted in a 36% loss of applied N compared with 19% in the absence of added water (Black et al., 1987)

Environmental conditions, such as temperature and moisture, and manure content, will influence microbial activities and can directly modify gaseous flux rate and dust formation. Manipulating the feedlot surface moisture through sprinkler irrigation rate or varying stocking density to maintain the moisture content within a 20 to 41% range (total mass basis) has been recommended to control dust at cattle feedlots (Auvermann and Romanillos, 2000; Sweeten et al., 1988; Sweeten, 1998). Miller and Berry (2005) found three microbial metabolisms: inactive, aerobic, and fermentative at low, moderate, and

high moisture contents, respectively, and recommended a narrow moisture range of 0.2 to 0.4 g H_2O g^{-1} dry matter as optimal for minimizing environmental impact from cattle feedlot production. Bouwmeester et al. (1985) found NH_3 losses were maximized when moisture content was adequate for urea hydrolysis either by humidifying the air between 80 and 90% RH or by 8 mm rain applications every 3 days.

In addition to moisture content affecting NH_3 volatilization, Bouwmeester et al. (1985) found increasing wind velocity from 1.7 to 3.4 m s^{-1} reduced NH_3 loss from 19 to 7.5%, likely due to rapid drying of the soil surface. Martin and Chapman (1951) found an increase in NH_4-N loss with decreasing soil water contents at 12 and 38ºC, and at 66 º C, there was a reversal of this trend. Akiyama et al. (2004) concluded NH_3 emission rates increased with increasing flow rate and reached a steady state at approximately 15 volume exchanges min^{-1}. Sommer and Ersboll (1996) found no further increase of NH_3 volatilization observed at 20 volume exchanges min^{-1}. Moe (1967) found additions of urease enzyme increased the rate of urea hydrolysis, the rate of NH_3 volatilization during the early part of incubation, and increased nitrification during the latter part of the incubation. Moe (1967) also found the enzyme inhibitor, p-chloromercuribenzoate, decreased the rate of urea hydrolysis.

Sommer and Ersboll (1996) observed NH_3 loss was exponentially related to the maximum soil pH and was inversely related to the concentration of exchangeable H^+. Kellems et al. (1979) found NH_3 volatilization to be positively correlated to the pH of the waste and feed source altered the waste pH. Of the feed sources investigated, milo produced the lowest pH and barley the highest (Kellems et al., 1979). Clough et al. (2003) applied synthetic cattle urine to pasture soil at various rates under laboratory conditions. They monitored NH_3 for up to 21 days and determined N rates up to 500 kg ha^{-1}, inorganic-N concentrations increased over time due to nitrification. Nitrification was inhibited in the 1000 kg N ha^{-1} treatment due to the sustained high ammoniacal -N and pH conditions.

The problem of N loss by NH_3 volatilization from AFOs has stimulated research efforts to try to reduce the amount of NH_3 lost to the atmosphere. Some of these efforts have included how different manure amendments may alter NH_3 volatilization (Eghball, 1999; Varel et al., 1999; Shi et al., 2001; McCrory and Hobbs, 2001). The most common

categories of amendments, according to mode of action, include digestive additives, acidifying additives, adsorbents, urease inhibitors, and saponins from Mohave yucca (McCrory and Hobbs, 2001). Digestive additives are selected microbial strains and/or enzymes enhancing the biodegradation of livestock waste (McCrory and Hobbs, 2001). Acidification is the process of reducing pH to inhibit urease hydrolysis and can be divided into three groups: acids, base precipitating salts, and substrates that induce acid production (McCrory and Hobbs, 2001). Molloy and Tunney (1983) found NH_3 volatilization was effectively stopped at pH 4.0 for cattle slurry. Ouyang et al. (1998) found NH_3 volatilization decreased when triple super phosphate and KCl were applied during urea fertilizer applications due to the subsequent acidification. Stevens et al. (1989) found NH_3 volatilization was reduced by 95% when cow slurry was reduced to pH 5.5. Adsorbents, most commonly clinoptilolite and peat, are used to adsorb NH_3, NH_4^+, or both. Urease inhibitors inhibit urea hydrolysis. Varel et al. (1999) evaluated two urease inhibitors, cyclohexylphosphorictriamid (CHPT) and N-(n-butyl) thiophosphoric triamide (NBPT) and concluded if applied weekly urea hydrolysis was inhibited. However, if regular application ceased, the inhibitors effects would diminish. The commercial diet or slurry additive based on saponins, an extract from the yucca plant, bind NH_4^+ prohibiting it from volatilizing (Headon and Walsh, 1993; Kemme et al., 1993).

Although chamber techniques are not well suited for measuring NH_3 emissions in the field they can be very useful in the laboratory. Woodbury et al. (2006) designed an inexpensive chamber (<$400) for field and laboratory NH_3 flux emissions using a stainless steel chamber having an internal gas mixing fan. However, Woodbury et al. (2006) did not give a detailed description of how the chamber was used in the laboratory. Sommer and Ersboll (1996) measured NH_3 volatilization from soil by packing soil into cylindrical screw-top plastic jars (10 cm i.d., 16.5 cm in height) leaving a headspace of 189 mL and surface area of 0.0079 m^2. Air was sucked through holes in the sides of the chambers and NH_3 was captured in an acid trap. They found that NH_3 flux did not change over an air flow rate of 3.9 L min^{-1} (20 volume exhanges min^{-1}) and that NH_3 loss was exponentially related to initial soil pH (Sommer and Ersboll, 1996). Kissel et al. (2004) packed soil in acrylic plastic cylinders (4.5 cm i.d., 20 cm long), an air flow rate

of 0.1 L min^{-1}, and a fluctuating RH (40% to 95%) treatment. Le Cadre et al. (2005) used a cylindrical glass chamber (55.4 cm^2 cross section, 14.7 cm high) with a head space of 270 cm^3, and an air flow rate of 2.95 L min^{-1} (11 volume exchanges min^{-1}). They found that air humidity and air flow rate were important contributors to variation in NH_3 flux (Le Cadre et al., 2005). The above studies using chambers in the laboratory are not always described well, are difficult if not impossible to reproduce, and do not consider all of the variables that need to quantified or controlled to make accurate NH_3 flux measurements. Therefore, a need still exists to develop and standardize a chamber system for laboratory evaluation of how different surface conditions (i.e., water content, soil type, duff layer characteristics, amendments, etc.) will affect volatilization rates. The lab studies will allow for statistical control which is very difficult to obtain in the field. Lab studies could also be used to develop and verify mechanistic models of NH_3 volatilization.

No matter how NH_3 is measured, or open-lot AFO surfaces are treated, large accumulations of waste high in N, P, Cl^-, and other salts must be managed to reduce the amount of loss and environmental impact. The following chapters will consider nutrient movement beneath cattle feedlot pens and a chamber method for measuring NH_3 volatilization in the laboratory.

References

Akiyama, H., I. P. McTaggart, and B. C. Ball. 2004. N_2O, NO, and NH_3 emissions from soil after the application of organic fertilizers, urea, and water. Water, Air, and Soil. Pollution. 156:113-129.

Auvermann, B. 2006. Recent developments in air quality from dairies and cattle feedyards. 21st Annual Southwest Nutrition & Management Conference. February 23-24, 2006. Tempe, AZ. 110-116.

Auvermann, B. W., and A. Romanillos. 2000. Manipulating stocking density to manage fugitive dust emission from cattle feedyards. pp. 61-70. In Proc. Of the Innovative Technologies for Planning Animal Feeding Operations, Denver. USDA-ARS Central Great Plains Res. Stn., Akron, CO.

Ball, P. R., D. R. Keeney, P. W. Theobald, and P. Nes. 1979. N-balance in urine-affected areas of a New-Zealand pasture. Agron. J. 71(2):309-314.

Black, A. S., R. R. Sherlock, and N. P. Smith. 1987. Effect of timing of simulated rainfall on ammonia volatilization from urea, applied to soil of varying moisture content. J. Soil Sci. 38:679-687.

Bouwmeester, R. J. B., P. L. G. Vlek, and J. M. Stumpe. 1985. Effect of environmental factors on ammonia volatilization from urea-fertilized soil. Soil Sci. Soc. Am. J. 49:376-381.

Carran, R. A., P. R. Ball, P. W. Theobald, and M. E. G. Collins. 1982. Soil-N balances in urine-affected areas under 2 moisture regimes in Southland. N. Z. J. Exp. Agric. 10(4):377-381.

Carrier, D., and B. Bernier. 1971. Pertes d'azote par volatilisation ammoniacale apres fertilisation en foret de pin gris. (In French, with English abstract.) Can. J. For. Res. 1:69-79.

Centers for Disease Control and Prevention (CDC). Department of Health and Human Services. 2004. Fact Sheet: Concentrated animal feeding operations.

Clough, T. J., R. R. Sherlock, M. N. Mautner, D. B. Milligan, P. F. Wilson, C. G. Freeman, and M. J. McEwan. 2003. Emission of nitrogen oxides and ammonia

from varying rates of applied synthetic urine and correlations with soil chemistry. Aust. J. Soil Res. 41:421-438.

Cole, A. 2006. Update on recent protein research for finishing beef cattle fed steam flaked corn-based diets. 21st Annual Southwest Nutrition and Management Conference. Tempe, AZ.

DeSutter, T. M., G. M. Pierzynski, and J. M. Ham. 2005. Movement of lagoon-liquor constituents below four animal-waste lagoons. J. Environ. Qual. 34:1234-1242.

Eghball, B. 1999. Liming effects of beef cattle feedlot manure or compost. Commun. Soil Sci. Plant Anal. 30:2563-2570.

FAO. 2001. 'Global estimates of gaseous emissions of NH_3, NO and N_2O from agricultural land.' (Food and Agriculture Organization of the United Nations and International Fertilizer Industry Association: Rome).

FAO. 2003. World Agriculture: Towards 2015/30 an FAO perspective, edited by J. Bruisnsma, FAO. Rome and London, Earthsan.

FAO. 2006. FAO statistical databases. Rome. [Available at http://faostat.fao.org/default.aspx].

Fenn, L. B. and S. Miyamoto. 1981. Ammonia loss and associated reactions of urea in calcareous soils. Soil Sci. Soc. Am.

Freney, J. R., O. T. Denmead, A. W. Wood, P. G. Saffigna, L. S. Chapman, G. J. Ham, A. P. Hurney, and R. L. Stewart. 1992. Factors controlling ammonia loss from trash covered sugarcane fields fertilized with urea. Fert. Res. 31:341-349.

Harper, L. A., V. R. Catchpoole, R. Davis, and K. L. Weir. 1983. Ammonia volatilization-soil, plant, and microclimate effects on diurnal and seasonal fluctuations. Agronomy J. 75(2):212-218.

Haynes, R. J. and R. R. Sherlock. 1986. *In*: "Mineral N in the Plant-Soil System" (R.J. Haynes. ed.) pp. 242-302. Academic Press, Orlando, FL.

Haynes R. J. and P. H. Williams. 1993. Changes in soil solution composition and pH in urine-affected areas of pasture. J. Soil Sci. 43:323-334.

Headon, D. R., and G. Walsh. 1993. *Yucca schidigera* extracts and ammonia control. pp. 686-693. In E. Collins and C. Boon (ed.) Livestock Environment IV, 4th Int.

Symp., Univ. of Warwick, Coventry, UK. 6-9 July 1993. Am. Soc. Agric. Eng., St. Joseph, MI.

Holland, E. A., and L. F. Lamarque. 1997. Modeling bio-atmospheric coupling of the nitrogen cycle through NOx emissions and NOx deposition. Nutrient Cycling in Agroecosystems. 48:7-24.

Huffman, R. L., and P. W. Westerman. 1995. Estimated seepage losses from established swine waste lagoons in the lower coastal plain of North Carolina. Trans. ASAE. 38:449-453.

Jarvis S. C., and P. F. Pain. 1990. Ammonia volatilization from agricultural land. Proceedings of the Fertilizer Society. 298. 1-35.

Kellems, R. O. J. R. Miner, and D. C. Church. 1979. Effect of ration, waste composition and length of storage on the volatilization of ammonia, hydrogen sulfide, and odors from cattle waste. J. of Animal. Sci. 48:436-445.

Kemme, P. A., A. W. Jongloed, B. M. Dellaert, and F. Krol-Kramer. 1993. The use of Yucca schidigera extract as a 'urease inhibitor' in pig slurry. pp. 330-335. In Proc. of the 1st Int. Symp. on nitrogen flow in pig production and environ. consequences, Wageningen, the Netherlands. 8-11 June 1993. EAAP Publ. no. 69. PUDOC, Wageningen, the Netherlands.

Keuken, M. P., A. Wayers-IJPelaan, J. J. Mols, R. P. Otjes, and J. Slanina. 1989. The determination of ammonia in ambient air by an automated thermodenuder System. Atmos. Environ. 23:2177-2185.

Kissel, D. E., and M. L. Cabrera. 1988. Factors affecting urea hydrolysis. pp. 53-66. In B. R. Bock and D. E. Kissel (ed.) Ammonia volatilization from urea fertilizers. National Fertilizers Development Center Bull. Y-206. Tennessee Valley Authority, Muscle Shoals, AL.

Kissel, D. E., M. L. Cabrera, N. Vaio, J. R. Craig, J. A. Rema, and L. A. Morris. 2004. Rainfall timing and ammonia loss from urea in a loblolly pine plantation. Soil Sci. Soc. Am. J. 68:1744-1750.

Le Cadre, E., S. Génermont, C. Decuq, S. Recous, and P. Cellier. 2005. A laboratory system to estimate ammonia volatilization. Agron. Sustain. Dev. 25:101-107.

Lockyer, D. R. and Whitehead, D. C. 1990. Volatilization of ammonia from cattle urine applied to grassland. Soil Biol. Biochem. 22:1137-1152.

Mannheim, T., J. Braschkat, and H. Marschner. 1995. Measurement of ammonia emission after liquid manure application: II. Comparison of the wind tunnel and the IHF method under field conditions. Z. Pflanzenernaehr. Bodenkd. 158:215-219.

Martin, J. P., and H. D. Chapman. 1951. Volatilization of ammonia from surface fertilized soils. Soil Sci. 71:25-34.

McCrory, D. F. and P. J. Hobbs. 2001. Additives to reduce ammonia and odor emissions from livestock wastes: A review. J. Environ. Qual. 30:345-355.

McKinley, D. 2007. Consequences of altered soil processes and ecosystem C and N storage resulting from conversion of native mesic grassland to coniferous forest. Kansas State University, Division of Biology. Dissertation. (not defended yet)

Miller, D. N., and E. D. Berry. 2005. Cattle feedlot soil moisture and manure content: I. Impacts on greenhouse gases, odor compounds, nitrogen losses, and dust. J. Environ. Qual. 34:644-655.

Moe, P. G. 1967. Nitrogen losses from urea as affected by altering soil urease activity. Soil Sci. Soc. Am. Proc. 31:380-382.

Molloy, S. P., and H. Tunney. 1983. A laboratory study of ammonia volatilization from cattle and pig slurry. Irish J. Agric. Res. 22:37-45.

Morse and Jackson. 2003. Fate of a representative pharmaceutical in the environment. Final repot submitted to Texas Water Institute. Texas Tech University.

National Research Council of the National Academics. 2003. Air emissions from animal feeding operations current knowledge, future needs. The National Academies Press, Washington D.C.

Norris, M. D. 2000. Biogeochemical consequences of land cover change in Eastern Kansas. Kansas State University, Division of Biology. Thesis.

Perrino, C., and M. Gherardi. 1999. Optimization of the coating layer for the measurement of ammonia by diffusion denuders. Atmos. Environ. 33:4579-4587.

Ouyang, D. S., A. F. Mackenzie, and M. X. Fan. 1998. Ammonia volatilization from urea amended with triple superphosphate and potassium Cl^-. Soil Sci. Soc. Am. J. 62:1443-1447.

Rabaud, N. E., T. A. James, L. L. Ashbaugh, and R. G. A. Flocchini. 2001. Passive sampler for the determination of airborn ammonia concentrations near large-scale animal facilities. Environ. Sci. Technol. 35:1190-1196.

Rayden, J. C., and D. R. Lockyer. 1985. Evaluation of a system of wind tunnels for field studies of ammonia loss from grassland through volatilization. J. Sci. Food Agric. 36:781-788.

Schwartz, P. E., and D. Randall. 2003. An abrupt climate change scenario and its implications for United States national security. [Available at http://www.greanpeace.org/raw/content/international/press/reports/an-abrupt-climate-change-scena.pdf]

Shah, S. B., P. W. Westerman, and J. Arogo. 2006. Measuring ammonia concentrations and emissions from agricultural land and liquid surfaces: A review. J. Air and Waste Manage. Assoc. 56:945-960.

Sherlock R. R., and K. M. Goh. 1985. Dynamics of ammonia volatilization from simulated urine patches and aqueous urea applied to pasture. IL. Theoretical derivation of a simplified model. Fert. Res. 5:181-195.

Shi, Y., D. B. Parker, N. A. Cole, B. W. Auvermann, and J. E. Mehlhorn. 2001. Surface amendments to minimize ammonia emissions from cattle beef feedlots. Trans. ASAE. 44(3):677-682.

Sommer, S. G., and A. K. Ersboll. 1996. Effect of air flow rate, lime amendments, and chemical soil properties on the volatilization of ammonia from fertilizers applied to sandy soils. Biol. Fertil. Soils 21:53-60.

Stevens, R. J., R. J. Laughlin, and J. P. Frost. 1989. Effect of acidification with sulphuric acid on the volatilization of ammonia from cow and pig slurries. J. Agricul. Sci. Cambridge. 113:389-395.

Steinfeld H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. de Haan. 2006. Livestock's long shadow: environmental issues and options. FAO, Rome, 390 pp.

Sweeten, J. M. 1998. Cattle feedlot manure and wastewater management practices. pp. 125-155. In J. L. Hatfield and B. A. Stewart (ed.) Animal waste utilization: Effective use of manure as a soil resource. Ann Arbor Press, Chelsea, MI.

Sweeten, J. M., C. B. Parnell, R. S. Etheredge, and D. Osborne. 1988. Dust emissions in cattle feedlots. pp. 557-578. In J. L. Howard (ed.) Stress and disease in cattle, veterinary clinics of North America. Food animal practice. Vol. 4 no. 3. W. B. Saunders, Philadelphia.

UN. 2005. World population prospects: The 204 revision. UN Department of Economic and Social Affairs. New York. USA. [Available at http://www.un.org/esa/population/publicatins/sixbillion/sixbilpart1.pdf]

United States Department of Agriculture. 2005. National Agricultural Statistics Service. Poultry Slaughter 2004 Annual Summary. www.usda.gov [accessed 24 March 2007].

United States Department of Agriculture. 2006a. National Agricultural Statistics Service. Cattle on Feed. www.usda.gov. [accessed 9 October 2006].

United States Department of Agriculture. 2006b. National Agricultural Statistics Service. Quarterly Hogs and Pigs. www.usda.gov [accessed 24 March 2007.]

United States Environmental Protection Agency. 2003a. Title 40 Protection of Environment, Chapter 1 Environmental Protection Agency, Part 122 EPA Administered Permit Programs: The National Pollutant Discharge Elimination System (CFR 122.21). National Archives and Records Administration. Code of Federal Regulations. [available online] http://www.access.gpo.gov/nara/cfr/waisidx_03/40cfr122_03.html (accessed on 21 March 2007).

United States Environmental Protection Agency. 2003b. Title 40 Protection of Environment, Chapter 1 Environmental Protection Agency, Part 122 EPA Administered Permit Programs: The National Pollutant Discharge Elimination System (CFR 122.23). National Archives and Records Administration. Code of Federal Regulations. [available online] http://www.access.gpo.gov/nara/cfr/waisidx_03/40cfr122_03.html (accessed on 21 March 2007).

Vallis. I., D. C. I. Peake, R. K. Jones, and R. L. McCown. 1985. Fate of urea-N from cattle urine in a pasture crop sequence in a seasonally dry tropical environment. Aust. J. Agric. Res. 36(6):809-817.

Varel, V. H., J. A. Nienaber, and H. C. Freetly. 1999. Conservation of nitrogen in cattle feedlot waste with urease inhibitors. J. Anim. Sci. 77:1162-1168.

Wallinga, D. 2002. Antimicrobial use in animal feed: An ecological and public health problem. Minnesota Medical Association. Volume 85: October 2002.

Woodbury, B. L., D. N. Miller, R. A. Eigenbert, and J. A. Nienaber. 2006. An inexpensive laboratory and field chamber for manure volatile gas flux analysis. Trans. ASABE. 49(3):767-772.

CHAPTER 3 - Nutrient Profiles Below Cattle Feedlot Pens.

Abstract

Soil chemical and physical properties beneath cattle feedlot pens are largely unstudied. This project was conducted to survey select soil chemical and physical properties of soil beneath active open air cattle feedlots. At four cattle feedlots in Kansas, the concentrations of NH_4-N, organic-N, organic-C, Cl^-, and P were high at the surface and rapidly decreased within 1.00 m. At three of the four feedlots, NO_3-N was generally below background concentration (4.1 mg kg^{-1}) for the entire profile while one feedlot had a >75 mg NO_3-N kg^{-1} increase in the top 1.00 m. Based on feeding data, only a small percent (7.9 to 1.2) of the total N deposited on the surface was found in the top 1.00 m below the pen surface for a range of 25 to 60 years of operation for Feedlot 1 and Feedlot 2. While in use, these feedlots do not appear to have a high potential for groundwater pollution from NO_3-N leaching. However, if they were to become inactive they may pose a severe threat to groundwater quality from organic-N mineralization and NH_4-N nitrification. If feedlots were closed and the land could be largely remediated by removing a layer of soil, these feedlots would have an average 48% profile N removed in a 0.25 m thick layer. .

Introduction

Steinfeld et al. (2006) aimed to assess the global impact of the livestock sector on environmental problems based on the most recent and complete data available. They took into account direct impacts and the impacts of feedcrop agriculture required for livestock production. The livestock sector has emerged as one of the top two or three most significant contributors to the most serious environmental problems, such as air emissions of NH_3, N_2O, NO_x, CH_4, volatile organic compounds, H_2S, particulate matter, and odors, runoff, and groundwater contamination. Livestock production, including feedcrop production, is the largest anthropogenic user of land and utilizes 70% of all agricultural land, 30% of the planet's land surface (Steinfeld et al., 2006). The environmental impact of livestock production has been extensively studied for air, water,

and surface soil quality (Steinfeld et al., 2006). However, the impact on soil quality at depth directly beneath cattle feedlot operations has not been as extensively studied and demands attention because it is a system variable. Cattle feedlots can cover sizable areas and their impact on the soil they operate on is relatively unresearched in areas other than Nebraska and Canada. Large quantities of N, P, and soluble salts are fed to cattle and significant amounts potentially remain on site in manure. For example, feedlot cattle are fed a high-N ration but have a low N retention in the animal (i.e., 15 %) (Cole, 2006). Thus, most of the fed N, typically over 100 kg ha^{-1} day^{-1}, is deposited on the pen surface. Up to 50% of excreted N may be lost to the air as NH_3 while the remainder accumulates on the surface (Cole, 2006).

Accumulations of N and other compounds on the pen surface are removed during pen cleaning, are washed into lagoons during runoff, or are leached and/or diffused into the subsoil beneath the pen; the latter could potentially lead to soil and water quality problems. The surface material removed during cleaning is moved to a storage or composting area prior to land application presenting additional risks of nutrient and salt leaching and surface runoff losses. In addition to N losses, P losses to fresh water bodies can cause eutrophication, and soluble salts containing Na^+, K^+, and Cl^- can cause soil chemical and physical problems (i.e. dispersion and subsequent compaction).

Evaluating the potential effect of animal waste leachate on groundwater quality requires consideration of three focus areas: 1) Toxicity and concentration, 2) The rate at which soluble constituents move into underlying soil, and 3) Aquifer vulnerability (Ham and DeSutter, 2000). At cattle feedlots, a main focus is N movement. Ammonium is generally tied up by cation exchange in the soil and moves by diffusion and can undergo nitrification. Nitrate and Cl^- are mobile and can move by water transport and diffusion, making them more of a threat to groundwater pollution. Groundwater studied by Mielke et al. (1970), Elliot et al. (1972) and Lorimor et al. (1972) was found to have low concentrations of NO_3-N 1.1 m below a river valley feedlot. Sweeten et al. (1995) also found no increases in NO_3-N, Cl^-, Na^+, P and NH_4-N in groundwater beneath feedlots where the water table was greater than 80 m below the surface. In contrast, Stewart et al. (1967) researched feedlots and cultivated cropland in Colorado, finding variable

accumulation of NO_3-N in soil and groundwater and concluded feedlots could pose local groundwater pollution problem.

Animal activity and management practices at open air feedlots alter the soil profile. Over time an organic and interface layer form on top of the original mineral soil. The organic layer is a fresh accumulation of manure. The interface layer is mixed organic matter and mineral soil caused by hoof action, and the third layer is the top of the natural soil profile that has become physically and chemically altered. Generally, the surface 15 cm is compacted and has high bulk density, 1.60 to 1.87 g cm^{-3}, is poorly aerated, and has platy or massive structure (Mielke et al., 1974; Olson et al., 2005). The manure also provides a habitat for microorganisms that produce organic gels and polysaccharides that plug soil pores, even in sandy soils. When kept moist they inhibit liquid infiltration, but when dry, may form cracks creating a greater potential for leaching (Mielke et al., 1974; Mitchell and Nevo, 1964). Regardless, waste is a significant source of moisture for the pen surface. At typical High-Plains feedlots with stocking rates of 18 m^2 $animal^{-1}$ and an average water consumption of 30 L day^{-1}, the annual deposition of water in the waste alone would be on the order of 70 cm yr^{-1} (Boyles et al., 2007; Davis et al., 2004). This moisture, coupled with normal precipitation, creates the potential for downward contaminant transport beneath the pen. Even without transport in the solute, nutrients could also move under the pen by the process of diffusion, albeit at a much slower rate.

At feedlot closure there is an increased potential of N movement because soil surface drying and cracking would promote water infiltration, air diffusion, and subsequent conversion of subsurface NH_4-N and organic-N to mobile NO_3-N (Mielke and Ellis, 1976; Saint-Fort et al., 1995; Ham, 2002). During most summers in Nebraska, 2 to 3 cm wide cracks can be observed at empty feedlots, particularly those with soils having high clay content (Mielke and Ellis, 1976).

The objective of this research is to survey select soil physical and chemical properties beneath pens from four feedlots in Kansas. The results presented will address the following questions: 1) how have the nutrients accumulated in the soil profile? 2) is there high variability in subsurface nutrients within and among feedlots? 3) does the total amount of a nutrient represent a significant fraction of the material initially deposited on

the pen surface as manure? and 4) could the quantity of nutrients accumulated beneath feedlots have the potential to impact local ground water quality?

Methods

Four feedlots in Kansas were chosen as sample sites: Feedlot 1, Feedlot 2, Feedlot 3, and Feedlot 4. Feedlot 1, Feedlot 2, Feedlot 3, and Feedlot 4 have 30 year average rainfall of 62.8, 67.2, 81.6, and 88.4 cm, respectively, and 30 year average temperatures of 12.8, 13.4, 12.5, and 12.7ºC, respectively. The feedlots ranged in size and capacity with Feedlots 1, 2, 3, and 4 had capacities of 30 000, 27 000, 9 000, and >2000 head, respectively. The pens at these feedlots range in age from about 24 to 50 yrs.

Soil cores were taken by a direct-push coring machine equipped with a 4.6 cm-i.d. sampling tube and single-use polyethylene teraphthalate copolymer plastic liners (LWW, D10006P, 1025151; Concord Environmental Equipment). At each feedlot, 4 to 5 pens were sampled. When a feedlot contained pens of different ages due to a previous expansion of the operation, an attempt was made to collect samples in the newer and older sections of the yard. The pens were either stocked with cattle at the time of sampling or had been emptied a few weeks prior. Soil cores were taken 5 to 15 m away from the cement pad in front of the feed bunks. Coring depths ranged from 1.80 m to 4.70 m with the majority terminating at 2.70 m. The soil cores were stored at -9ºC until processed.

Each soil core was described to determine the horizons, color, structure, and texture. Then the core was separated into horizons. From each horizon samples were created by depths of approximately 10 cm. Due to horizon thickness variability, not all samples were exactly 10 cm. After 2.00 m, the sample sizes were increased to 20 cm in length while continuing with the same methodology of keeping any one sample within the boundaries of one horizon. After the cores were divided into samples, each sample, at field moisture, was sieved to pass through a 2 mm sieve. All samples were stored at -9ºC between analyses.

Soil moisture content was determined gravimetrically. The pH was determined using a 1:1 soil:water slurry (Wateson and Brown, 1998). Total N and organic C were determined using a LECO CNS 2000 combustion analyzer (CNS, 1995) (Leco, St.

Joseph, Michigan). Extractable NO_3-N and NH_4-N were determined using a modification of the procedure presented in Gelderman and Beegle (1998) using 2.00 g ± 0.05 g field moist soil with 20 mL 1 M KCl in a glass 125 mL Erlenmeyer flask. The flask was shaken for 30 minutes at 200 rpm on an orbital shaker and then filtered through Whatman No. 2 filter paper. The extracts were analyzed by the Kansas State University Soil Testing Lab (KSU-STL) with a Rapid Flow Analyzer (Alpkem Corp., Clackamas, OR). Nitrate was determined by Cd-reduction and NH_4^+-N was determined by an indolphenol color development (Gelderman and Beegle, 1998; Alpkem No. A303-S170, 1986; Alpkem No. A303-S021, 1986). Extractable P was determined using 2.00 g ± 0.05 g field moist soil and 40 mL 0.5 M $NaHCO_3$ pH 8.5 in a glass 125 mL Erlenmeyer flask that was shaken for 30 minutes at 200 rpm on an orbital shaker and then filtered through Whatman No. 2 filter paper (Frank et al., 1998). The P concentration was determined by measuring the absorbance of 880 nm light with a DU-64 spectrophotometer (Beckman Coulter, Inc., Fullerton, CA) after a 20 minute color development period with an acid molybdenate and ascorbic acid solution. Extractable Cl^- was determined using 5.00 g ± 0.05 g field moist soil and 20 mL 0.01 M $Ca(NO_3)_2$ in a polypropylene sample cup that was shaken for 5 minutes at 200 rpm on an orbital shaker and then filtered through pre-rinsed filter paper (Gelderman et al., 1998). The extracts were analyzed by the KSU-STL with a Technicon Auto Analyzer II (Technicon Industrial System, Tarrytown, NY) using a mercury thiocyanate color development (Gelderman et al., 1998). Texture (particle size analysis) for each horizon was measured by the method outlined by Gee and Bauder (1986) with a modification. The modification was to measure the sand fraction by wet sieving. Composite samples were made for each horizon.

At two feedlots, Feedlot 1 and Feedlot 2, data for three representative pens was gathered in November 2005 by Joel DeRouchy. The information included feeding data and pen management information. The nutritional information collected included feed nutrient composition and feed intake levels, which are reported on an as-fed basis. A N retention value of 29.2 g hd^{-1} day^{-1} (NRC, 1996) was used in estimations. Nitrogen retention values are a function of feed-N content and manure N content. Excreted N per day was calculated by subtracting N intake per head per day from the 29.2 g of estimated N retained. In addition, the number of cattle per pen and pen area were collected

allowing for calculation of stocking rate and amount of N excreted per area within each pen. The N deposition calculations was used to estimate the fraction of deposited N that is moving down the soil profile.

Statistical analysis to compare differences within and among feedlots was not performed because there was no replication due to time and expense.

Results and Discussion

Nutrient Deposition Rates From Feeding Data

As part of a feedlot mass balance study, the rate of N deposition onto the pen surface was estimated. At Feedlot 1 and Feedlot 2, the stocking rate was 17 m^2 hd^{-1} and 33 m^2 hd^{-1} and average animal weight was 439 and 373 kg, respectively (Table 3-1). Using an average N retention rate of 29.2 g N hd^{-1} day^{-1}, an estimated 3.2 kg N m^{-2} yr^{-1} at Feedlot 1 and 1.6 kg N m^{-2} $year^{-1}$ at Feedlot 2 were deposited on the pen surface. When the amount deposited on the pen surface was compared to the amount found below the pen surface, for the upper 1.00 m, for these two feedlots, only a small percentage of profile N was found below the pen surface (Table 4-3). At Feedlot 1, the percentage of N found vs. deposited ranged from 2.9 to 1.2 for 25 to 60 years of operation. At Feedlot 2, the percentage of N found vs. deposited ranged from 7.9 to 3.3 for 25 to 60 years of operation.

Ammonium

Ammonium is not a very mobile constituent in soils because it participates in cation exchange, but upon exchange site saturation, NH_4-N can then leach. Ammonium has also been reported as a strong indicator of lagoon seepage (DeSutter et al., 2005; Huffman and Westerman, 1995). The concentration of NH_4-N was high at the surface, 375 to 8000 mg kg^{-1} at all feedlots except at Feedlot 2 which ranged from 43 to 335 mg kg^{-1} (Figures 3-1 to 3-4). At all feedlots, the NH_4-N concentration rapidly decreased within the upper 0.50 to 1.00 m. The general trend of rapid decrease in concentration within a short distance was expected due to the presence of a hard pan created by animal action and reduced infiltration from microbial byproducts (Mikele et al., 1974; Olson et al., 2005). At Feedlot 3 and Feedlot 4, there was an increase in NH_4-N around 0.50 to

1.00 m with a range of 760 to 950 mg kg^{-1} and 167 to 312 mg kg^{-1}, respectively (Figures 3-3 and 3-4). At Feedlot 2, NH_4-N was higher at the surface and decreased to very low concentrations, generally <5.6 mg kg^{-1} within the first 0.60 m (Figure 3-2).

A background concentration of 5.6 mg NH_4-N kg^{-1}, based on findings of McKinley (2007) and Norris (2000) at a natural prairie setting, was used to estimate the depth at which the soil profile was not affected by leaching of NH_4-N from cattle manure. At Feedlot 1, four pens return to background at approximately 1.00 to 1.30 m and one pen did not reach background for the depth sampled (Figure 3-1). At Feedlot 3, three pens returned to background at approximately 1.15 m, one pen returned to background at 1.97 m, and one did not reach background for depth sampled (Figure 3-3). At Feedlot 4, one pen returned to background at 1.80 m, two at 2.70 m, and one at 1.20 m with exception to the depth from 1.68 to 2.18 m where the concentration rose to 10.0 mg NH_4-N kg^{-1} (Figure 3-4). Schuman and McCalla (1975) had similar findings in Nebraska except for the extremely elevated concentrations at the very surface. Saint-Fort et al. (1995) found little movement of NH_4-N in any feedlot soil samples having a maximum surface concentration of 70 mg kg^{-1} and >1 mg kg^{-1} after 1.00 m.

Organic Nitrogen

At all feedlots the organic-N was high at the surface, ranging from 500 to 22000 mg kg^{-1}, and rapidly decreased within the first 25 cm and then decreased to a relatively stable range of 150 to 600 mg kg^{-1} at approximately 1.00 m (Figures 3-1 to 3-4). The relatively high concentration of organic-N at depths deeper than 1.50 m is currently unexplained. Possibilities include organic matter leaching, organic acid leaching, or residual organic matter from before the feedlot operation existed. In attempt to explain the organic-N concentrations, Figure 3-5 shows organic C and organic N were highly correlated with an r^2 value of 0.91. The C:N ratio of 14:1 and low concentrations of NH_4-N suggests the presence of residual organic matter. Campbell and Racz (1975) found a C:N ratio range of 12:1 to 16:1. Olson et al. (2005) found total N concentrations (before feedlot activity) to be within the range of concentrations found below the manure pack of the feedlots in Kansas.

Nitrate

Nitrate is a mobile soil constituent of importance in high N systems because organic-N and NH_4-N can be biologically transformed into NO_3-N, which can threaten groundwater resources potentially causing health problems such as methemoglobinemia in humans and animals. Most of the N deposited on the pen surface is in the form of organic-N or urea-N. The organic-N can be mineralized into NH_4-N which can be nitrified into NO_3-N. Urea-N can be hydrolyzed into NH_4-N and transformed to NH_3 or nitrified into NO_3-N. It has been estimated approximately 50% of urea-N is volatilized as NH_3 (Cole, 2006). In addition, the NO_3-N can also be denitrified under oxygen limiting conditions. Nitrate is not expected to be present in high concentrations because the main form of N deposition is urea and conditions are generally not suitable for nitrification.

A background concentration of 4.1 mg NO_3-N kg^{-1}, based on findings of McKinley (2007) and Norris (2000) at a natural prairie setting, was used to estimate the depth at which the soil has not been affected by leaching of NO_3-N from cattle manure. At Feedlot 1 and Feedlot 3, the NO_3-N was below background for the entire profile of all pens (Figure 3-1 to 3-4). At Feedlot 4, NO_3-N for pens 4B and 4D remained below background for the entire profile and pens 4A and 4C were below background except for small NO_3-N increases with maximum concentrations of 32.9 and 10.7 mg kg^{-1} at 0.21 and 0.36 m, respectively (Figure 3-4). Saint-Fort et al. (1991) found similar NO_3-N behavior and concentrations at an active feedlot in Alberta, Canada.

At Feedlot 2, NO_3-N was low at the very surface, but between the surface and approximately 1.00 m there was an increase in concentration where the maximums were 278, 510, 435, and 74.1 mg kg^{-1} at pens 2A, 2B, 2C and 2D, respectively, before returning to background levels around 1.80 m (Figure 3-2). The data suggest this NO_3-N formed in place via nitrification and was not translocated from the soil above. This hypothesis is supported by soil acidification (Figure 3-6d) at the same depth and no corresponding increase in Cl^- concentration (Figure 3-6e) (Gast et al., 1974). The zone of nitrification at Feedlot 2 is unique to the four feedlots studied and does not have any known differences in management. Mielke and Ellis (1976) found similar increases in NO_3-N under abandoned feedlots but at depths around 3.00 to 4.00 m instead of in the first 1.00 m as found at Feedlot 2. At Feedlot 2, it may be possible that the pens not

having cattle in them at sampling, had been empty long enough to allow them to dry out allowing for nitrification to occur to a depth of 1.0 m. DeSutter et al. (2005) found NO_3-N near the bottom of anaerobic lagoons at feedlots allowed to dry out over the summer, but found negligible NO_3-N at lagoons only recently emptied. If the surface is allowed to dry, it appears nitrification can occur readily.

At active feedlots, Mielke et al. (1974) and Ellis et al. (1975) found similar NO_3-N concentrations as found at Feedlot 1, Feedlot 3, and Feedlot 4. Saint-Fort et al. (1991, 1995) measured potentially mineralizable N (PMN) as well as NO_3-N and found little mineralization of N to NO_3-N despite high levels of PMN and proposed that denitrification can occur beneath feedlots, thereby not forming significant amounts of leachable NO_3^--N. Elliott et al. (1972) measured the composition of soil air beneath a feedlot in Nebraska and found high concentrations of methane, concluding the soil profile had low redox potential, conditions conducive for denitrification. Mielke et al. (1974) also concluded reduced conditions prevented NO_3-N from reaching the water table in Nebraska studies. In addition, soil cores at Feedlot 3 and Feedlot 4 had redoximorphic features such as Fe-Mn streaks or nodules and some had gleyed colors (Appendix A-47 to A-55). Many researchers measure soil NO_3-N to predict if it is a hazard to water quality, but Maulé and Fonstad (2002) suggest that NO_3-N is not a good indicator of leaching from manure because N is subject to biological transformations.

Chloride and pH

Chloride was measured to evaluate relative water movement beneath pen surfaces because it is a mobile soil constituent and is not subject to significant biological transformations. The pH was measured to see how manure may have affected the natural soil pH over time as well as to determine if pH conditions were conducive for NH_3 volatilization and/or nitrification. High pH values around 8 would indicate conditions were favorable for NH_3 volatilization, and lower pH values, lower than the natural pH, would indicate nitrification may have occurred.

The distribution of Cl^- with depth was similar for Feedlots 1, 3, and 4 therefore, only data from Feedlot 1 is shown in Figure 3-6b. The Cl^- profile for Feedlot 2 was not similar to the other feedlots (Figure 3-6e). Chloride was high at the surface, ranging from

about 800 to 14 000 mg kg^{-1}, rapidly decreased within the first meter, and remained relatively low, <4 to 1000 mg kg^{-1}. Saint-Fort et al. (1991) found similar Cl^- behavior with concentrations within the range found at these feedlots. At approximately 3.00 m, at Feedlot 2, the Cl^- began to increase, possibly due to natural soil characteristics, having pedogenic carbonates.

The distribution of Cl^- with depth appears to be consistent with diffusion based transport when compared to the data found by Jang and Hong (2002). The Cl^- profiles found at the four feedlots are most similar to Jang and Hong's (2002) predictions for Cl^- migration by diffusion with a hardened barrier. Diffusion based transport is not surprising because the compacted layer at the surface allows for little infiltration. Mielke and Mazurak (1976) found water infiltration for feedlot surfaces was 1.2 mm day^{-1}, Maulé and Fonstad (2002) found feedlot surface seepage to be 0.005 mm day^{-1} to 0.016 mm day^{-1}, and Glanville et al. (2001), Ham (1999, 2002), Ham and DeSutter (1999, 2000) found lagoon seepage from actively used lagoons was 0.2 and 2.4 mm day^{-1}. Mielke et al. (1974) found soil water content (34 to 40%) was narrow for feedlot soil and remained relatively constant with depth. Average soil moisture for each feedlot was 7.0, 8.3, 15.9, and 19.7% at Feedlot 1, Feedlot 2, Feedlot 3, and Feedlot 4, respectively.

The pH of all pens at Feedlot 1, 3, and 4, had a similar trend, being slightly elevated at the surface with a pH 8.5 and then acidification to about pH 7.5 to 6.5 for the remainder of the profile (Figure 3-6a). The surface pH at Feedlot 2 was similar to Feedlot 1 (Figure 3-6d), however there was a zone of strong acidification that peaked at about pH 5.5 around 75 cm. This zone of acidification was in the same area where there was a NO_3-N accumulation. Below the zone of acidification, pH increases, ranging from 7.5 to 8.5 at approximately 1.5 m and remained stable with increasing depth. The elevated surface pH was due to accumulation of $CaCO_3$ from cattle diets and urea hydrolysis. The slightly alkaline pH found at depths below 1.50 m are typically found for the soil series mapped in these areas (Soils Survey Staff, 2007).

Phosphorus

For all feedlots, the extractable P concentrations were high at the surface, ranging from about 20 to 9000 mg kg^{-1}, and rapidly decreased within the first 0.50 m of the

profile to range between <1.0 and 80 mg kg^{-1} (Figures 3-6c and 3-6f). Campbell and Racz (1975) found Olsen extractable P concentrations ranging downward from 76 to 0.4 mg kg^{-1}, and the majority of P beneath a feedlot was in the inorganic form.

Texture

In the upper 0.25 cm, the predominant soil textures at Feedlot 1 were loamy sand to loam, at Feedlot 2, silt loam to clay loam, at Feedlot 3, loam to silt loam, and Feedlot 4 silt loam to clay (Appendix A-19 to A-37). The soil textures at Feedlot 1 were predominantly sand, loamy sand, sandy loam, and loam. At Feedlot 2, soil textures were predominantly loam, silt loam, silty clay loam, clay loam. At Feedlot 3, soil textures were predominantly loam, silt loam, clay loam in the upper 0.60 cm and then predominantly loam, sandy loam, loamy sand, and sand at lower depths. Lastly, Feedlot 4 soil textures were predominantly clay loam, silty clay loam, and clay, silty clay and silt loam.

Variability Among and Within Feedlots

A high level of variability of N, P, Cl^-, and C exists below each pen on each feedlot and among feedlots (Table 3-2). Total masses of each N species per area were determined by summation and assuming a constant bulk density of 1350 kg m^{-3}. Feedlot 3 had the most N below the surface followed by Feedlot 4, Feedlot 2, and Feedlot 1 (Figure 3-7). For a depth of 2.70 m the mass of NH_4-N ranged from 50 to 1400 g m^{-2} with an average of 575 g m^{-2} among feedlots. Ammonium variability is greatest in the top 0.25 m with a coefficient of variation (calculated from the average of NH_4-N of all four feedlots (Table 3-3)) of 20% and decreased to 3% by 1.00 m. Organic-N variability is greater than NH_4-N variability, with organic-N variability remaining fairly constant between the 0.25, 0.50, and 1.00 m depths. Factors contributing to the variability observed include depth of the manure pack, extent of mixing with the mineral soil, and pen cleaning frequency and method. The mass of organic-N ranged from 2.5 to 6.2 kg organic-N m^{-2} with an average of about 4.0 kg m^{-2} among feedlots. For all feedlots, an average of 54.6, 76.7, and 94.2 % of NH_4-N was found in the top 0.25, 0.50, and 1.00 m of the soil profile, respectively. For all feedlots, an average of 49.8, 65.2, and 77.6% organic-N was found in the top 0.25, 0.50 and 1.00 m of the soil profile, respectively.

Summary and Conclusions

The survey of select physical and chemical properties beneath pens was completed for four feedlots in Kansas. Based on feeding data, only a small percent (7.9 to 1.2) of the total N deposited on the surface was found in the top 1.00 m below the pen surface for a range of 25 to 60 years of operation for Feedlot 1 and Feedlot 2. High levels of variability of N, P, Cl^-, and C below each pen on individual feedlots and among feedlots were observed. Ammonium concentrations were high at the surface, rapidly decreased with depth in the upper 0.50 to 1.00 m, and generally returned to background levels at some depth greater than 1.00 m. Organic-N was high at the surface and rapidly decreased in the first 0.25 m. Nitrate was generally below the background concentration of 4.1 mg kg^{-1} for the entire profile at Feedlots 1, 3, and 4 was most likely due to denitrifying conditions and/or lack of nitrification. At Feedlot 2, NO_3-N was low at the surface, but between the surface and approximately 1.00 m there was an increase in concentration with maximums over 75.0 mg kg^{-1}, before returning to background levels at 1.80 m, suggesting a zone of nitrification. The shapes of Cl^- and P profiles were similar for all feedlots having high concentrations at the surface and rapid decrease in concentration within the first 1.00 and 0.50 m, respectively. The pH profiles for Feedlots 1, 3, and 4 the pH profiles are similar (slightly alkaline to alkaline), while Feedlot 2 had a zone of acidification in the top 1.00 m.

The data found at these Kansas feedlots support the prior conclusion that soil beneath feedlots do not contribute significant amounts of N and P to groundwater while in use (Elliott et al., 1972; Lorimor et al., 1972; Schuman and McCalla, 1975). This conclusion should be useful to argue against the proposal of soil liners being installed at confinement areas before an AFO begins operation. However, if these feedlots were to close, and the soil profile allowed to dry, there is a potential for groundwater contamination via mineralization of PMN or N-leaching. If feedlots were closed and the land could be largely remediated by removing a layer of soil, these feedlots would have an average 48% profile N removed in a 0.25 m thick layer. Further studies into denitrifying conditions and infiltration would be beneficial to increase understanding of soil characteristics beneath cattle feedlots.

References

Alpkem Corperation. RFA Methodology No. A303-S021. Ammonia N. 1986. Clackamas, OR 97015.

Alpkem Corporation. RFA Methodology No. A303-S170. Nitrate/Nitrite. 1986. Clackamas, OR 97015.

Boyles, S., S. Loerch, F. Fluharty, W. Shulaw, and H. Stanfield. 2007. Beef Management Primer [Online]. Available at http://beef.osu.edu/library/feedlot/index.html (Accessed Feb 27 2007). Ohio State University, OH.

Campbell, L. B., and G. J. Racz. 1975. Organic and inorganic P content, movement, and mineralization of P in soil beneath a feedlot. Can. J. Soil Sci. 55:457-466.

CNS 2000 instrument method "C, N, and Sulfur Testing in Soil/Plant Tissue." 1995. LECO Corporation, St. Joseph, MI.

Cole, A. 2006. Update on recent protein research for finishing beef cattle fed steam flaked corn-based diets. 21st Annual Southwest Nutrition and Management Conference. Tempe, AZ.

Davis, J. G., T. L. Stanton, and T. Haren. 2004. Feedlot Manure Management. Bulletin No. 1.220. Colorado State University Cooperative Extension – Agriculture [Online]. Available at www.ext.colostate.edu/pubs/livestk/01220.html. (Accessed Nov 5 2004).

DeSutter, T. M., G. M. Pierzynski, and J. M. Ham. 2005. Movement of lagoon-liquor constituents below four animal-waste lagoons. J. Environ. Qual. 34:1234-1242.

Elliot, L. F., T. A. Travis, T. M. McCalla, L. N. Mielke. 1972. Ammonium, nitrate, and total nitrogen in the soil water of feedlot and field soil profiles. Appl. Microbiol. 23:810-813.

Ellis, J. R., L. N. Mielke, and G. E. Schuman. 1975. The nitrogen status beneath beef cattle feedlots in eastern Nebraska. Soil Sci. Soc. Amer. Proc. 39:107-111.

Frank, K., D. Beegle, and J. Denning. 1998. Chapter 6 *In:* Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional

Publication No. 221. (Revised). University of Missouri Agricultural Experiment Station, Columbia, MO. pp. 25-26.

Gast, R. G., W. W. Nelson, and J. M. MacGregor. 1974. Nitrate and chloride accumulation and distribution in fertilized tile-drained soils. J. Environ. Qual. 3(3):209-213.

Gee, G. W., and J. W. Bauder. 1986. Particle-size analysis. pp. 383-411. *In* A. Klute (ed). Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSA, Madison, WI.

Gelderman, R.H., and D. Beegle. 1998. Chapter 5 *In:* Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Publication No. 221 (Revised). University of Missouri Agricultural Experiment Station, Columbia, MO. pp. 18-19.

Gelderman, R. H., J. L. Denning, and R. J. Goos. 1998. Chapter 11 *In:* Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Publication No. 221. (Revised). University of Missouri Agricultural Experiment Station, Columbia, MO. pp. 49-50.

Glanville, T. D., J. L. Baker, S. W. Melvin, and M. M. Aqua. 2001. Measurement of leakage form earthen manure storage structures in Iowa. Trans. ASAE 44:1609-1616.

Huffman, R. L., and P. W. Westerman. 1995. Estimated seepage losses from established swine waste lagoons in the lower coastal plain of North Carolina. Trans. ASAE. 38:449-453.

Ham, J. M. 1999. Measuring evaporation and seepage losses from lagoons used to contain animal waste. Trans. ASAE. 42:1303-1312.

Ham, J. M. 2002. Seepage losses from animal waste lagoons: A summary of a four year investigation in Kansas. Trans. ASAE. 45:983-992.

Ham, J. M., and T. M. DeSutter. 1999. Seepage losses and nitrogen export from swine-waste lagoons: A water balance study. J. Environ. Qual. 28:1090-1099,

Ham, J. M., and T. M. DeSutter. 2000. Toward site-specific design standards for animal-waste lagoons: Protecting ground water quality. J. Environ. Qual. 29:1721-1732.

Jang, Y., and G. Hong. 2002. Analysis of effective diffusion and transport of inorganic solute through a landfill liner system. Environ. Geol. 42:929-936.

Lorimor, J. C., L. N. Mielke, L. F. Elliott, and J. R. Ellis. 1972. Nitrate concentration in groundwater beneath a beef cattle feedlot. Water Res. Bull. 8:999-1005.

Maulé, C. P., and T. A. Fonstad. 2002. Solute migration and moisture flux beneath cattle feedlot pens. Trans. ASAE. 45(1):75-81.

Mckinley, D. 2007. Consequences of conversion of native mesic grassland to coniferous forest on soil processes and ecosystem C and N storage. Kansas State University, Division of Biology. Dissertation.

Mielke, L. N., and J. R. Ellis. 1976. Nitrogen in soil cores and ground water under abandoned cattle feedlots. J. Environ. Qual. 5(1):71-75.

Mielke, L. N., J. R. Ellis, N. P. Swanson, J. C. Lorimor, and T. M. McCalla. 1970. Groundwater quantity and fluctuation in a shallow unconfined aquifer under a level feedlot *In*: Relationship of agriculture to soil and water pollution. pp. 31-40. Proc. Cornell Univ. Conf. on Agr. Waste Mgmt. Rochester, NY, Jan. 1970.

Mielke, L. N., and A. P. Mazurak. 1976. Infiltration of water on a cattle feedlot. Trans. ASAE. 19(2):341-344.

Mielke, L. N., P. Norris, and T. M. McCalla. 1974. Soil profile conditions of cattle feedlots. J. Environ. Qual. 3(1):14-17.

Mitchell, R., and Z. Nevo. 1964. Effect of bacterial polysaccharide accumulation on infiltration of water through sand. Appl. Microbiol. 12:219-223.

Norris, M. D. 2000. Biogeochemical consequences of land cover change in Eastern Kansas. Kansas State University, Division of Biology. Thesis.

NRC. 1996. Nutrient Requirements of Dairy Cattle (7th Rev. Ed.). National Academy Press, Washington, D.C.

Olson, B. M., J. J. Miller, S. J. Rodvang, and L. J. Yanke. 2005. Soil and groundwater quality under a cattle feedlot in southern Alberta. Water Qual. Res. J. Canada. 40(2):131-144.

Saint-Fort R., J. S. Schepers, and R. F Spalding. 1991. Potentially mineralizable nitrogen and nitrate leaching under different land-use conditions in western Nebraska. J.

Environ. Sci. Health, Part A:Environ. Sci. Eng. Toxic Hazard Subst. Control. A26(3):335-345.

Saint-Fort, R., R. M. Raina, and B. Prescott. 1995. Subsurface environmental quality under a cattle feedlot and adjacent cropfield. J. Environ. Sci. Health, Part A:Environ. Sci. Eng. Toxic Hazard Subst. Control. A30(3):637-650.

Schuman, F. E. and T. M. McCalla. 1975. Chemical characteristics of a feedlot soil profile. Soil Sci. 119(2):113-118.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, Official Soil Series Descriptions [Online]. Available at http://soils.usda.gov/technical/classification/osd/index.html (accessed 08 March 2007).

Sweeten, J. M., T. H. Marek, and D. McReynolds. 1995. Groundwater quality near two cattle feedlots in Texas hig plains: A case study. Appl. Eng. Agr. 11:845-850.

Steinfeld H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. de Haan. 2006. Livestock's long shadow: environmental issues and options. FAO. Rome, 390 pp.

Stewart, B. A., F. G. Viets, Jr., G. L. Hutchinson, W. D. Kemper, F. E. Clark, M. L. Fairbourn, and F. Strauch. 1967. Distribution of nitrates and other pollutants under fields and corrals in the middle South Platte Valley of Colorado. USDA-ARS 41-134. Washington, D. C. 206 p.

Wateson, M. E., and J. R. Brown. 1998. Chapter 4, *In:* Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Publication No. 221. (Revised). University of Missouri Agricultural Experiment Station, Columbia, MO. pp. 13-14

Table 3-1. Nitrogen loading at pen surface in two commercial feedlots, Feedlot 1 and Feedlot 2. Data from Joel Derouchy, Kansas State University.

	Feedlot 1				Feedlot 2			
Item,	Pen 1[#]	Pen 2	Pen 3	Average	Pen 1	Pen 2	Pen 3	Average
Average weight (kg)	341	449	527	439	324	367	427	373
Head per pen (hd)	241	237	280	253	68.0	61.0	48.0	59.0
Area per head (m^2 hd^{-1})	17.9	17.2	15.3	16.8	28.2	31.5	40.0	33.2
Daily N intake, as fed (g hd^{-1} day^{-1})	156	192	218	189	139	191	222	184
Daily N Retention (g hd^{-1} day^{-1})*	26.8	29.1	31.8	29.2	26.8	29.1	31.8	29.2
Daily N Excretion (g hd^{-1} day^{-1})	129	163	186	160	112	162	190	155
Daily Pen N Excretion (kg m^{-2} day^{-1})	0.0072	0.0095	0.0122	0.0096	0.0040	0.0052	0.0048	0.0047
Yearly Pen N Excretion (kg m^{-2} $year^{-1}$)	2.6	3.5	4.5	3.2	1.5	1.9	1.8	1.6

*NRC (1996)

= Pen numbers are arbitrary labels. They do not correspond to pen numbers at the feedlot.

Table 3-2. Mass of N fractions, extractable Cl^-, and organic C for each profile to a depth of 2.70 m by 1.0 m^2.

Sum of elements beneath pen in 1 m^2 by 2.7 m deep.

Feedlot	Pen	Extractable NH_4-N	Extractable NO_3-N	Organic N	Total N	Extractable Cl^-	Organic C
		g m^2	g m^2	kg m^2	kg m^2	kg m^2	kg m^2
1	1A	303	5.0	1.4	1.7	1.4	13.3
	1B	177	7.8	1.9	2.1	0.8	7.5
	1C	1000	14.0	3.6	4.6	2.6	49.4
	1D	770	6.1	4.0	4.8	2.2	32.8
	1E	551	0.6	2.3	2.8	1.4	26.6
	Average	560 (336)	6.7 (4.9)	2.6 (1.1)	3.2 (1.4)	1.7 (0.7)	25.9 (16.6)
2	2A	18.6	268.8	2.9	3.2	2.6	21.0
	2B	39.3	454.6	3.2	3.7	2.3	28.4
	2C	50.5	136.2	3.7	3.8	2.5	33.0
	2D	92.5	78.8	5.2	5.4	4.0	46.1
	Average	50.2 (31.1)	235 (167)	3.8 (1.0)	4.0 (1.0)	2.8 (0.8)	32.1 (10.6)
3	3A	1922	1.0	9.6	11.6	5.1	108
	3B	2705	1.3	5.1	7.8	5.4	91.5
	3C	1090	3.7	6.2	7.3	5.0	74.3
	3D	640	0.8	3.3	3.9	2.6	36.3
	3E	690	2.0	6.7	7.4	4.6	82.5
	Average	1409 (888)	1.8 (1.2)	6.2 (2.3)	7.6 (2.7)	4.6 (1.1)	78.5 (26.7)
4	4A	270	5.9	3.6	3.9	1.8	26.7
	4B	285	0.9	2.2	2.5	1.4	23.8
	4C	286	4.8	4.0	4.3	1.7	35.0
	4D	284	1.3	5.1	5.4	1.6	45.3
	Average	280 (7.8)	3.2 (2.5)	3.7 (1.2)	4.0 (1.2)	1.6 (0.2)	32.7 (9.6)
1, 2, 3, and 4	Average	575 (594)	61.6 (115)	4.1 (1.5)	4.7 (2.0)	2.7 (1.4)	42.3 (24.3)

Assumed area of 1 m^2, bulk density of 1350 kg m^{-3}, and depth of 2.7 m.

* = Sampling did not reach 2.7 m; Pen 2B ended at 2.10 m, Pen 2D ended at 2.38 m, and Pen 4B ended at 1.80 m.

( ) = Standard Deviation

Table 3-3. Average sum of N fractions, extractable Cl^-, and organic C beneath each feedlot in 1 m^2 by 2.7 m deep and percentage of sum at 0.25, 0.50, and 1.00 m.

Average sum of element beneath each feedlot in 1 m^2 by 2.70 m deep and percentage of sum at 0.25, 0.50. And 1.00 m.

	Feedlot	Extractable NH_4-N	Extractable NO_3-N	Organic N	Total N	Extractable Cl^-	Organic C
		g	g	kg	kg	kg	kg
Average Sum	1	560 (336)	6.7 (4.9)	2.6 ± 1.1	3.2 (1.4)	1.7 (0.7)	25.9 (16.6)
% in Top 0.25 m		63.9 (13.2)	11.9 (20.2)	57.8 (32.8)	52.4 (25.1)	50.7 (18.8)	66.6 (32.7)
% in Top 0.5 m		87.0 (2.5)	34.9 (34.5)	65.2 (29.8)	62.3 (22.3)	75.4 (6.4)	74.0 (29.6)
% in Top 1.0 m		96.9 (3.1)	43.8 (38.0)	74.7 (22.9)	73.3 (18.0)	90.8 (6.7)	81.8 (21.3)
Average Sum	2	50.2 (31.1)	234 (167)	3.8 (1.0)	4.0 (1.0)	2.8 (0.8)	32.1 (10.6)
% in Top 0.25 m		55.6 (27.1)	16.8 (11.4)	49.2 (12.8)	47.7 (12.4)	39.0 (9.8)	53.2 (14.8)
% in Top 0.5 m		75.5 (22.9)	51.0 (36.1)	63.9 (18.5)	63.1 (17.5)	63.0 (11.0)	66.9 (17.9)
% in Top 1.0 m		92.6 (4.6)	85.4 (10.3)	78.5 (13.1)	78.8 (12.2)	85.1 (8.7)	80.4 (13.7)
Average Sum	3	1409 (888)	1.8 (1.2)	6.2 (2.3)	7.6 (2.7)	4.6 (1.1)	78.5 (26.7)
% in Top 0.25 m		45.2 (20.8)	32.5 (17.2)	68.2 (18.6)	65.0 (17.6)	55.1 (14.0)	71.3 (20.7)
% in Top 0.5 m		70.3 (20.2)	33.6 (19.7)	82.3 (15.1)	80.9 (15.2)	79.6 (8.4)	85.7 (17.0)
% in Top 1.0 m		91.6 (10.9)	39.9 (23.4)	91.9 (8.7)	92.0 (9.1)	93.6 (5.8)	93.1 (10.2)
Average Sum	4	280.0 (7.8)	3.2 (2.5)	3.7 (1.2)	4.0 (1.2)	1.6 (0.2)	32.7 (9.6)
% in Top 0.25 m		53.7 (3.7)	49.6 (20.4)	23.9 (6.3)	26.2 (5.9)	20.6 (4.5)	27.8 (7.6)
% in Top 0.5 m		74.0 (7.3)	74.6 (12.5)	49.6 (9.1)	51.4 (9.1)	48.8 (7.9)	56.8 (7.6)
% in Top 1.0 m		95.9 (34.4)	79.5 (26.6)	65.4 (28.4)	67.6 (28.6)	71.7 (30.7)	73.5 (28.9)
Average Sum	1, 2, 3, and 4	575 (594)	61.6 (115)	4.1 (1.5)	4.7 (2.0)	2.7 (1.4)	42.3 (24.3)
% in Top 0.25 m		54.6 (10.1)	27.7 (4.2)	49.8 (11.3)	47.8 (8.2)	41.3 (6.1)	54.7 (10.6)
% in Top 0.5 m		76.7 (7.2)	48.5 (19.1)	65.2 (13.4)	64.4 (12.2)	66.7 (13.9)	70.8 (12.2)
% in Top 1.0 m		94.2 (2.5)	62.1 (23.6)	77.6 (11.0)	77.9 (10.4)	85.3 (9.8)	82.2 (8.1)

Assumed area of 1 m^2, bulk density of 1350 kg m^{-3}, and depth of 2.7 m.

* = Sampling did not reach 2.7 m; Pen 2B, Pen 2D Pen 4B

( ) = Standard Deviation

Table 3-4. Calculations of average estimated N deposition on pen surface compared to amount of average total N found in 1.00 depth and years of operation for Feedlot 1 and Feedlot 2.

			Years of operation							
	Average N Deposition on pen surface	Average Total N in 1.00 m	25	30	35	40	45	50	55	60
	$kg\ m^{-2}\ year^{-1}$	$kg\ m^{-2}$	%	%	%	%	%	%	%	%
Feedlot 1	3.2	2.4	2.9	2.4	2.1	1.8	1.6	1.5	1.3	1.2
Feedlot 2	1.6	3.2	7.9	6.6	5.6	4.9	4.4	3.9	3.6	3.3

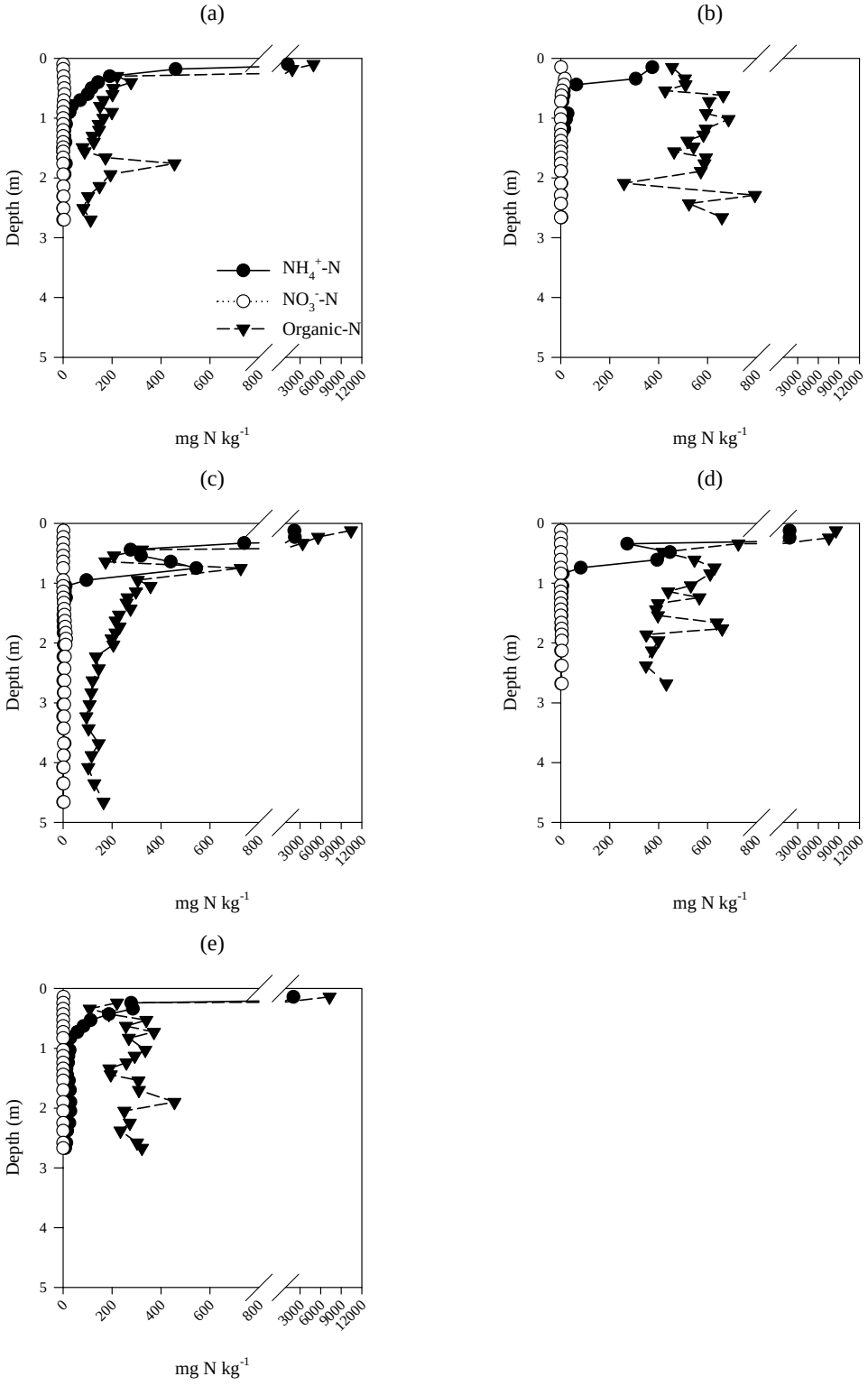

Figure 3-1. Nitrogen profiles (NO_3-N, NH_4-N, and organic N) of the pens sampled at Feedlot 1. (a) Pen 1A, (b) Pen 1B, (c) Pen 1C, (d) Pen 1D, and (e) Pen 1E.

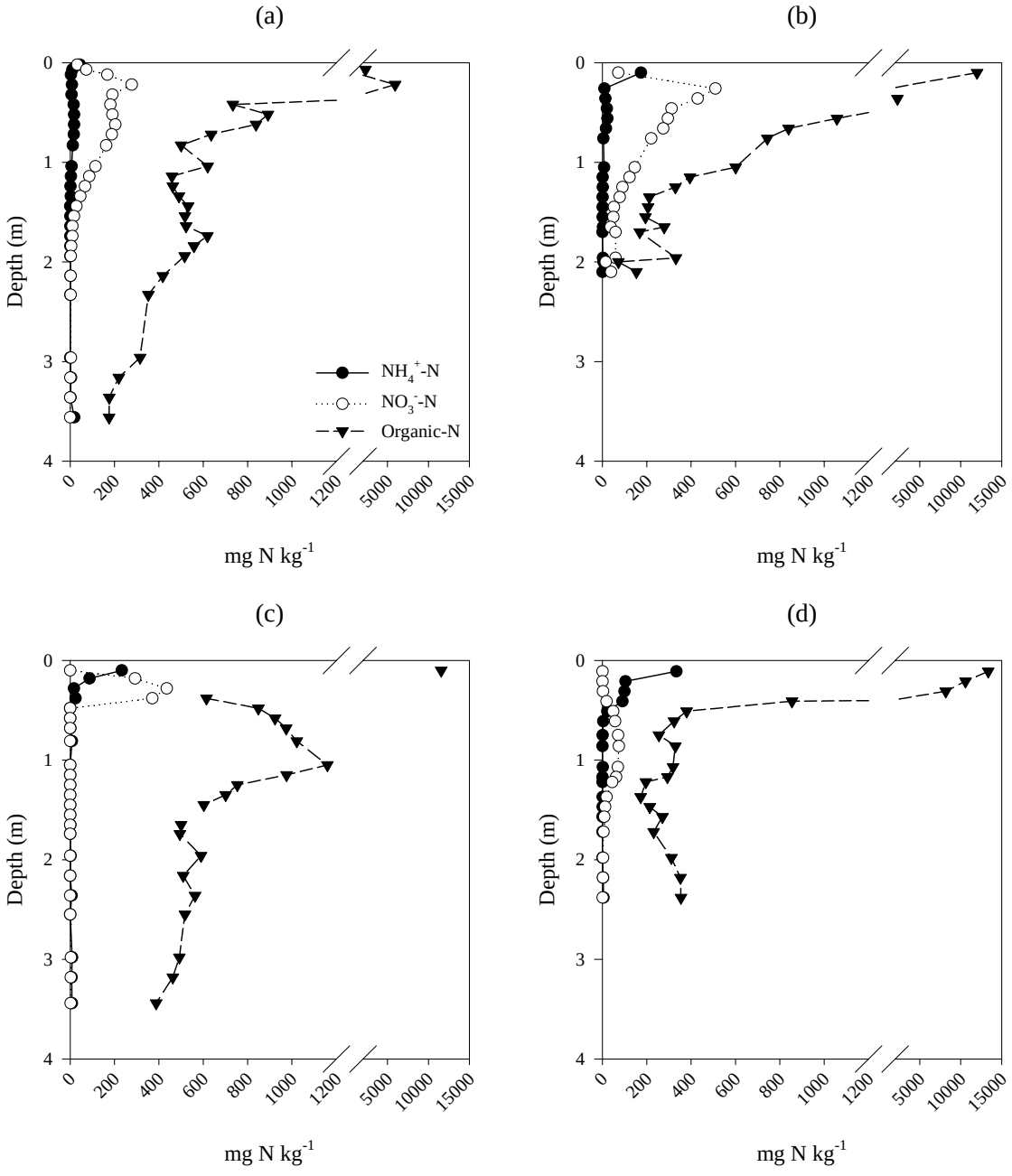

Figure 3-2. Nitrogen profiles (NO_3-N, NH_4-N, and organic N) of the pens sampled at Feedlot 2. (a) Pen 2A, (b) Pen 2B, (c) Pen 2C, (d) Pen 2D.

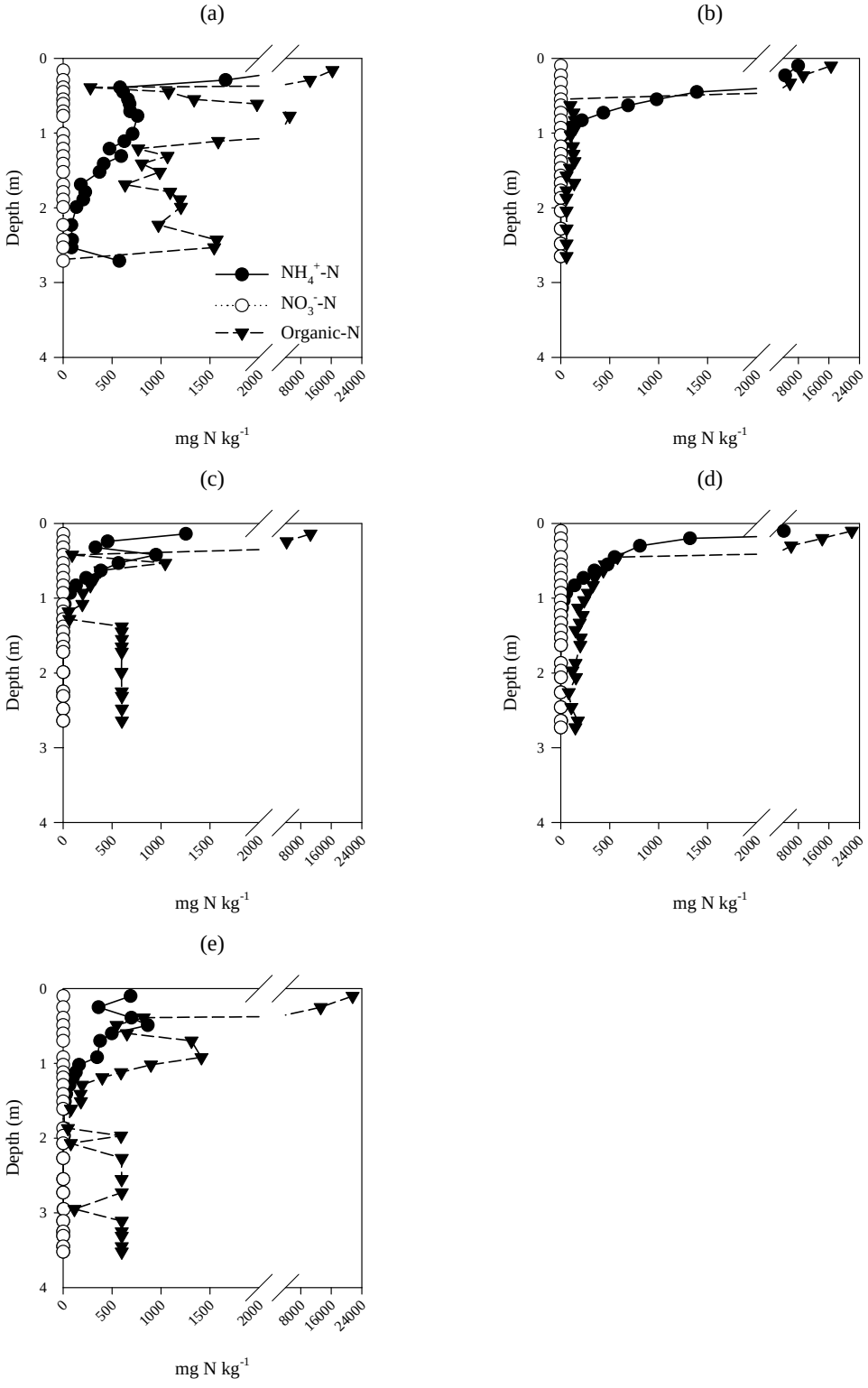

Figure 3-3. Nitrogen profiles (NO_3-N, NH_4-N, and organic N) of the pens sampled at Feedlot 3. (a) Pen 3A, (b) Pen 3B, (c) Pen 3C, (d) Pen 3D, (e) Pen 3E.

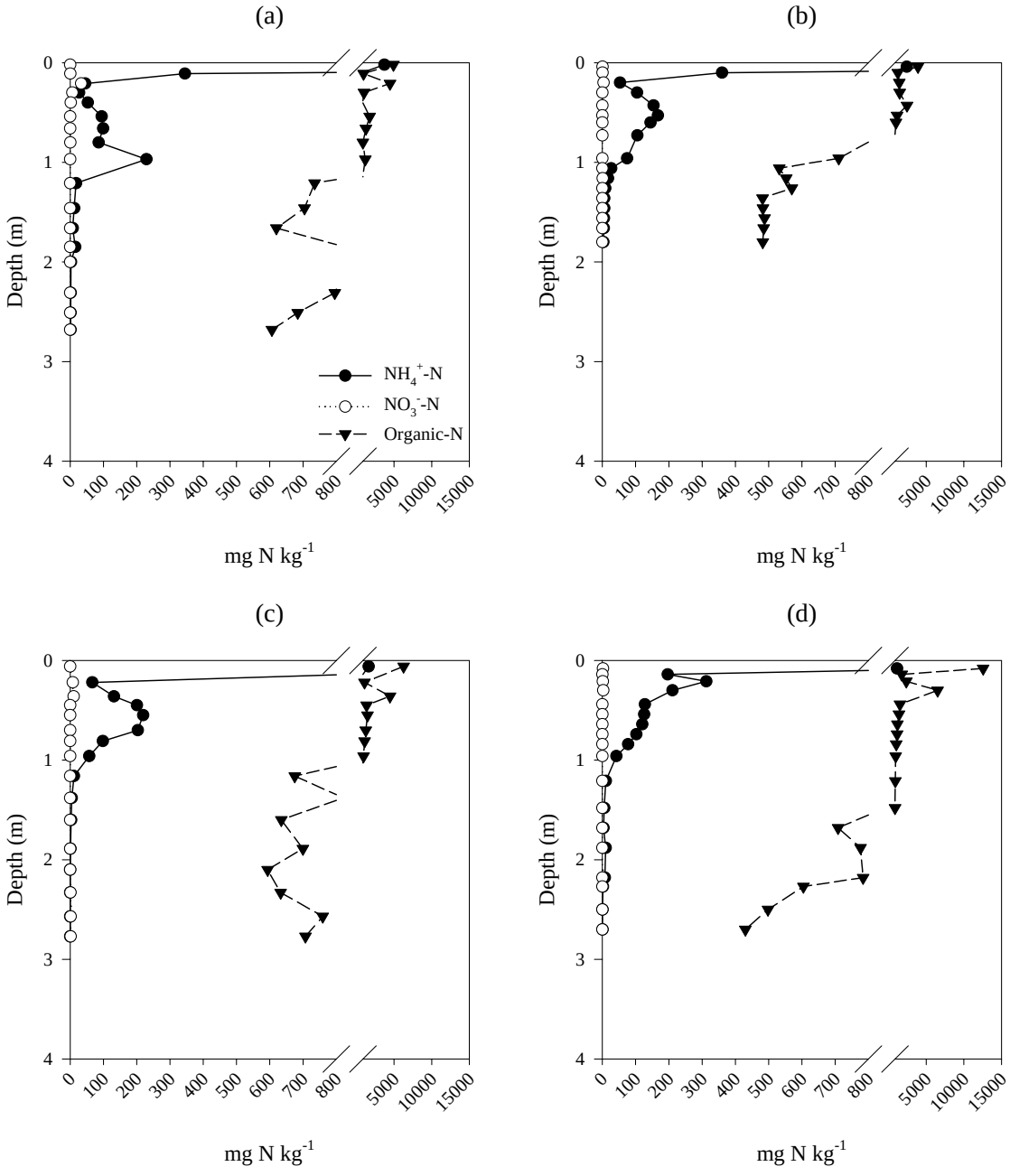

Figure 3-4. Nitrogen profiles (NO_3-N, NH_4-N, and organic N) of pens sampled at Feedlot 4. (a) Pen 4A, (b) Pen 4B, (c) Pen 4C, and (d) Pen 4D.

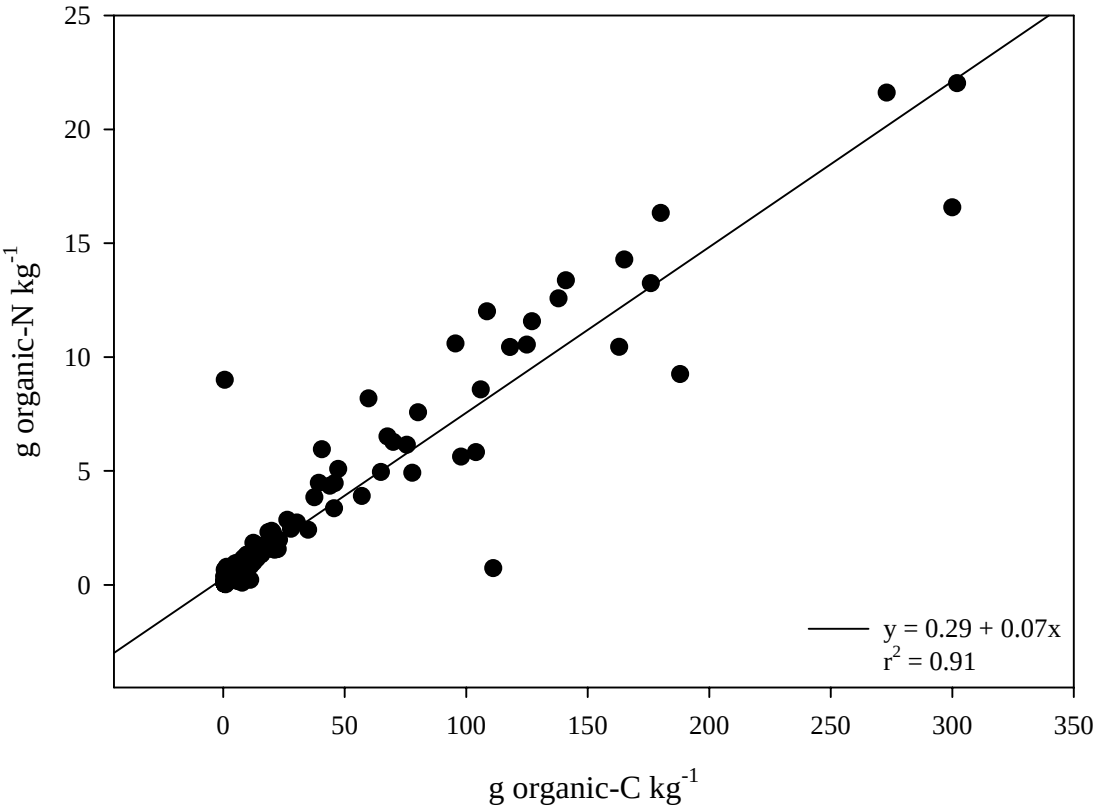

Figure 3-5. Organic C vs Organic N for all feedlots.

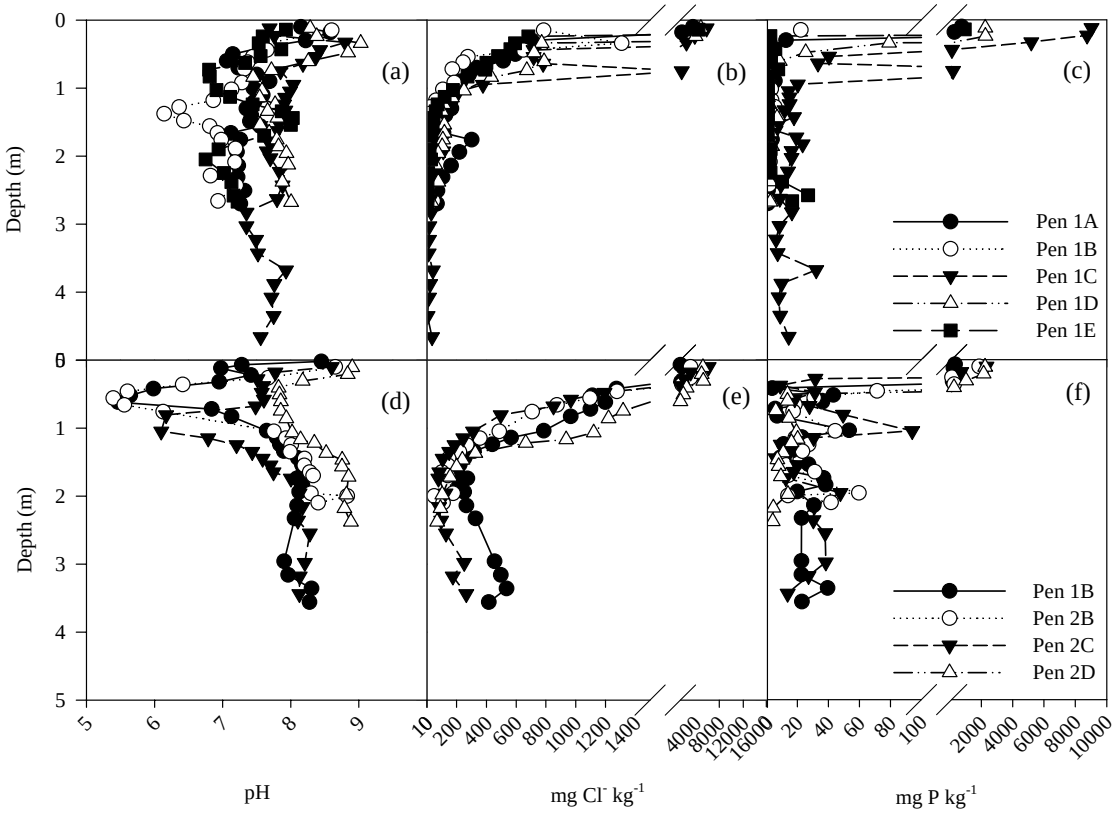

Figure 3-6. pH, Cl^-, and P profiles for Feedlot 1 (a, b, and c) and Feedlot 2 (d, e, and f). The profiles for Feedlot 1 are similar for Feedlots 3 and 4.

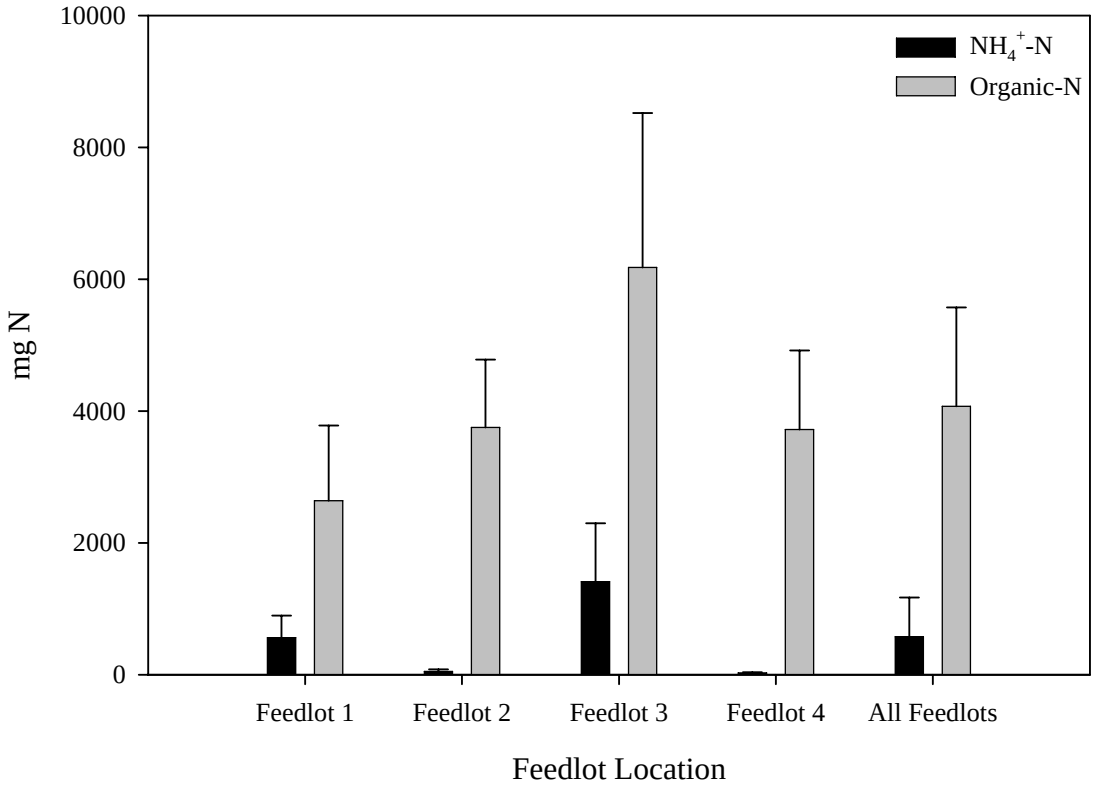

Figure 3-7. Average mass by feedlot of NH_4-N and organic-N to a depth of 2.70 m. Error bars show standard deviation from the mean.

CHAPTER 4 - Laboratory Chamber System For Measuring Ammonia Volatilization Flux

Abstract

The objective of this study was to develop and test a chamber method using a modified vacuum desiccator allowing for the investigation of NH_3 volatilization mechanisms in the laboratory. Ammonia volatilization at the soil surface is dependent upon air flow, soil and air temperatures, soil water content, pH, the concentrations of NH_3 and NH_4^+ in both the air and soil solution, and factors affecting soil temperature including humidity. This chamber was built to control and/or quantify as many of these variables as possible so the process in question could be evaluated. This endeavor is important because a simple, reproducible apparatus and technique is needed to help measure NH_3 volatilization in the laboratory. Furthermore, a technique for quantifying and predicting NH_3 volatilization is important because animal feeding operations (AFOs) are one of the largest contributors of NH_3 to the atmosphere, which can cause N enrichment (increased net biomass) in unwanted areas, increased acid precipitation, and particulate matter deposition. The chambers created allowed for repeated measurements with small error and appear to be a feasible, inexpensive apparatus to investigate NH_3 volatilization mechanisms. In addition, the chamber allows for various pretreatments of the incoming air and various collection methods at the outlet. Using synthetic urine as an N source, NH_3 was affected by initial soil moisture content This chamber has promise to provide excellent data to assist the efforts being made in NH_3 volatilization studies from feedlot pens.

Introduction

Ammonia is an air pollutant of great concern to the owners, managers, and neighbors of open air animal feeding operations (AFO) (Auvermann, 2006). Nitrogen in animal manure can be converted to NH_3 by hydrolysis and mineralization and then

volatilized (Oenema et al., 2001). Ammonia may be carried away from the source by air movement and can form secondary aerosols by interacting with SO_4^{-2} and NO_x to form $(NH_4)_2SO_4$ and NH_4NO_3 particulate matter. Particulate matter can persist in the atmosphere longer than gaseous molecules and thus can be transported further from the source and be deposited downwind. Dry and wet deposition of N can cause changes in the ecosystem such as enhanced plant growth, eutrophication, and various other unnatural alterations (Fenn et al., 2003). In addition, particulate matter can contribute to regional haze. Therefore, studying the quantity, rate, and mechanisms of NH_3 volatilization is important.

Scientifically credible estimates of air emissions from AFOs are complicated by numerous factors such as the kinds and numbers of animals, diets, housing, manure management, topography, environmental factors, and management actions to mitigate emissions and their effects. These factors all affect the amount and degree of dispersion in the atmosphere (NRC, 2003). In order to determine the potential adverse impacts to the environment accurate estimations of air emissions from AFOs are needed. In addition, these air emission estimates will be useful for developing methods to reduce NH_3 being released into the atmosphere. Therefore, the National Research Council (NRC) (2003) recommended research should continue to determine accurate and precise analytical techniques to measure and report NH_3 emissions, especially if there is a push for new legislation forcing operations to report this data. Under the Emergency Planning and Community Right-to-Know Act (EPCRA) industries are held to certain monitoring and reporting NH_3 regulations. Plaintiffs of recent lawsuits under EPCRA assert that the routine airborne emissions of NH_3 from many AFOs exceed the monitoring and reporting thresholds of 100 lb day^{-1} and that any such AFO, including those that have not been monitoring and reporting NH_3 emissions, should be penalized similarly to the industries covered under EPCRA.

Studies have been conducted to measure the amount of NH_3 volatilization from open-air AFOs, urea fertilizer studies, and manure amendments. Shah et al. (2006) wrote a thorough review on measuring NH_3 volatilization emissions in the field. Measurement and collection techniques have included acid scrubbers, filter packs, denuders, or optical methods connected to enclosures or micrometeorological apparatus (Shah et al., 2006).

For chambers used in the field the choice of chamber materials, chamber dimensions, and airflow rates all affect the convective heat transfer and albedo of the system (Shah et al., 2006). Ammonia also sorbs too many surfaces; therefore, the choice of material is important especially when making absolute measurements especially in small concentrations. Shah et al. 2006 summarized that NH_3 sorption was affected by temperature, tubing length, gas concentration. Currently, low density polyethylene and Teflon tubing having the lowest sorption capacities and glass denuders are effective if rinsed. However, more data is required to compare different types of tubing material in a range of temperatures, lengths, and inlet concentrations. Additionally, Shah et al. (2006) summarized chambers have small footprints and high spatial variability which are unsuitable for developing NH_3 emission factors but the chambers could be useful in comparing relative emissions when NH_3 sources are applied uniformly to the surface. For example, enclosures left in the field during rainfall can over estimate NH_3 flux, and removal of enclosure between samplings can decrease the change in environment caused by the chamber (Keuken et al., 1989; Mannheim et al., 1995).

Although chamber techniques are not well suited for measuring NH_3 emissions in the field they can be very useful in the laboratory. Woodbury et al. (2006) designed an inexpensive chamber (<$400) for field and laboratory NH_3 flux emissions using a stainless steel chamber having an internal gas mixing fan. However, Woodbury et al. (2006) did not give a detailed description of how the chamber was used in the laboratory. Sommer and Ersboll (1996) measured NH_3 volatilization from soil by packing soil into cylindrical screw-top plastic jars (10 cm i.d., 16.5 cm in height) leaving a headspace of 189 mL and surface area of 0.0079 m^2. Air was sucked through holes in the sides of the chambers and NH_3 was captured in an acid trap. They found that NH_3 flux ceased to change over an air flow rate of 3.9 L min^{-1} (20 volume exhanges min^{-1}) and that NH_3 loss was exponentially related to initial soil pH (Sommer and Ersboll, 1996). Kissel et al. (2004) packed soil in acrylic plastic cylinders (4.5 cm i.d., 20 cm long), with an air flow rate of 0.1 L min^{-1}, and a fluctuating RH (40% to 95%) treatment. Le Cadre et al. (2005) used a cylindrical glass chamber (55.4 cm^2 cross section, 14.7 cm high) with a head space of 270 cm^3, and an air flow rate of 3.0 L min^{-1} (11 volume exchanges min^{-1}). They found

that air humidity and air flow rate were important contributors to variation in NH_3 flux (Le Cadre et al., 2005).

The above studies using chambers in the laboratory are not always described well, are difficult if not impossible to reproduce, and do not consider all of the variables that need to quantified or controlled to make accurate NH_3 flux measurements, however the the work by Le Cadre et al. (2005) is the most advanced. Therefore, a need still exists to develop and standardize a chamber system for laboratory evaluation of how different surface conditions (i.e., water content, soil type, manure duff layer characteristics, amendments, etc.) will affect volatilization rates. Laboratory studies will allow for statistical control, which is very difficult to obtain in the field. Laboratory studies could also be used to develop and verify mechanistic models of NH_3 volatilization. The objectives of this study were to 1) develop an experiment chamber, 2) perform mass balance testing using the chamber, 3) investigate the effect of humidity on NH_3 volatilizing from soil, 4) and investigate how soil type and soil moisture effect NH_3 volatilization.

Theory

Ammonia volatilization from the soil surface into the atmosphere can be modeled using the approach of Wu et al. (2003) as described in Ham and Parker (2007),

$$J_{s,NH_3} = g_{a,N}\frac{\theta_o}{\theta_s}\left(\frac{K_a K_H}{pH^{-10}}C_{NH_4^+(aq)} - C_{N,a}\right) \qquad (4\text{-}4)$$

where $C_{N,a}$ is the NH_3 concentration of air above the surface (mol mol^{-1}), C_{NH4aq}, is the aqueous NH_3 concentration in the soil (mol mol^{-1}), K_a is the equilibrium constant for the aqueous-gas phase NH_3 reactions, K_H is Henry's constant, θ_o is the soil water content at surface (kg m^{-3}), θ_s is the soil water content at saturation (kg m^{-3}), $g_{a,N}$ is the aerodynamic conductance for NH_3 at the soil surface (m s^{-1}), and pH is soil pH at the aqueous-gas interface.

Aerodynamic conductance, g_a, is dependent on wind speed and the diffusivity of NH_3 in air, which is slightly temperature dependent. The equilibrium constants, K_a and

K_H, are also strongly influenced by temperature. Thus, volatilization at the surface is dependent upon air flow, soil and air temperatures, soil water content, pH, and the concentrations of NH_3 in both the air and soil solution. Furthermore, given soil temperature is dependent on the soil energy balance, flux is also affected by anything impacting convective and latent heat fluxes which would include humidity of the air and solar radiation to the list of governing variables. This equation demonstrates that a chamber system for studying NH_3 volatilization must strive to control or quantify as many of these variables as possible so the process under study can be evaluated.

The effects of environmental variables on NH_3 flux chambers were standardized and controlled by; 1) working in a constant temperature room, 2) measuring g_a as a function of air flow and by maintaining constant and uniform turbulent flow in all chambers, 3) controlling the humidity of the air to standardize drying effects on θ_o and soil temperature, and 4) scrubbing all NH_3 from the incoming air. The remaining variables that affect flux are primarily soil physicochemical properties, which are the variables of interest in this type of study (i.e., soil type, soil amendments, initial water content, NH_4^+ in the soil, soil pH, and other soil chemical properties).

Methods

For all experiments, a vacuum desiccator (Space Saver Vacuum Desiccator, Scienceware, Pequannock, NJ) approximately 17 cm in diameter, was adapted and used as the reaction vessel (Figure 4-1). Singurindy et al. (2006) made modifications to this desiccator for NH_3 and N_2O measurements from sand, however the modifications and implementation techniques for this study were unique. The top half of the desiccator, referred to as cover, is polycarbonate and was modified as follows. The nob at the top of cover was drilled, tapped, and fitted with a 0.635 cm brass hose barb. At the opening on the side, near the bottom edge of the cover, where the open/closed valve was originally fitted, a 0.635 cm brass hose barb was also fitted. On the opposite side from the side hose barb, another 0.635 cm hole was drilled to act as a sensor access port, and was plugged with a stopper when not in use. An acrylic disc was adhered to the inside ledge of the cover with silicone sealant to reduce the volume of head space to 71 cm^3 and provide uniform air mixing over the underlying soil sample. Before the acrylic disc was

inserted, a grid of 21 holes were drilled through it using a #54 drill bit (0.1397 cm) and a layer of clear Teflon tape was adhered to the side of the disc facing the base of the dissector. To allow uniform air flow through the drilled holes, the tape at the edge of each hole was melted away using the tip of a soldering iron.

The base of the desiccator was modified to reduce the volume by inserting an acrylic disc, adhered with silicone sealant, to the inside ledge. On the bottom edge of the base, four small holes were drilled to insert rubber bands that would stretch over the top nob of the cover. The neoprene o-ring that came with the desiccator was placed in the groove on the base, unmodified. To improve the seal of the chamber, vacuum grease was spread on the bottom flange of the cover. Four rubber bands were stretched over the top nob of the cover and small binder clips (4 to 6) were clipped around the edge where the cover and base meet.

A double head pump (Dia-Vac, Model No. 01320T, Airdimensions, Inc, Deerfield Beach, FL) in series was used to create two air lines (Figure 4-2). Each line ran to a relative humidity (RH) treatment. One treatment, 0% RH, included a single 2 L bottle filled 75% full with activated silica gel desiccant and the second treatment, 75% RH, included a series of three bottles, DI H_2O, super saturated NaCl, and an empty reservoir. Two manifolds were assembled, one for each side of the pump. The first was a PVC manifold (schedule 40) having 20 on/off gate valves, only four were utilized. Connected to each gate valve was a series of plastic tubing and fittings to reduce the tubing size to 0.635 cm i.d. (Bev-A-Line IV, 0.635 cm i.d., 0.953 cm o.d., 0.159 cm wall) to connect to the hose barb on the top nob of the chamber cover. A quick disconnect fitting was inserted between the on/off gate valve and the covers' hose barb. The second manifold was made out of 0.953 cm tubing and brass Ts. At each of the three brass Ts there was an on/off gate valve. From the gate valve, 0.635 cm tubing had a quick disconnect fitting and ended at the hose barb at the cover of the chamber. This was referred to as air in. Airflow into each chamber was measured by 10 L min^{-1} ball float flow meters (Model RMA-21, Dwyer Instruments, Inc., Michigan City, ID).

Air exiting the chamber was routed through low density polyethylene (LDPE) tubing to an acid trap made from 240 mL glass bottles filled with 75 mL 0.1 M H_3PO_4. The tubing was threaded through one hole of two in a #7 rubber stopper fitted into the top

of the acid trap bottle. The tubing extended to the bottom of the bottle and included 0.159 cm polypropylene T-fitting at the end to bubble the air through the acid to scrub NH_3 from the air, resulting in aqueous NH_4^+. Ammonia collected in the trap was processed by bringing the volume to 250 mL and then analyzed by cation-exchange chromatography using a Dionex ICS-1000 (Sunnyvale, CA), IonPac CS12A column, and 20 mM methanesulfonic acid eluent. The air coming into the chamber was not initially scrubbed free of NH_3 because a previous experiment (data not reported here) under these same conditions proved it was unnecessary, the room air contained negligible concentrations of NH_3.

Aerodynamic Characteristics

The aerodynamic conductance, g_a, of the chamber was determined using the heat foil technique of McInnes et al. (1994) using the sensors used in the field experiment of Tarara and Ham (1999). This technique determines g_a from the energy balance between a pair of adjacent sensors, heated and unheated, placed flush with the soil surface. A heated sensor and an unheated sensor were installed into one chamber each, so that the sensor surface was equal to that of the soil surface when the chamber was filled with soil. In a 20ºC controlled temperature room, conductance was measured between flows of 2 and 16 L min^{-1} using two different heat flux levels (100 and 200 W m^{-2}). After a change in flow rate or power level, the chamber was allowed to equilibrate for one hour before conductance was computed. A datalogger (23X, Campbell Sci. Inc., Logan, UT) was used to record the output from the conductance sensor, control the power to the heater, and control the air flow rate via a mass flow controller (Mass-Trak, Sierra Instruments Inc., Monterey, CA). The air flow rate, set with the mass flow controller, was also checked with a displacement flow meter.

Mass Balance Testing

Two different treatments were investigated using an inorganic reaction to ensure a complete conversion of NH_4^+ to NH_3 and to eliminate any biological and enzymatic variables. The first treatment included the application of liquid into a Petri dish (100 x 15 mm, polypropylene) with no media. The second treatment was identical to the first except the liquid was applied to a Petri dish filled with glass beads. Glass beads were

used to represent soil, eliminating all chemical and biological variables. For each treatment, three chambers were run at 0% RH and three chambers at 75% RH. For Treatment 1, a Petri dish was sealed inside the chamber using the rubber bands and binder clips. For all experiments using a Petri dish, a Styrofoam insert was used to raise the Petri dish 2.6 cm to the same height g_a was determined. Through the sensor access hole, 25 mL (15 mg) of 33.3 mM NH_4^+ as $(NH_4)_2SO_4$ and 5 mL (840 mg) of 3 M KOH were pipetted into the Petri dish. The chamber was then sealed and connected to the air at 6 L min^{-1} and acid trap for approximately 6 hours. This experiment was replicated three times and the averages and standard deviations were calculated.

For Treatment 2, 85 g of glass beads 10 mm deep (0.43- to 0.60 mm diameter, Agsco Corp., Wheeling, IL) with a bulk density of 1530 kg m^{-3} (Basinger, 1999) were weighed into a Petri dish. Then 5 mL (840 mg) of 3 M KOH was pipetted into the center of the beads and sealed inside the chamber. Through the sensor access hole the N was pipetted into the Petri dish. For Trial 1, 25 mL (15 mg) of 33.3 mM NH_4^+ was added, and for Trial 2 and 3, 15 mL (9 mg) of 33.3 mM NH_4^+ was added, creating moisture contents of 29.4 and 17.6%, respectively. Trial 1 samples, having a moisture content of 29.4% were flooded and liquid pooled on the surface. The chamber was then sealed and connected to the air and acid trap for approximately 22 hours. This experiment was replicated twice and the averages and standard deviations were calculated. The mass balance of the N was conducted at completion of the experiment by summing the N found after rinsing all surfaces inside the chamber, the Petri dish, the glass beads, and the acid trap with DI water.

Soil Media - Effect of Humidity

To investigate the effect of relative humidity on NH_3 volatilization, 70 g of soil at 16.6% soil moisture was packed to a depth of 10 mm into a Petri dish. The Petri dish was then sealed into the chamber. Through the sensor access hole, 10 mL of synthetic urine containing urea (11.5 g L^{-1}), glycine (2.9 g L^{-1}), $KHCO_3$ (13.8 g L^{-1}), KCl (2.5 g L^{-1}), KBr (4.2 g L^{-1}), K_2SO_4 (1.4 g L^{-1}), following deKlein et al. (2003) was pipetted onto the soil surface. If there was complete urea hydrolysis and NH_3 volatilization, then 68.0 mg NH_4^+ was expected to be captured. The chamber was connected the air and acid trap and

acid traps were changed at 2, 6, 24, 48, 72, and 96 hours. Three chambers were at 0% RH and three chambers were at 75% RH. This experiment was repeated three times and averages and standard deviation between repetitions was calculated.

Effect of Soil Type and Water Content

To determine how soil type and synthetic urine application rate affect NH_3 volatilization, two soils and two synthetic urine application rates were used. The two soils used were a Tully (fine, mixed, superactive, mesic Pachic Argiustolls) with a silty clay loam texture and a Haynie (coarse-silty, mixed, superactive, calcareous, mesic Mollic Udifluvents) with a silty loam texture. The soil was treated with 1 M NH_4Cl to saturate the exchange sites, dried, and ground to pass a 2mm sieve. The excess salts were not removed. The soil was mixed to 7.5% soil moisture content and packed to a depth of 2.6 cm, resulting in bulk densities of 1.2 and 1.1 for the Tully and Haynie soils, respectively. For each soil type, chambers 1 thru 3 were treated with 90 mL synthetic urine (de Klien et al., 2003) and chambers 4 thru 6 were treated with 45 mL synthetic urine. The solution was applied by pipette in three concentric circles dividing the total area of application into three equal sections. For the 90 mL and 45 mL application rates, if the urea was completely hydrolyzed and volatilized, 612 mg and 306 mg NH_3 would be produced, respectively. The chamber was then sealed and connected to the air and acid trap. Acid traps were changed at or around 2, 6, 24, 48, 72, 120, 168, 194 hrs. For this experiment, all six chambers were at 75% RH and 20ºC.

Statistics

Statistical analysis was performed for the Mass Balance Testing and Soil Media – Effect on Humidity experiments. In order to establish whether the amount of NH_3 captured was significantly different between humidity treatments, a one-way analysis of variance (ANOVA) was performed using PROC GLM (SAS Version 9.1, SAS Institute Inc. 2002-2003). To test whether chambers were different within humidity treatment, a one way ANOVA was also performed using PROC GLM. The F-test was used to determine significant differences at alpha = 0.05.

Results

Aerodynamic Characteristics

The aerodynamic conductance increased with flow rate as expected and proved to be proportional to the square root of the air exchange rate (Figure 4-3). The fact that g_a was proportional to flow rate is consistent with the theory of forced convection from a flat plate (Campbell and Norman, 1998). Conductance continued to increase, albeit more slowly, at air exchange rates greater than 20 times per minute. These results differ from those of Akiyama et al. (2004) who showed that mass transport from an NH_3 chamber ceased to increase at exchange rates greater than 15 times per minute and are more similar to results by Le Cadre et al. (2005). The aerodynamic conductance of bare soils under field conditions often ranges from 10 to 25 mm s^{-1} depending on wind speed. Operating the chamber at flow rates over 10 L min^{-1} often produced air leaks. Thus, the flow rates for the experiments were set at 8 exchanges min^{-1} (6 L min^{-1}) which produced a conductance of 14.5 mm s^{-1}. This conductance was equal to that measured from bare soils under field conditions with wind speeds of about 2 to 3 m s^{-1} (Tarara and Ham, 1999). Using a model of turbulent transport from a flat plate, sample calculations showed that this level of flow produced a Reynolds number of about 6800 in the chamber; fully turbulent flow is assumed when Reynolds numbers are greater than 3000. Thus, aerodynamic conditions in the chamber were a reasonable approximation of the turbulent transport from a feedlot pen.

Mass Balance Testing

Initial testing of any reaction vessel study should include a mass balance experiment. Therefore, a known amount of N was applied inside the chamber and the fraction recovered in the acid trap was quantified. For Treatment 1 with no media, volatilization of NH_3 occurred immediately and it is suggested that some N was lost through the side hole before it could be plugged. Approximately 89.1 ± 7.0% NH_4^+ was recovered and there was no statistical difference between humidity treatments or between chambers in each humidity treatment (Table B-2). This treatment will not be discussed further because the rate of reaction was too fast to allow for a complete mass balance due to N escaping before the chamber can be sealed. The glass bead media, Treatment 2,

resulted in an average recovery of 96.7 ± 2.2% and there was no statistical difference between humidity treatments or between chambers in each humidity treatment (Table 4-1). The glass bead media slowed down the rate of reaction and subsequent volatilization because the reactants had to diffuse through the pores in the media to react and then the NH_3 had to diffuse to the surface. The two treatments showed that a mass balance of N could be completed, that a porous media slowed down the rate of reaction, that the method had successful repeatability, and the chambers had little variation between them.

Soil Media - Effect of Humidity

To examine the effect of humidity on NH_3 volatilization from soil the flux of NH_3 was measured at 0 and 75% RH. The flux of NH_3 volatilized from the 0% RH treatment was very small (Figure 4-4). Approximately 0.7% of NH_3 applied was captured. The flux of NH_3 volatilized from the 75% RH treatment was significantly different then the 0% RH treatment. The 75% RH treatment had a sigmoidal pattern and about 4.1% of the added urea was volatilized as NH_3. The 0% RH treatment is suggested to have volatilized less NH_3 because of an increased rate of evaporation in comparison to the 75% RH treatment causing a reduced soil moisture content below the level needed for urease hydrolysis, or allowed for a crust to form on the surface reducing diffusion. The sigmoidal curve observed in the 75% RH treatment could be due to the NH_4^+ produced from urea hydrolysis saturating the clay CEC sites. To try and account for NH_4^+ cation exchange site saturation the soils for following studies were pretreated with NH_4Cl to more closely mimic the soil found at a feedlot surface.

Effect of Soil Type and Water Content

The effect of soil type and water content was examined by looking at the NH_3 volatilized from two soil types with two synthetic urine application rates. The 90 mL application rate to the Tully soil had a greater percentage of NH_3 volatilized than from the 45 mL application rate (Figure 4-5). For the 90 mL application rate, about 74.9 mg NH_3 (12.2 %) was recovered and for the 45 mL application rate 29.8 mg NH_3 (9.7%) was recovered. The volatilization rates for the two application rates were also different. The 45 mL application rate had the most rapid loss within the first 24 hours and then the rate exponentially decreased for the remainder of the experiment. In the first 24 hours of the

45 mL application rate, 51% of the total NH_3 volatilized was captured, while only 37% was captured for the 90 mL application rate. The 90 mL application rate had four different rates of volatilization, changing at 24, 48, and 72 hours. The change in volatilization rates could be due to soil cracking, allowing for preferential flow or different stages of evaporation. The difference in volatilization rate for the two treatments is most likely due to soil moisture content changes from evaporation. The 45 mL application rate had less initial moisture, and dried out faster than the 90 mL application rate, which would reduce the moisture available for the urease enzyme to hydrolyze the urea in the urine. Soil surface crusting may have also occurred in the 45 mL application rate reducing or slowing down the escape of NH_3. The pH of the soils was also measured. The urine pH was 8.2, the starting soil pH was 5.4 and the ending pH of the two application rates, 90 mL and 45 mL were 7.3 and 6.2, respectively. This shows the urine treatment, and/or urea hydrolysis raised the pH of the soil, especially seen in the 90 mL application rate where the pH changed the most.

For the Haynie soil, the volatilization trends for the 90 mL and 45 mL application rate were similar, but on a longer time scale than the Tully soil (Figure 4-6). The 90 mL application rate for the Haynie soil had 295 mg NH_3 (48.2 %) captured and the 45 mL application rate had 206 mg NH_3 (67 %) captured in 194 hours. The Haynie soil allowed for greater NH_3 volatilization than the Tully soil when starting with the same amount of urea and moisture content. The 45 mL application rate for the Haynie soil had one rate of volatilization, and had not plateaued by the end of experiment at 194 hours. The 90 mL application rate had multiple volatilization rates, similar to the Tully 90 mL application rate. The changes in volatilization rate occurred at 24, 72, and 194 hours. At 194 hours, it appears there would be another volatilization rate change, similar to the Tully soil experiment. The pH measurements were 7.3 for the starting soil pH, and 7.3 and 7.2 at the end of the 90 mL and 45 mL application rates, respectively. For the Haynie soil, there was not a large pH change, but there was more NH_3 volatilization. The Haynie soil did not have the same soil cracking as the Tully soil. The Tully soil had large cracks appear after approximately 3 days while the Haynie soil only had a few fine cracks at the end of the experiment.

Conclusions

In conclusion, an inexpensive, versatile chamber was developed for use in the laboratory. Mass balance testing showed that 96.7 ± 2.2% of N could be recovered from an inorganic NH_3 volatilization reaction. Preliminary experiments investigating how humidity, synthetic urine application rate, and soil texture influenced NH_3 volatilization found that ammonia flux was greater with 75% RH vs. 0% RH, the coarser soil texture of silt loam compared to a silty clay loam had greater NH_3 flux, and the two synthetic urine application rates had different fluxes and amounts of NH_3 recovered. Further experiments are needed to draw any other conclusions as to the mechanisms of NH_3 volatilization using this chamber.

Further Work

The chamber created is easy to use and can be inserted into various air flow systems. Further research can investigate different humidity treatments by different techniques, such as used by Le Cadre et al. (2005), or other mechanical means such as using a dew point generator. In addition, using an acid scrubber is not the only collection technique that must be used. This chamber could be paired with filter packs, denuders, or optical techniques. Various sensors could also be inserted, such as a soil encapsulated thermocouple to measure the change in surface soil temperature or a soil moisture probe to measure the change is soil moisture over time. The chambers are not restricted to only NH_3 volatilization reactions and can be used to measure other volatile compounds. It is important for the advancement of this research to develop a standard technique in order to be able compare work from different groups to eventually draw accurate and precise conclusions. Further experiments using different soil textures, humidity, initial soil moisture contents, and initial soil pH could be performed to further investigate these variables. The change in pH and soil moisture content over time could also be easily investigated. Once sufficient satisfactory data have been collected using soil as a media, manure could be the next media of investigation. With a manure media all of the same variables investigated for soil can be investigated as well as others including differences in manure collection, storage, and handling. Urine patches could also be investigated as well as repeated applications of urine to the same area, which is what happens at feedlots.

In addition, to just using manure as an experimental media, manure amendments can be studied to aid in NH_3 reduction at open air AFOs. This chamber has promise to provide excellent data to assist the efforts already being made in NH_3 volatilization studies.

References

Akiyama, H. I. P., McTaggart, and B. C. Ball. 2004. N_2O, NO, and NH_3 emissions from soil after the application of organic fertilizers, urea, and water. Water, Air, and Soil Pollution. 156:113-129.

Auvermann, B. 2006. Recent developments in air quality from dairies and cattle feedyards. 21st Annual Southwest Nutrition & Management Conference. February 23-24, 2006. Tempe, AZ. 110-116.

Basinger, J. M. 1999. Laboratory and field evaluation of the dual probe heat-pulse method for measuring soil water content. M.S. Thesis. Kansas State University, Manhattan.

Campbell, G. S., and J. M. Norman. 1998. An introduction to environmental biophysics. 2nd edition. Springer. New York, NY.

deKlein C. M. M., L. Barton, R. R. Sherlock, Z. Li, and R. P. Littlejohn. 2003. Estimating a nitrous oxide emission factor for animal urine from some New Zeland pastoral soils. Aust. J. Soil Res. 41:381-399.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, and D. W. Johnson. 2003. Ecological effects of nitrogen deposition in the western United States. BioScience. 53:404-420.

Ham, J. M., and D. Parker. 2007. Mass and energy balance model of flux chambers used to measure NH_3 volatilization. Trans ASAE. In preparation.

Keuken, M. P., A. Wayers-IJPelaan, J. J. Mols, R. P. Otjes, J. Slanina. 1989. The determination of ammonia in ambient air by an automated thermodenuder System. Atmos. Environ. 23:2177-2185.

Kissel, D. E., M. L. Cabrera, N. Vaio, J. R. Craig, J. A. Rema, and L. A. Morris. 2004. Rainfall timing and ammonia loss from urea in a loblolly pine plantation. Soil Scil Soc. Am. J. 68:1744-1750.

Le Cadre, E., S. Génermont, C. Decuq, S. Recous, and P. Cellier. 2005. A laboratory system to estimate ammonia volatilization. Agron. Sustain. Dev. 25:101-107.

Mannheim, T., J. Braschkat, and H. Marschner, 1995. Measurement of ammonia emission after liquid manure application: II. Comparison of the wind tunnel and the IHF method under field conditions. Z. Pflanzenernaehr. Bodenkd. 158:215-219.

McInnes, K. J., J.L. Heilman, and M. J. Savage. 1994. Aerodynamic conductances along a bare ridge-furrow tilled soil surface. Agric. and For. Meteorology. 68:119-131.

National Research Council of the National Academics. 2003. Air emissions from animal feeding operations current knowledge, future needs. The National Academies Press, Washington D.C.

Oenema, O., A. Bannink, S. G. Sommer, and L. Velthof. 2001. Gaseous nitrogen emissions from livestock farming systems. Pp. 255-289 in Nitrogen in the environment: Sources, problems and management, R. F. Follet, and J. L. Hatfield (des.) Elsevier. 520 pp.

Shah, S. B., P. W. Westerman, and J. Arogo. 2006. Measuring ammonia concentrations and emissions from agricultural land and liquid surfaces: A review. J. Air and Waste Manage. Assoc. 56:945-9460.

Singurindy, O., B. K. Richards, M. Molodovskaya, and T. S. Steenhuis. 2006. Nitrous oxide and ammonia emissions from urine-treated soils: texture effect. Vadose Zone J. 5:1236-1245.

Sommer, S. G., and A. K. Ersboll. 1996. Effect of air flow rate, lime amendments, and chemical soil properties on the volatilization of ammonia from fertilizers applied to sandy soils. Biol. Fertil. Soils 21:53-60.

Tarara, J. M., and J. M. Ham. 1999. Measuring sensible heat flux in plastic mulch culture with aerodynamic conductance sensors. Agric. and For. Meteorology. 95:1-13.

Woodbury, B. L., D. N. Miller, R. A. Eigenbert, and J. A. Nienaber. 2006. An inexpensive laboratory and field chamber for manure volatile gas flux analysis. Trans. ASABE. 49(3):767-772.

Wu, J., D. L. Nofziger, J. G. Warren, and J. A. Hattey. 2003. Modeling ammonia volatilization from surface-applied swine effluent. Soil Sci. Soc. Am. J. 67:1-11.

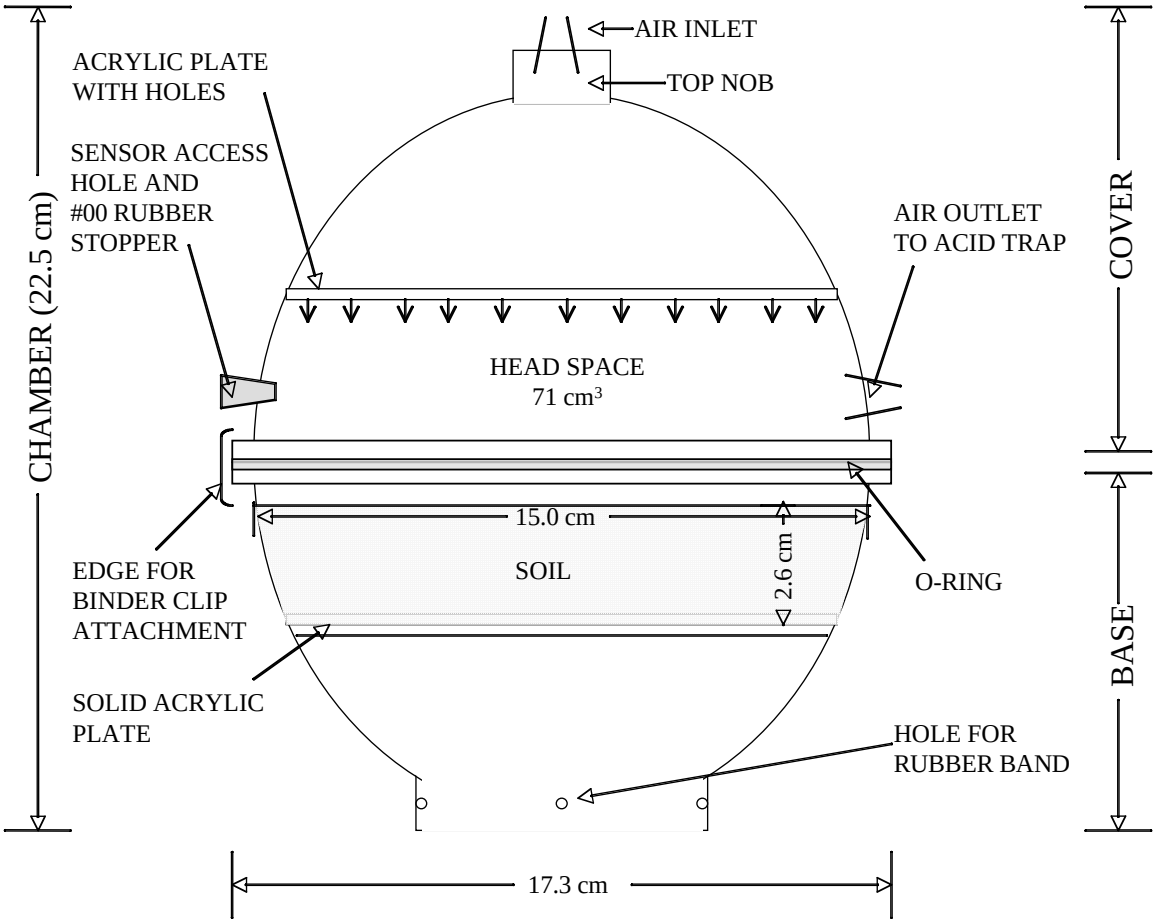

Figure 4-1. Line drawing of the chamber and its modifications. Not drawn to scale.

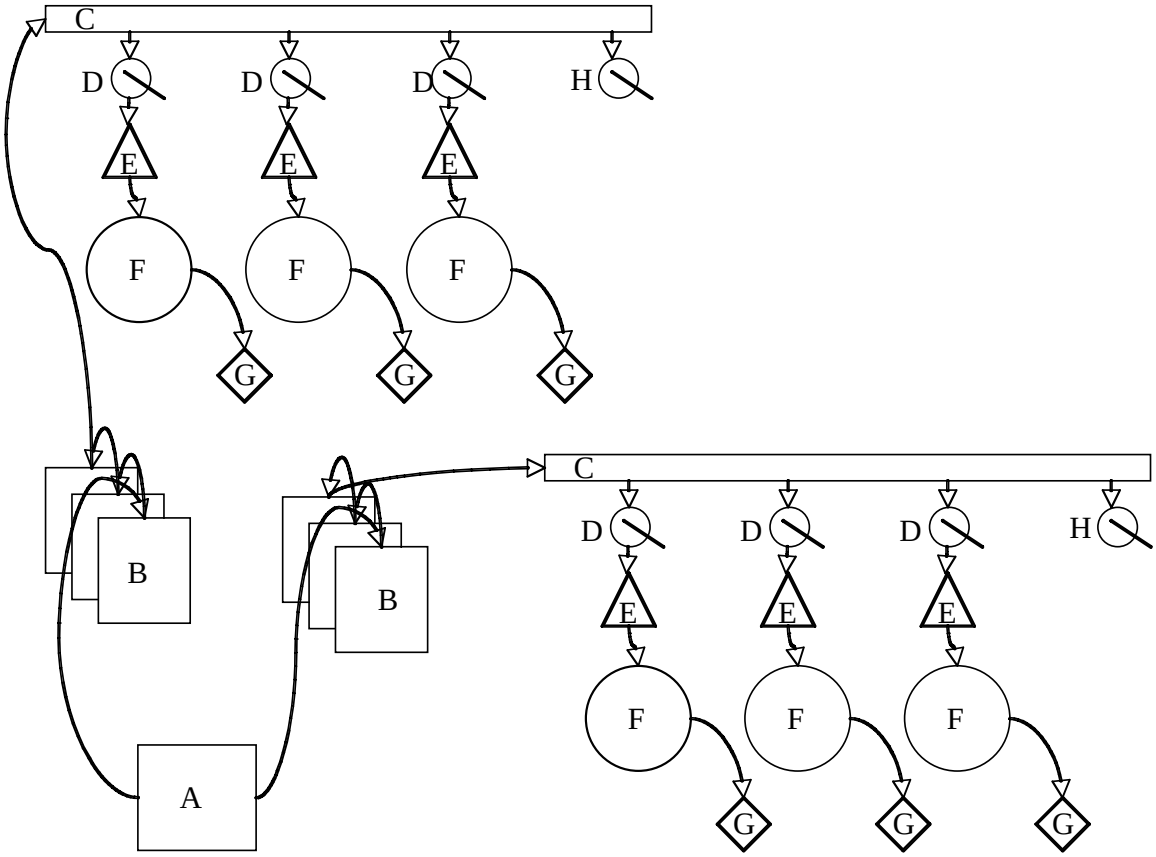

Figure 4-2. Schematic of entire system. (A) is the double head pump in series. (B) is the air treatment showing the 75% RH treatment having three 2 L bottles taped together. The 0% RH treatment would only have one bottle. (C) is the manifold. (D) are the on/off gate valves. (E) is the 10 L min^{-1} flow meter. (F) is the chamber. (G) is the acid trap. (H) is the bleed valve to release extra air.

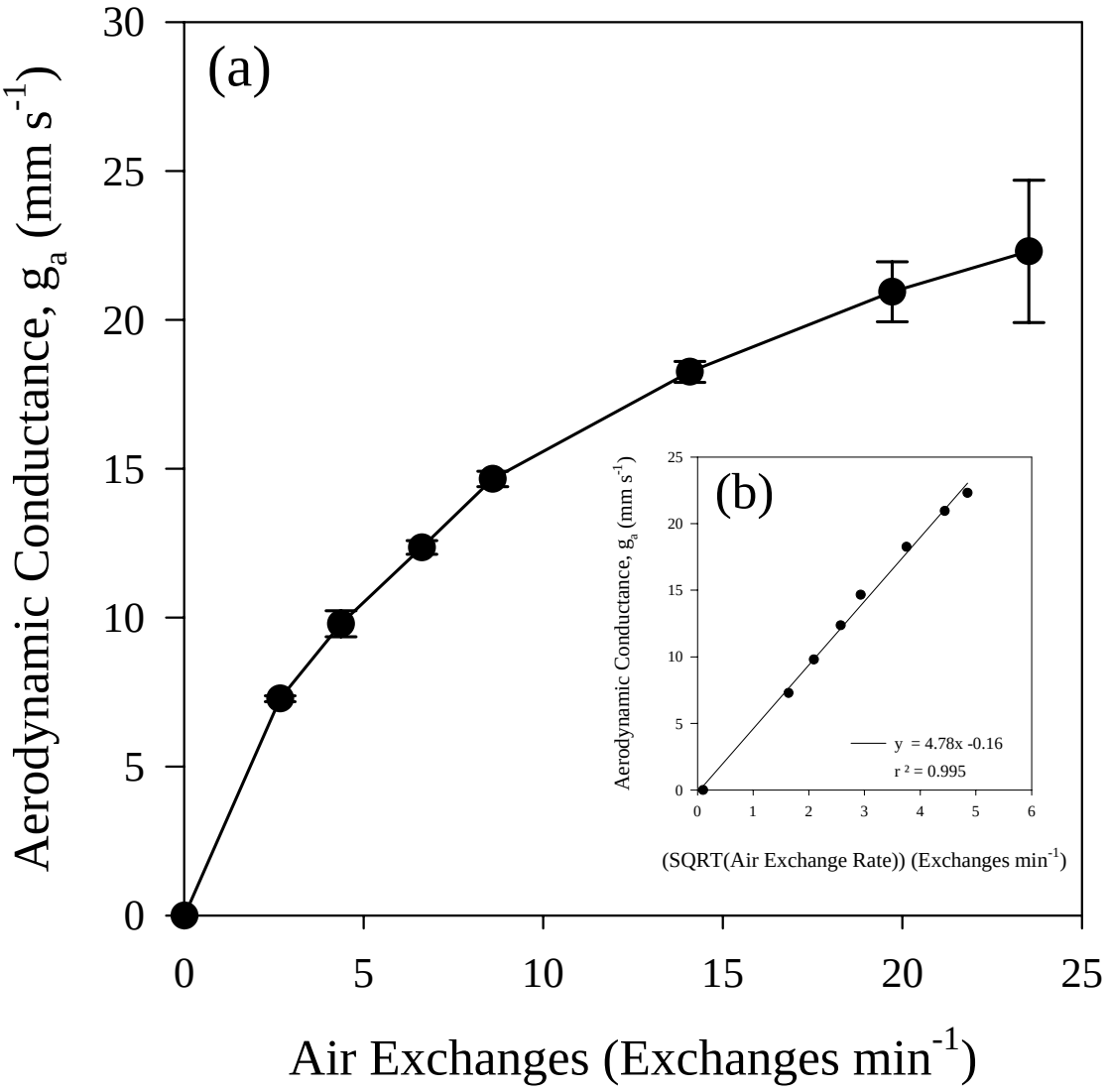

Figure 4-3. Aerodynamic conductance of the chamber. (a) is the number of air exchanges vs g. (b) is the square root of the air exchanges vs g_a. Error bars represent standard deviation.

Table 4-1. Mass balance data of % N recovered during reaction of $(NH_4)_2SO_4$ with KOH where chambers 1 thru 3 had 0% RH and chambers 4 thru 6 had 75% RH. There was no significant difference between RH treatments or between chambers in each RH treatment at alpha = 0.05.

% N Recovered					
	Chamber				
	1	2	3	Average	S.D.
1	93.2	92.3	70.4	85.3	12.9
2	94.4	96.9	95.4	95.5	1.3
3	94.6	98.1	96.9	96.5	1.8
Average*	94.5	97.5	96.1	96.0	1.5
S.D*	0.2	0.8	1.1		
	Chamber				
	4	5	6	Average	S.D.
1	92.6	95.1	94.0	93.9	1.2
2	97.8	95.8	92.8	95.5	2.5
3	98.4	99.7	100.1	99.4	0.9
Average*	98.1	97.8	96.5	97.4	2.7
S.D*	0.4	2.8	5.2		

* Calculations for only Trial 2 and Trial 3.
Grey sections indicate the average and S.D of all four chambers for trials 2 and
RH = Relative Humidity

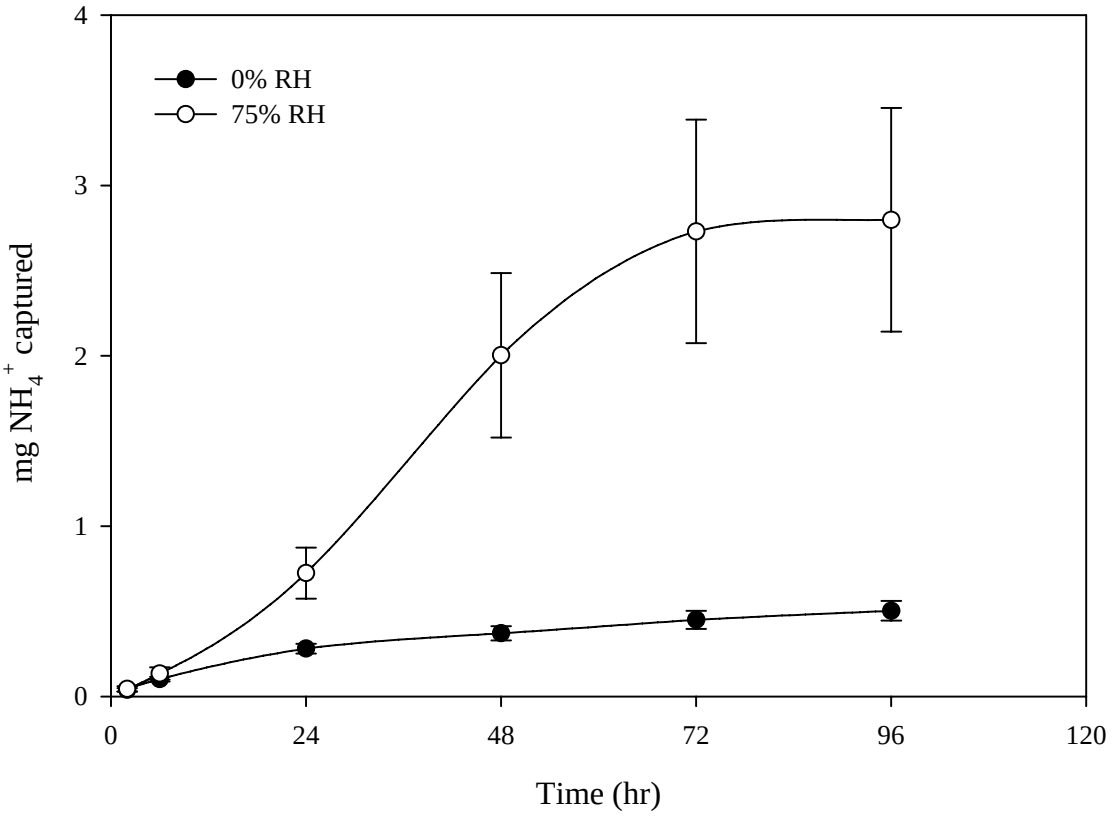

Figure 4-4. Ammonia volatilized and captured as NH_4^+ after 10 mL of synthetic urine was applied to Tully soil packed into a Petri dish. Chambers 1 thru 3 were at 0% RH and chambers 4 thru 6 were at 75% RH. Error bars show the S.D. between chambers for three repetitions for each RH treatment.

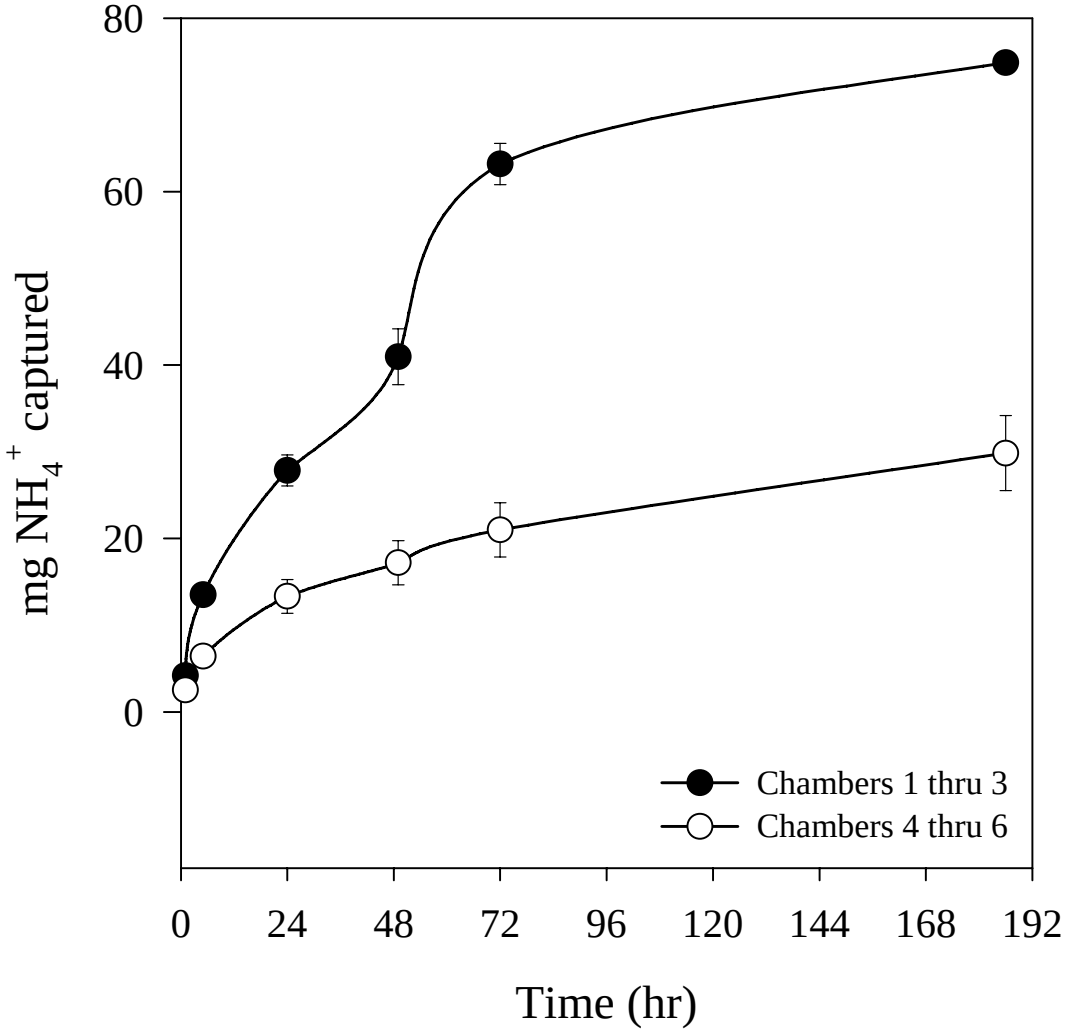

Figure 4-5. Ammonia volatilized and captured as NH_4^+ after synthetic urine was applied to Tully soil packed 2.6 cm deep and bulk density of 1.2 g cm^{-3}. Chambers 1 thru 3 had 90 mL of synthetic urine applied and chambers 4 thru 6 had 45 mL of synthetic urine. The RH for all chambers was 75%. Error bars represent standard deviation.

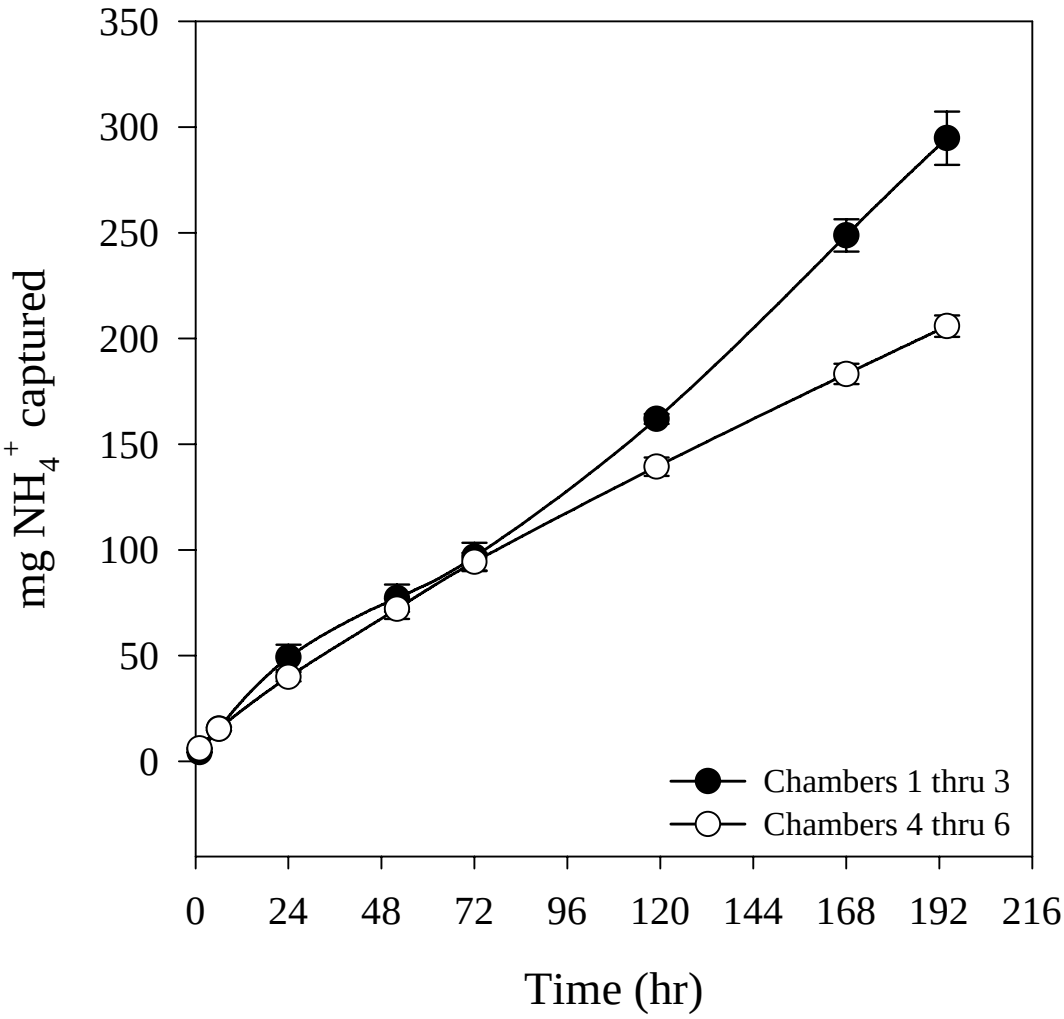

Figure 4-6. Ammonia volatilized and captured as NH_4^+ after synthetic urine was applied to Haynie soil and packed 2.6 cm deep and bulk density of 1.1 g cm^{-3}. Chambers 1 thru 3 had 90 mL of synthetic urine applied and chambers 4 thru 6 had 45 mL of synthetic urine. The RH for all chambers was 75%. Error bars represent standard deviation.

CHAPTER 5 - Conclusions

The survey of select physical and chemical properties beneath pens was completed for four feedlots in Kansas. Based on feeding data, only a small percent (7.9 to 1.2) of the total N deposited on the surface was found in the top 1.00 m below the pen surface for a range of 25 to 60 years of operation. High levels of variability of N, P, Cl^-, and C below each pen on individual feedlots and among feedlots were observed. Ammonium concentrations were high at the surface and rapidly decreased with depth in the first 0.50 to 1.00 m and generally returned to background levels at some depth greater than 1.00 m. Organic-N was high at the surface and rapidly decreased in the first 0.25 m. Nitrate was generally below the background concentration of 4.1 mg NO_3-N kg^{-1} for the entire profile at Feedlots 1, 3, and 4 was most likely due to denitrifying conditions and/or lack of nitrification. At Feedlot 2, NO_3-N was low at the surface, but between the surface and approximately 1.00 m there was an increase in concentration with maximums over 75.0 mg kg^{-1}, before returning to background levels at 1.80 m, suggesting a zone of nitrification. The shapes of Cl^- and P profiles were similar for all feedlots having high concentrations at the surface and rapid decrease in concentration within the first 1.00 and 0.50 m, respectively. The pH profiles for Feedlots 1, 3, and 4 the pH profiles are similar (slightly alkaline to alkaline), while Feedlot 2 had a zone of acidification in the top 1.00 m.

The data found at these Kansas feedlots support the conclusion that soil beneath feedlots do not contribute significant amounts of N and P to groundwater while in use. This conclusion should be useful to argue against the proposal of soil liners being installed at confinement areas before an AFO begins operation. However, if these feedlots were to close, and the soil profile allowed to dry, there is a potential for groundwater contamination via mineralization of PMN or N-leaching. If the surface 0.25 m was removed then 47.8% of the total N would be removed. Further studies into denitrifying conditions and infiltration would be beneficial to increase understanding of soil characteristics beneath cattle feedlots.

An inexpensive, versatile chamber was successfully developed for use in the laboratory. Mass balance testing showed that 96.7 ± 2.2% of N could be recovered from an inorganic NH_3 volatilization reaction. Preliminary experiments investigating how humidity, synthetic urine application rate, and soil texture influenced NH_3 volatilization found that ammonia flux was greater with 75% RH vs. 0% RH, the coarser soil texture of silt loam compared to a silty clay loam had greater NH_3 flux, and the two synthetic urine application rates had different fluxes and amounts of NH_3 recovered. Further experiments are needed to draw any other conclusions as to the mechanisms of NH_3 volatilization using this chamber.

The chamber created is easy to use and can be inserted into various air flow systems. Further research can investigate different humidity treatments by different techniques, such as used by Le Cadre et al. (2005), or other mechanical means such as using a dew point generator. In addition, using an acid scrubber is not the only collection technique that must be used. This chamber could be paired with filter packs, denuders, or optical techniques. Various sensors could also be inserted, such as a soil encapsulated thermocouple to measure the change in surface soil temperature or a soil moisture probe to measure the change is soil moisture over time. The chambers are not restricted to only NH_3 volatilization reactions and can be used to measure other volatile compounds. It is important for the advancement of this research to develop a standard technique in order to be able compare work from different groups to eventually draw accurate and precise conclusions. Further experiments using different soil textures, humidity, initial soil moisture contents, and initial soil pH could be performed to further investigate these variables. The change in pH and soil moisture content over time could also be easily investigated. Once sufficient satisfactory data have been collected using soil as a media, manure could be the next media of investigation. With a manure media all of the same variables investigated for soil can be investigated as well as others including differences in manure collection, storage, and handling. Urine patches could also be investigated as well as repeated applications of urine to the same area, which is what happens at feedlots. In addition, to just using manure as an experimental media, manure amendments can be studied to aid in NH_3 reduction at open air AFOs. This chamber has promise to provide excellent data to assist the efforts already being made in NH_3 volatilization studies.

Appendix A - Data From Soil Profile Survey.

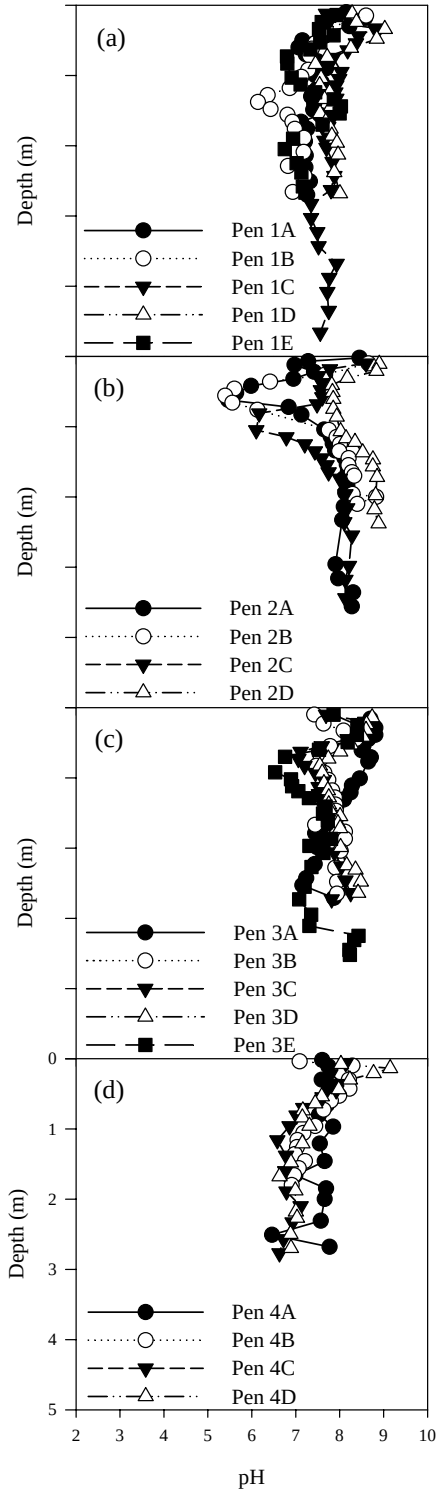

Figure A-1. pH profiles for each feedlot. (a)Feedlot 1, (b) Feedlot 2, (c) Feedlot 3, and (d) Feedlot 4.

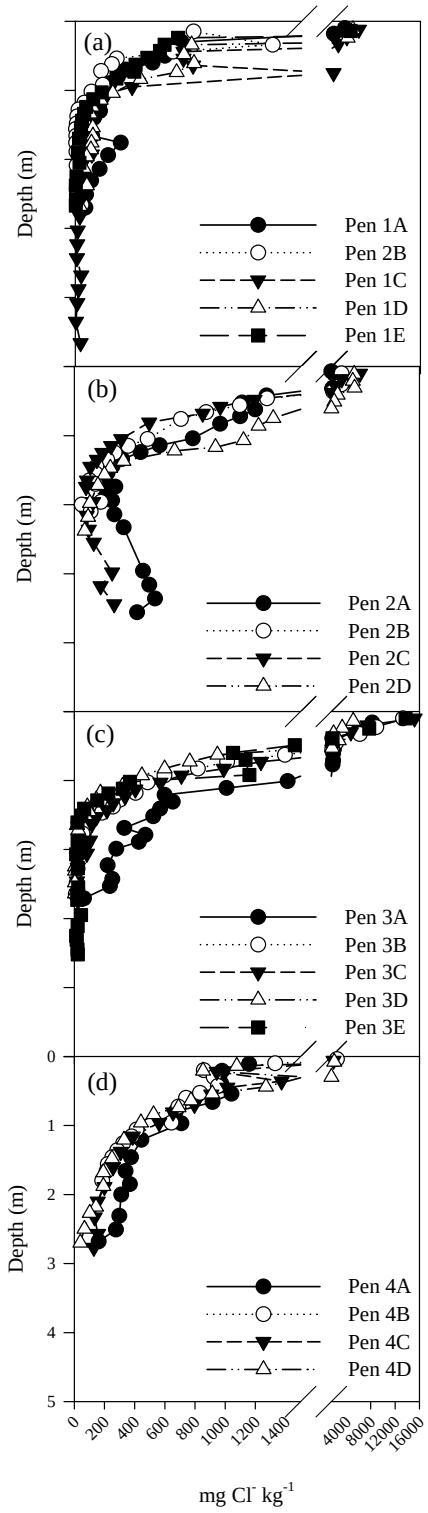

Figure A-2. Chloride profiles for each feedlot. (a) Feedlot 1, (b) Feedlot 2, (c) Feedlot 3, and (d) Feedlot 4

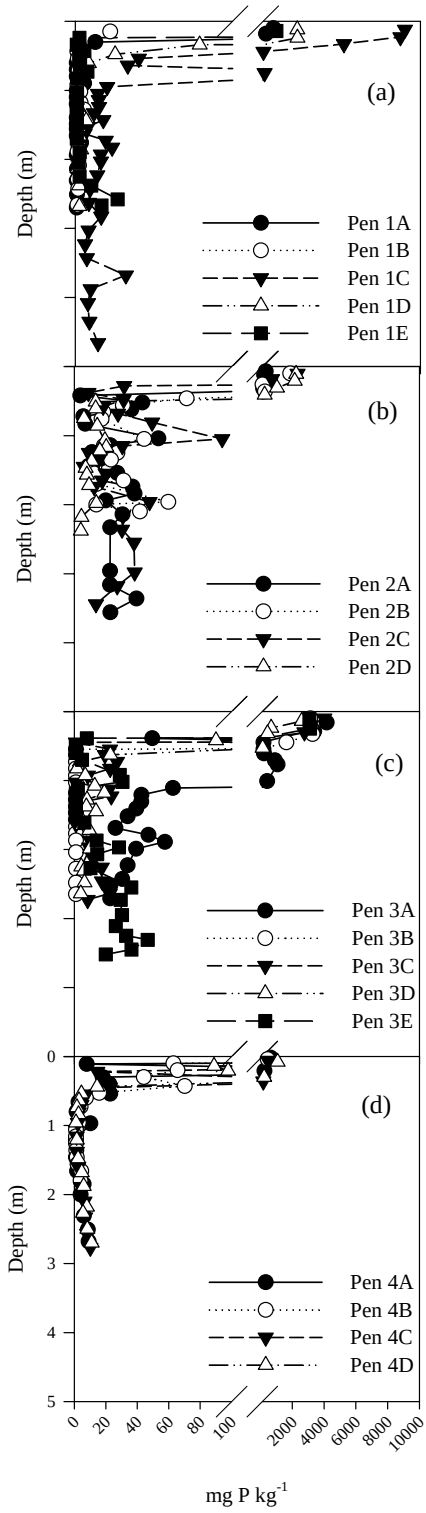

Figure A-3. Phosphorus profiles for each feedlot. (a) Feedlot 1, (b) Feedlot 2, (c) Feedlot 3, and (d) Feedlot 4.

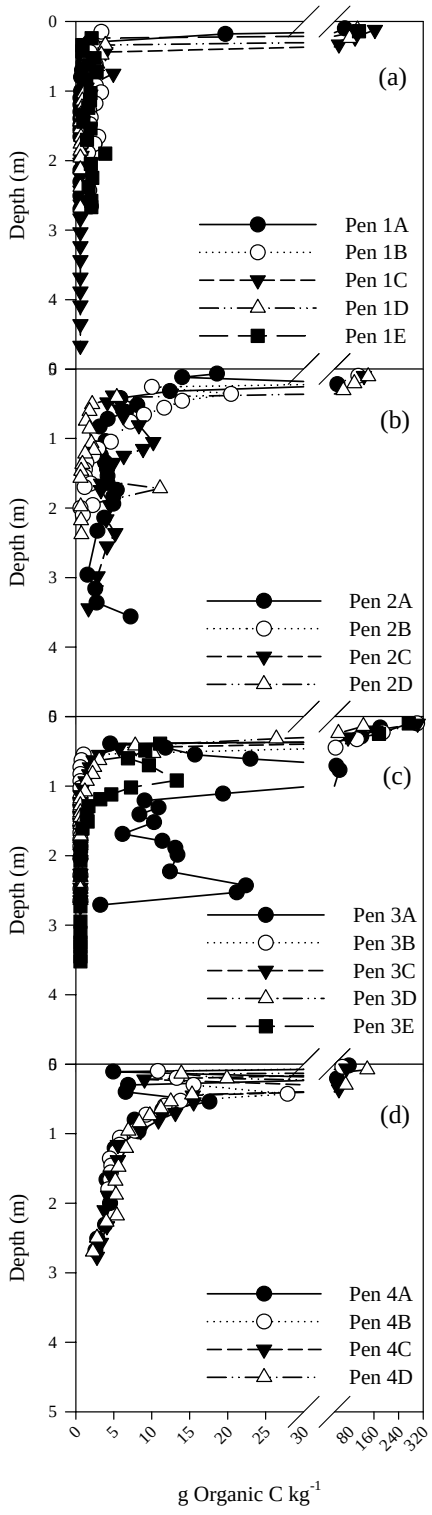

Figure A-4. Organic C profiles for each feedlot. (a) Feedlot 1, (b) Feedlot 2, (c) Feedlot 3, and (d) Feedlot 4.

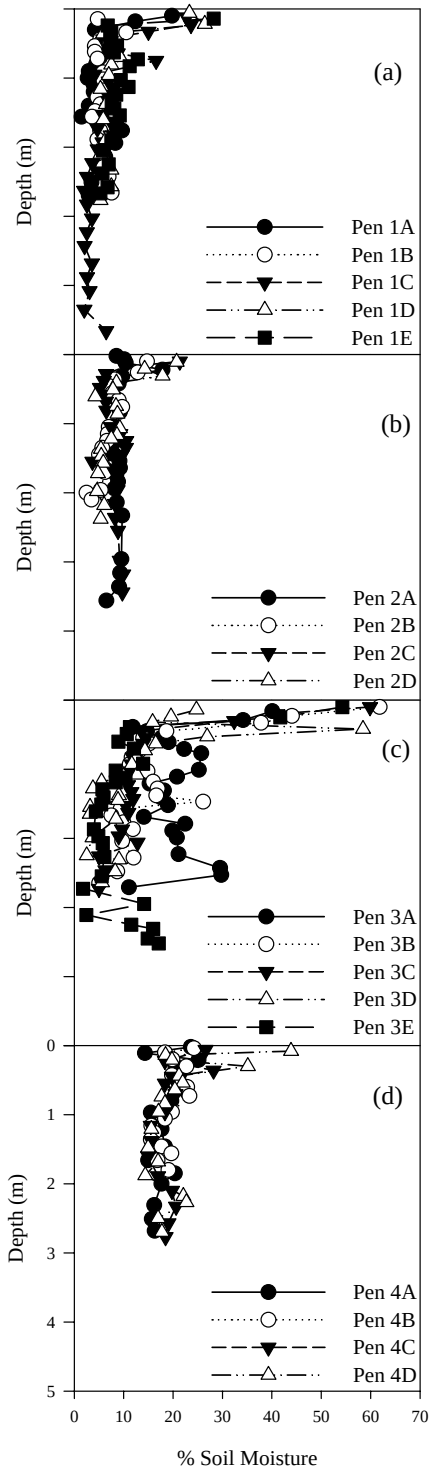

Figure A-5. Percent soil moisture profiles for each feedlot. (a) Feedlot 1, (b) Feedlot 2, (c) Feedlot 3, and (d) Feedlot 4.

Table A-1. Pen 1A data by sample depth of pH, moisture NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 1A									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.10	8.2	19.8	1180	<0.1	4950	6.1	747	3610	64.9
0.18	8.6	12.4	460	0.2	1840	2.3	277	1791	19.7
0.30	8.2	4.2	191	2.1	221	0.4	12.8	705	1.8
0.40	7.6	5.8	143	3.1	277	0.4	1.8	658	1.4
0.50	7.2	7.4	116	4.8	205	0.3	4.4	594	1.0
0.60	7.1	6.1	101	5.7	202	0.3	<1.0	513	1.0
0.70	7.2	5.2	69.9	2.3	165	0.2	<1.0	334	0.8
0.80	7.5	4.4	35.5	1.3	151	0.2	<1.0	285	0.7
0.90	7.7	2.9	26.6	0.3	199	0.2	5.6	228	1.4
1.00	7.5	2.7	7.4	<0.1	165	0.2	1.0	183	0.7
1.10	7.6	3.9	11.4	0.1	145	0.2	<1.0	157	<0.6
1.20	7.5	3.9	5.6	<0.1	147	0.2	<1.0	159	<0.6
1.30	7.4	4.5	4.6	<0.1	120	0.1	3.8	165	<0.6
1.40	7.4	2.9	9.5	0.2	125	0.1	<1.0	124	<0.6
1.49	7.4	3.1	0.3	<0.1	80.2	0.1	<1.0	79.9	<0.6
1.56	7.6	1.5	0.5	<0.1	88.1	0.1	<1.0	49.4	<0.6
1.66	7.1	5.0	0.1	<0.1	173	0.2	<1.0	112	0.6
1.76	7.3	9.6	11.1	<0.1	455	0.5	3.8	302	2.5
1.94	7.2	8.3	6.4	0.6	194	0.2	1.0	219	0.7
2.14	7.2	6.3	1.5	1.6	149	0.2	1.1	163	<0.6
2.31	7.2	5.1	<0.1	1.8	102	0.1	1.0	106	<0.6
2.51	7.3	3.5	<0.1	1.6	83	0.1	1.2	71.9	<0.6
2.70	7.3	2.9	<0.1	3.5	112	0.1	<1.0	67.8	<0.6

Table A-2. Pen 1B data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 1B									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.15	8.6	4.7	374	1.3	455	0.8	22.3	784	3.4
0.34	7.7	10.5	306	16.3	507	0.8	2.3	1310	2.2
0.44	7.7	5.3	63.7	12.7	510	0.6	1.4	649	1.9
0.54	7.4	4.2	12.2	5.0	427	0.4	1.7	275	1.7
0.62	7.4	4.2	11.6	2.7	664	0.7	3.3	244	2.6
0.72	7.3	4.7	7.2	0.9	606	0.6	2.1	172	2.6
0.92	7.3	5.8	27.8	0.4	594	0.6	1.5	184	2.6
1.02	7.1	5.8	21.7	0.4	686	0.7	3.2	107	3.3
1.18	6.9	5.8	14.2	1.0	593	0.6	3.4	61.3	2.6
1.28	6.4	4.7	1.5	0.9	583	0.6	5.5	21.6	1.8
1.38	6.1	5.3	1.6	0.6	518	0.5	2.9	14.1	2.0
1.48	6.4	4.2	1.8	0.7	543	0.5	1.9	9.4	1.9
1.56	6.8	3.6	0.9	<0.1	463	0.5	1.9	4.3	1.7
1.66	6.9	6.4	1.1	<0.1	593	0.6	2.9	6.2	3.0
1.76	7.0	5.2	0.8	<0.1	587	0.6	2.0	5.9	2.5
1.89	7.2	4.7	1.5	<0.1	572	0.6	1.5	7.4	1.6
2.09	7.2	5.9	2.2	<0.1	259	0.3	2.3	8.4	1.7
2.29	6.8	5.8	1.9	<0.1	794	0.8	1.6	28.5	1.4
2.43	7.2	7.0	0.6	<0.1	524	0.5	1.9	10.8	1.8
2.66	6.9	7.6	2.4	<0.1	659	0.7	1.4	41.9	2.0

Table A-3. Pen 1C data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 1C									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.12	7.7	22.8	2153	1.5	10445	12.6	9030	5864	163
0.23	7.8	23.6	2231	0.7	5628	7.9	8750	3906	97.9
0.33	8.8	15.0	740	0.3	3359	4.1	5190	2522	45.6
0.44	8.4	5.9	276	<0.1	322	0.6	127	717	3.9
0.54	8.4	7.1	318	<0.1	208	0.5	40.4	718	2.2
0.64	8.2	8.8	440	<0.1	173	0.6	33.4	782	1.9
0.75	7.9	16.6	544	<0.1	726	1.3	190	1730	4.9
0.95	8.0	4.1	95.0	<0.1	305	0.4	20.4	377	1.4
1.05	8.0	7.0	9.9	<0.1	357	0.4	14.5	215	1.9
1.14	7.9	8.1	7.2	0.5	297	0.3	15.0	185	1.4
1.24	7.9	6.7	11.5	1.5	263	0.3	15.1	161	1.2
1.33	7.9	6.9	2.8	3.2	259	0.3	11.9	160	1.1
1.43	7.9	6.8	2.5	4.6	276	0.3	17.9	102	0.9
1.53	7.8	5.8	1.4	5.9	229	0.2	8.0	84.7	0.7
1.63	7.8	7.4	1.3	7.4	215	0.2	6.0	77.1	0.7
1.73	7.7	4.7	1.9	8.1	231	0.2	19.3	64.9	0.9
1.83	7.7	7.4	1.7	10.6	215	0.2	23.4	77.0	0.8
1.93	7.7	5.7	10.9	11.6	198	0.2	16.4	110.4	0.8
2.03	7.7	4.7	2.8	9.9	205	0.2	16.3	57.2	<0.6
2.23	7.8	3.7	1.5	7.6	134	0.1	14.0	49.1	<0.6
2.43	7.9	2.6	2.5	5.7	145	0.2	9.4	22.8	<0.6
2.63	7.8	2.0	1.0	5.4	121	0.1	8.8	25.2	0.6
2.83	7.4	2.6	2.5	5.3	115	0.1	16.5	30.2	<0.6
3.03	7.4	3.6	0.5	4.1	108	0.1	8.5	16.3	<0.6
3.23	7.5	2.6	0.5	3.6	95.2	0.1	6.3	13.8	<0.6
3.43	7.5	2.1	0.6	2.6	104	0.1	7.4	11.3	<0.6
3.68	7.9	3.6	6.2	2.9	145	0.2	32.3	39.7	<0.6
3.88	7.8	2.6	2.9	1.9	116	0.1	9.8	22.3	<0.6
4.08	7.7	3.1	0.5	1.8	103	0.1	8.0	13.5	<0.6
4.35	7.8	2.1	<0.10	1.1	128	0.1	9.1	4.5	<0.6
4.66	7.6	6.5	0.1	2.6	165	0.2	14.5	34.8	<0.6

Table A-4. Pen 1D data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 1D									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.12	8.3	23.3	1817	1.0	8582	10.4	2250	4914	106
0.24	8.4	26.4	1806	1.0	7573	9.4	2260	4034	80.2
0.34	9.0	5.8	272	<0.1	725	1.0	79.1	771	3.9
0.48	8.8	7.0	446	<0.1	416	0.9	25.4	720	3.4
0.61	8.3	8.2	393	<0.1	546	0.9	8.6	788	2.8
0.74	7.7	9.3	81.7	<0.1	628	0.7	2.3	672	2.1
0.84	7.4	7.5	8.4	<0.1	610	0.6	1.6	431	1.3
1.04	7.6	7.0	6.0	<0.1	532	0.5	1.0	249	1.1
1.14	7.5	5.3	4.0	<0.1	439	0.4	1.0	168	0.9
1.24	7.8	6.4	3.2	<0.1	567	0.6	1.8	114	0.8
1.34	7.7	5.9	2.7	<0.1	397	0.4	1.5	100	0.7
1.44	7.8	6.4	2.6	0.2	389	0.4	7.0	64.3	<0.6
1.54	7.6	5.3	2.7	1.0	397	0.4	2.1	116	<0.6
1.66	7.7	7.5	2.4	2.5	637	0.6	2.8	118	0.7
1.76	7.8	7.5	1.7	3.4	660	0.7	2.0	107	0.6
1.86	7.8	5.3	4.6	3.6	350	0.4	3.8	103	<0.6
1.96	7.9	4.7	2.9	4.3	399	0.4	2.0	75.4	<0.6
2.13	8.0	4.7	1.2	3.8	373	0.4	1.4	56.5	<0.6
2.38	7.9	2.6	2.1	4.0	348	0.4	2.4	77.2	<0.6
2.68	8.0	3.1	1.7	3.9	431	0.4	2.6	31.1	<0.6

Table A-5. Pen 1E data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 1E									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.14	7.9	28.2	2015	1.6	7291	9.3	934.3	4552	111.2
0.24	7.6	6.8	278	<0.1	220	0.5	2.7	682	2.1
0.34	7.5	7.5	285	<0.1	109	0.4	<1.0	592	0.9
0.43	7.9	7.3	187	<0.1	187	0.4	5.8	562	0.9
0.53	7.6	8.7	112	<0.1	340	0.5	2.5	479	2.5
0.63	7.3	8.0	83.2	<0.1	257	0.3	3.1	401	1.7
0.73	6.8	12.8	57.8	<0.1	371	0.4	7.8	392	2.7
0.83	6.8	11.2	29.2	<0.1	269	0.3	1.5	273	1.4
1.03	6.9	9.4	26.6	<0.1	336	0.4	1.2	176	1.9
1.13	7.1	11.0	21.2	<0.1	293	0.3	<1.0	120	1.9
1.24	7.4	8.5	20.2	<0.1	259	0.3	<1.0	72.8	1.6
1.34	7.9	7.6	14.1	<0.1	189	0.2	<1.0	59.6	0.9
1.44	8.0	8.1	15.9	<0.1	195	0.2	<1.0	45.7	1.0
1.54	8.0	9.2	23.6	<0.1	308	0.3	<1.0	37.9	1.9
1.70	7.6	8.6	27.9	<0.1	310	0.3	<1.0	25.1	1.5
1.90	6.9	7.5	29.3	<0.1	455	0.5	2.9	17.6	3.9
2.05	6.8	5.8	29.7	0.1	250	0.3	2.2	27.5	2.0
2.25	7.0	7.0	25.4	0.1	272	0.3	2.8	8.3	2.2
2.38	7.1	5.7	16.6	0.0	234	0.3	10.2	<4.0	1.7
2.58	7.2	6.7	13.5	0.1	302	0.3	26.9	5.4	2.0
2.67	7.2	5.3	8.6	0.2	307	0.3	16.7	<4.0	2.1

Table A-6. Pen 2A data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 2A									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.02	8.5	8.5	43.2	32.2	NS	NS	NS	NS	NS
0.07	7.3	10.1	9.8	72.1	2318	2.4	321	1508	18.6
0.12	7.0	10.4	3.1	168	1719	1.9	225	2100	14.0
0.22	7.4	17.9	8.2	277	5944	6.2	548	3574	40.6
0.32	6.9	9.7	6.5	190	1843	2.0	167	1632	12.4
0.42	6.0	9.0	15.8	182	734	0.9	3.8	1275	5.9
0.52	5.6	7.1	17.6	190	892	1.1	43.3	1113	8.1
0.62	5.5	8.1	17.9	204	838	1.1	36.2	1200	6.6
0.72	6.8	9.2	16.7	188	635	0.8	5.7	1099	4.2
0.83	7.1	9.2	12.0	162	500	0.7	7.0	967	3.1
1.04	7.6	7.9	6.3	115	620	0.7	53.4	786	3.9
1.14	7.8	8.1	3.2	86.2	459	0.5	22.9	566	2.5
1.24	7.8	8.6	1.6	66.7	463	0.5	11.3	439	3.3
1.34	7.9	7.1	2.5	45.8	491	0.5	16.5	317	3.8
1.44	8.1	8.0	0.1	28.1	532	0.6	9.0	254	4.1
1.54	8.2	9.2	1.1	17.3	518	0.5	27.3	220	4.2
1.64	8.2	9.2	1.0	10.2	523	0.5	15.0	201	4.2
1.74	8.1	8.5	1.1	9.8	619	0.6	37.0	272	5.4
1.84	8.2	8.9	1.0	4.7	558	0.6	38.3	217	4.9
1.94	8.1	8.1	0.9	2.7	516	0.5	20.0	250	4.9
2.14	8.1	8.6	1.4	1.9	418	0.4	30.7	266	3.7
2.33	8.1	9.7	0.8	2.0	352	0.4	22.8	327	2.8
2.96	7.9	9.5	0.6	3.2	315	0.3	22.6	455	1.5
3.16	8.0	9.3	3.9	0.7	219	0.2	22.7	497	2.6
3.36	8.3	9.1	1.4	0.3	176	0.2	39.6	535	2.7
3.56	8.3	6.5	18.1	<0.10	176	0.2	23.0	416	7.2

NS = No sample

Table A-7. Pen 2B data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 2B									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.10	8.7	14.7	174	71.7	12005	12.3	1860	3208	109
0.26	7.7	12.8	8.5	510	1327	1.8	125	3174	10.0
0.36	6.4	8.2	13.4	429	2288	2.7	272	1779	20.5
0.46	5.6	7.2	20.4	312	1298	1.6	71.4	1278	14.0
0.56	5.4	7.7	22.6	295	1057	1.4	30.9	1097	11.7
0.66	5.6	9.0	16.0	274	840	1.1	18.5	874	9.0
0.76	6.1	9.7	4.3	220	744	1.0	17.3	707	7.2
1.05	7.8	7.0	7.6	146	601	0.8	44.4	486	4.6
1.15	7.9	6.8	1.2	122	394	0.5	18.7	357	2.9
1.25	8.0	6.6	1.5	90.3	329	0.4	27.4	268	2.3
1.35	8.0	5.6	0.8	77.9	211	0.3	23.3	218	1.4
1.45	8.2	5.0	1.1	52.2	206	0.3	12.8	147	1.2
1.55	8.2	5.5	1.2	49.6	194	0.2	12.8	142	1.2
1.65	8.3	6.1	2.2	36.9	279	0.3	31.2	102	2.0
1.70	8.3	6.2	<0.10	58.8	168	0.2	14.2	141	1.2
1.96	8.3	5.4	2.3	59.3	331	0.4	59.7	176	2.2
2.00	8.8	2.5	4.9	14.7	72.3	0.1	14.0	49.4	<0.6
2.10	8.4	3.5	<0.10	38.7	153	0.2	41.8	108	0.9

Table A-8. Pen 2C data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 2C									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.10	8.6	21.4	233	<0.1	11567	11.8	2330	6234	127
0.18	7.8	10.2	87.3	292	NS	NS	716	3238	NS
0.28	7.5	6.4	16.9	435	NS	NS	31.6	2215	NS
0.38	7.6	6.0	24.5	371	615	1.0	9.0	1604	4.9
0.48	7.6	5.2	0.1	<0.1	849	0.8	31.4	1194	4.2
0.58	7.6	5.6	0.1	<0.1	924	0.9	18.4	967	5.8
0.68	7.5	6.4	0.7	<0.1	974	1.0	27.9	851	6.3
0.81	6.2	6.5	8.0	<0.1	1022	1.0	49.5	497	8.3
1.05	6.1	7.4	<0.1	<0.1	1160	1.2	94.1	311	10.2
1.15	6.8	9.3	<0.1	<0.1	976	1.0	30.6	245	8.9
1.25	7.2	10.5	<0.1	<0.1	754	0.8	9.3	186	6.3
1.35	7.4	10.4	<0.1	<0.1	701	0.7	15.5	150	4.9
1.45	7.6	9.6	<0.1	<0.1	603	0.6	6.0	106	4.0
1.55	7.7	3.7	<0.1	<0.1	NS	NS	20.0	NS	NS
1.65	7.7	7.8	1.0	<0.1	500	0.5	17.7	84.0	3.3
1.74	8.0	8.6	<0.1	<0.1	495	0.5	12.6	77.7	3.3
1.96	8.1	8.7	2.0	<0.1	590	0.6	47.8	125	4.5
2.16	8.2	8.3	0.1	<0.1	510	0.5	31.0	82.1	4.0
2.36	8.1	8.2	6.6	<0.1	563	0.6	30.3	95.9	5.2
2.55	8.3	8.9	0.1	0.5	517	0.5	38.0	129	4.1
2.98	8.2	9.2	8.5	3.2	492	0.5	38.4	250	2.9
3.18	8.1	9.9	6.8	2.4	463	0.5	27.3	174	2.6
3.44	8.1	9.7	7.8	2.3	388	0.4	13.8	265	1.7

NS = No sample

Table A-9. Pen 2D data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 2D									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.11	8.9	20.7	333	<0.1	13367	13.7	2240	5276	141
0.21	8.8	14.2	104	<0.1	10596	10.7	2140	5049	95.6
0.31	8.2	17.9	99.4	2.8	8178	8.3	1020	5328	59.8
0.41	7.8	8.5	90.0	19.2	855	1.0	250	2552	5.4
0.51	7.8	7.8	22.0	48.2	380	0.5	13.6	2001	2.2
0.61	7.9	4.3	4.2	57.5	323	0.4	13.7	1513	1.8
0.75	7.9	8.5	1.0	71.2	255	0.3	6.1	1318	1.3
0.86	7.9	8.7	0.6	74.1	329	0.4	14.6	1221	1.8
1.07	8.0	9.2	1.7	69.3	318	0.4	19.5	1122	2.0
1.17	8.1	8.6	0.3	61.6	293	0.4	20.2	936	2.4
1.22	8.3	7.5	<0.1	44.1	196	0.2	16.3	664	1.2
1.37	8.5	5.4	0.7	18.6	173	0.2	11.0	325	0.9
1.47	8.8	5.4	0.6	12.2	213	0.2	7.2	238	0.7
1.57	8.8	5.8	0.2	8.2	271	0.3	7.9	200	<0.6
1.72	8.9	4.8	0.2	5.3	232	0.2	9.4	156	11.1
1.98	8.8	4.6	0.2	2.5	311	0.3	14.0	104	0.6
2.18	8.8	6.1	3.4	1.8	352	0.4	4.6	91.4	0.7
2.38	8.9	5.3	5.0	0.9	354	0.4	4.2	68.9	0.7

Table A-10. Pen 3A data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 3A									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.16	8.7	40.1	2374	1.9	16324	18.7	4160	8237	180
0.29	8.8	34.2	1660	0.8	10439	12.1	3370	5908	118
0.39	8.8	11.8	581	0.2	278	0.9	49.6	1654	4.5
0.45	8.7	14.7	612	0.1	1078	1.7	183	1757	11.8
0.55	8.5	17.6	663	0.3	1337	2.0	187	1941	15.7
0.61	8.5	19.1	679	0.2	1981	2.7	213	1805	23.0
0.71	8.7	22.2	685	0.2	3845	4.5	894	1823	37.5
0.77	8.7	25.7	760	0.2	5090	5.9	1075	1708	47.3
1.01	8.5	25.2	710	0.1	2740	3.5	410	1414	30.3
1.11	8.3	20.8	626	0.2	1584	2.2	62.7	1009	19.4
1.21	8.3	15.2	474	0.2	766	1.2	42.7	599	9.1
1.31	8.1	18.2	593	0.1	1067	1.7	42.6	652	10.9
1.41	7.9	17.7	415	0.1	805	1.2	39.4	569	8.4
1.52	7.7	19.0	372	0.2	988	1.4	33.9	523	10.3
1.69	7.6	14.1	182	0.1	632	0.8	26.2	331	6.2
1.79	7.4	22.4	226	0.1	1094	1.3	47.2	472	11.4
1.89	7.6	19.8	206	0.1	1194	1.4	57.7	428	13.1
1.99	7.5	20.8	136	0.2	1204	1.3	39.3	279	13.4
2.23	7.4	21.1	85.2	0.1	975	1.1	33.9	221	12.4
2.43	7.2	29.5	91.9	0.1	1568	1.7	30.5	252	22.4
2.53	7.2	29.8	86.3	0.1	1544	1.6	22.8	235	21.2
2.71	7.9	11.1	57.5	0.1	342	0.4	22.7	63	3.2

Table A-11. Pen 3B data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 3B									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.1	7.4	61.8	7936	2.1	16562	24.5	3130	13281	300
0.23	7.6	44.1	4544	1.3	9255	13.8	3140	8912	188
0.33	8.1	37.8	2970	0.9	5819	8.8	3270	6200	104
0.45	8.4	18.6	1390	0.2	2450	3.8	1620	2356	35
0.55	7.8	14.0	980	<0.1	0.0	0.9	<1.0	1675	1.0
0.63	7.5	15.1	687	<0.1	98	0.8	<1.0	1397	0.7
0.73	7.6	13.2	435	0.2	129	0.6	<1.0	1014	<0.6
0.83	7.5	11.6	214	0.2	143	0.4	<1.0	819	<0.6
0.93	7.7	11.2	92.7	0.3	149	0.2	<1.0	597	<0.6
1.03	7.7	14.8	23.6	0.4	102	0.1	<1.0	487	<0.6
1.18	7.8	15.9	7.9	0.6	125	0.1	<1.0	406	<0.6
1.28	7.9	16.9	2.1	0.8	129	0.1	<1.0	301	<0.6
1.38	7.9	16.6	2.2	0.8	140	0.1	<1.0	256	<0.6
1.47	7.9	26.1	2.2	0.5	93.8	0.1	<1.0	182	<0.6
1.57	7.9	9.4	1.1	0.1	58.7	0.1	<1.0	78.5	<0.6
1.67	7.4	7.5	1.2	0.1	138	0.1	<1.0	56.8	<0.6
1.77	8.1	9.9	1.3	<0.1	58.6	<0.06	<1.0	54.1	<0.6
1.87	8.1	11.9	2.2	<0.1	57.7	<0.06	<1.0	38.5	<0.6
2.04	8.0	9.7	1.3	<0.1	58.6	<0.06	<1.0	24.0	<0.6
2.28	7.9	12.0	0.7	0.2	59.1	<0.06	<1.0	21.6	<0.6
2.48	7.9	8.7	0.7	<0.1	59.2	<0.06	<1.0	17.2	<0.6
2.65	7.9	5.0	0.8	<0.1	59.1	<0.06	<1.0	9.9	<0.6

Table A-12. Pen 3C data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 3C									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.1	7.7	59.9	4176	2.1	22022	26.2	4010	15177	302
0.2	8.6	41.1	1320	0.7	14279	15.6	3160	7471	165
0.3	8.4	32.4	809	<0.1	6151	7.0	2760	4722	75.6
0.45	8.2	13.7	550	0.2	580	1.1	1.0	1788	5.7
0.55	7.6	14.4	477	<0.1	450	0.9	22.7	1676	3.1
0.63	7.1	14.0	343	<0.1	435	0.8	19.4	1694	2.3
0.73	7.1	13.3	231	<0.1	347	0.6	27.1	1237	1.8
0.83	7.2	11.8	141	<0.1	327	0.5	22.8	991	1.8
0.93	7.5	11.6	56.6	<0.1	277	0.3	8.5	710	1.3
1.03	7.6	11.5	30.3	0.3	239	0.3	1.0	571	0.9
1.13	7.5	10.5	12.7	0.7	179	0.2	22.0	405	<0.6
1.23	7.5	10.9	3.8	1.3	225	0.2	23.5	336	<0.6
1.33	7.6	11.6	3.2	1.8	193	0.2	1.0	257	<0.6
1.43	7.6	11.9	2.3	2.2	152	0.2	1.0	217	<0.6
1.53	7.8	10.5	1.5	2.2	204	0.2	1.0	147	<0.6
1.63	7.8	10.9	2.3	2.5	198	0.2	1.0	117	<0.6
1.87	7.7	9.7	1.6	2.1	149	0.2	10.1	104	<0.6
1.97	7.5	9.0	3.6	1.9	119	0.1	9.5	78.8	<0.6
2.06	7.9	12.8	1.3	2.4	155	0.2	10.4	82.4	<0.6
2.26	8.0	5.0	0.3	0.9	80	0.1	17.4	23.5	<0.6
2.46	8.1	6.3	0.7	1.0	107	0.1	17.6	17.6	<0.6
2.64	8.3	5.5	4.3	0.5	174	0.2	22.5	19.9	<0.6
2.73	7.8	4.7	0.6	0.1	148	0.1	8.4	22.0	<0.6

Table A-13. Pen 3D data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 3D									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.14	8.7	24.7	1254	1.5	10545	11.8	2590	5130	125
0.24	8.6	19.6	454	1.3	4344	4.8	670	3308	43.9
0.32	8.6	15.8	330	0.2	2850	3.2	435	1882	26.4
0.42	8.5	58.4	948	0.2	91.5	1.0	90.1	2731	7.8
0.53	8.3	26.9	566	<0.1	1044	1.6	124	1615	10.2
0.63	8.0	16.5	386	<0.1	380	0.8	22.9	948	3.1
0.73	7.7	14.3	236	<0.1	327	0.6	3.6	765	2.4
0.83	7.6	12.6	132	<0.1	278	0.4	1.7	598	2.2
0.93	7.6	11.6	71.6	0.2	201	0.3	7.0	448	1.4
1.08	7.6	12.7	17.1	<0.1	196	0.2	12.9	320	1.2
1.18	7.7	5.5	8.0	<0.1	56.8	0.1	19.0	173	<0.6
1.28	7.8	3.8	2.5	<0.1	62.8	0.1	8.1	145	<0.6
1.38	7.8	9.0	1.3	<0.1	58.6	<0.06	7.7	85.9	<0.6
1.45	7.8	8.9	1.0	<0.1	58.9	<0.06	13.8	98.1	<0.6
1.55	8.0	3.2	0.5	<0.1	59.4	<0.06	4.3	24.5	<0.6
1.65	8.0	3.1	1.3	0.2	58.4	<0.06	5.0	17.7	<0.6
1.72	8.0	8.4	1.1	0.1	58.8	<0.06	9.5	26.0	<0.6
1.99	8.0	3.7	3.5	<0.1	56.4	<0.06	9.9	16.7	<0.6
2.25	8.2	2.5	0.8	<0.1	59.1	<0.06	4.4	4.0	<0.6
2.31	8.4	9.1	0.5	0.1	59.3	<0.06	6.0	4.4	<0.6
2.48	8.5	8.3	0.4	<0.1	59.5	<0.06	6.5	<4.0	<0.6
2.64	8.4	5.6	0.4	<0.1	59.5	<0.06	4.2	<4.0	<0.6

Table A-14. Pen 3E data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 3E									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.1	7.9	54.3	690	1.5	21609	22.3	3070	13716	273
0.25	8.4	41.7	362	1.3	13237	13.6	3110	7744	176
0.39	8.4	11.3	697	<0.1	822	1.5	7.9	1710	11.1
0.49	8.2	10.6	864	<0.1	546	1.4	1.0	1462	9.2
0.6	7.5	8.9	497	0.1	652	1.2	1.0	1052	6.9
0.7	6.8	12.1	378	0.1	1312	1.7	5.0	1136	9.6
0.92	6.5	13.9	346	0.1	1414	1.8	29.0	1161	13.3
1.02	6.9	8.4	163	0.1	897	1.1	30.7	369	7.3
1.12	6.9	10.4	130	0.1	592	0.7	2.3	322	4.7
1.19	7.1	8.4	101	<0.1	401	0.5	<1.0	226	3.2
1.29	7.3	5.7	63.9	0.2	194	0.3	<1.0	152	1.7
1.41	7.7	5.9	32.1	0.2	177	0.2	<1.0	65.8	1.4
1.51	7.6	5.5	18.2	0.1	182	0.2	<1.0	46.5	1.6
1.61	7.7	4.4	8.1	<0.1	80.5	0.1	6.4	20.8	0.9
1.87	7.8	4.0	14.3	0.2	49.7	<0.06	14.2	21.4	0.7
1.97	7.3	4.9	8.2	0.3	51.5	<0.06	28.4	40.6	<0.6
2.07	7.6	5.8	2.6	0.2	77.4	0.1	14.6	13.0	<0.6
2.27	7.4	6.1	1.3	0.4	58.3	<0.06	10.3	23.2	<0.6
2.55	7.2	5.6	0.8	2.3	57.0	<0.06	36.2	26.3	<0.6
2.73	7.1	1.8	0.4	1.2	58.4	<0.06	29.5	20.1	<0.6
2.95	7.4	14.1	3.5	6.8	115.8	0.1	30.3	44.4	<0.6
3.11	7.3	2.4	0.9	0.8	58.3	<0.06	26.4	22.1	<0.6
3.25	8.4	11.5	0.8	0.2	58.9	<0.06	32.9	12.4	<0.6
3.31	8.3	16.0	1.3	0.2	58.5	<0.06	46.7	15.4	<0.6
3.45	8.2	14.9	1.2	0.2	58.7	<0.06	36.4	20.4	<0.6
3.52	8.2	17.1	1.5	0.2	58.3	<0.06	20.0	23.4	<0.6

Table A-15. Pen 4A data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 4A									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.02	7.6	23.6	3726	<0.1	4923	8.7	639	NS	77.8
0.11	7.7	14.3	345	0.5	945	1.3	7.8	1159	4.9
0.21	8.0	25.2	45.3	32.9	4472	4.6	244	980	39.3
0.30	7.6	20.5	27.1	6.4	997	1.0	18.0	961	6.9
0.40	7.8	21.3	52.9	1.9	820	0.9	22.3	974	6.6
0.54	7.9	20.5	95.0	0.4	1755	1.9	22.8	1042	17.6
0.66	7.7	22.7	99.1	0.2	1271	1.4	2.7	917	11.4
0.80	7.5	19.6	85.7	0.7	864	1.0	1.4	671	7.7
0.97	7.9	15.5	229.5	0.2	1170	1.4	10.2	710	8.3
1.21	7.6	17.6	17.9	0.1	735	0.8	<1.0	445	5.1
1.46	7.7	18.3	12.1	0.1	705	0.7	<1.0	376	5.1
1.66	7.0	14.9	7.6	0.1	620	0.6	1.8	341	4.0
1.85	7.7	20.4	15.4	0.2	824	0.8	5.9	369	4.4
2.00	7.7	17.6	2.6	<0.1	829	0.8	4.0	310	4.5
2.31	7.6	16.2	2.0	<0.1	796	0.8	6.0	298	3.9
2.51	6.5	15.7	1.6	0.1	684	0.7	8.5	276	2.8
2.68	7.8	16.3	1.3	<0.1	607	0.6	9.2	162	2.6

NS = No sample

Table A-16. Pen 4B data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 4B									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.04	7.1	24.2	2413	0.5	3896	6.3	444	2450	57.0
0.10	8.3	18.3	360	0.6	1229	1.6	63.1	1331	10.8
0.20	8.0	19.9	53.5	3.6	1423	1.5	65.7	858	13.3
0.30	8.2	22.7	105	0.1	1485	1.6	44.2	924	15.5
0.43	8.2	19.8	154	0.1	2456	2.6	70.3	951	27.9
0.53	8.0	20.5	167	<0.1	1143	1.3	15.8	833	13.8
0.60	7.8	22.8	145	<0.1	985	1.1	7.4	740	11.7
0.73	7.6	23.3	105	<0.1	837	0.9	4.0	690	9.3
0.96	7.4	19.8	74.6	0.2	711	0.8	2.9	645	7.8
1.06	7.2	18.3	26.6	<0.1	532	0.6	1.0	414	5.8
1.16	7.0	15.6	16.9	1.0	553	0.6	1.0	380	5.8
1.26	7.0	16.2	9.0	<0.1	570	0.6	1.0	324	5.3
1.36	7.0	15.5	6.0	0.1	482	0.5	1.2	284	4.5
1.46	7.2	17.6	5.7	<0.1	483	0.5	1.6	252	4.7
1.56	7.1	19.6	5.0	0.2	488	0.5	2.1	222	4.6
1.66	7.0	16.9	4.5	0.1	485	0.5	4.5	215	4.5
1.80	6.9	19.0	3.5	<0.1	482	0.5	3.9	184	4.3

Table A-17. Pen 4C data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 4C									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.06	8.1	26.6	1611	<0.1	6279	7.9	465	1891	70.0
0.22	7.8	18.3	66.7	7.8	1075	1.2	14.6	944	9.1
0.36	8.0	28.2	132	10.7	4468	4.6	175	1374	45.9
0.45	7.9	19.8	201	<0.1	1349	1.6	22.7	1014	15.4
0.55	7.6	18.3	220	<0.1	1470	1.7	7.4	909	15.5
0.70	7.2	20.5	203	<0.1	1257	1.5	4.5	796	13.1
0.81	7.0	19.6	98.4	<0.1	1082	1.2	2.7	655	10.9
0.96	6.9	18.3	57.4	<0.1	942	1.0	2.3	563	8.5
1.16	6.6	15.5	11.5	<0.1	675	0.7	1.4	388	5.5
1.38	6.8	15.6	4.8	<0.1	821	0.8	1.5	307	5.5
1.60	6.8	14.9	2.9	<0.1	635	0.6	2.5	256	4.6
1.89	6.8	17.0	0.9	<0.1	700	0.7	4.3	200	4.2
2.10	7.1	19.8	0.2	<0.1	594	0.6	6.5	155	3.8
2.33	6.9	20.6	<0.1	0.9	633	0.6	6.9	135	4.1
2.57	6.7	19.0	<0.1	1.4	759	0.8	8.1	157	3.3
2.77	6.6	18.5	<0.1	1.6	707	0.7	10.2	130	2.8

Table A-18. Pen 4D data by sample depth of pH, moisture, NH_4-N, NO_3-N, organic-N, total N, P, Cl^-, and organic C, and texture.

Pen 4D									
Lower Depth	pH	Moisture	NH_4-N	NO_3-N	Organic-N	Total N	P	Cl^-	Organic C
m		%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
0.08	8.0	43.9	1126	2.4	12572	13.7	1070	2001	138
0.14	9.2	18.5	197	0.4	1743	1.9	88.8	1078	13.9
0.21	8.8	19.8	312	1.5	2366	2.7	97.8	852	19.9
0.30	8.2	35.1	211	3.2	6516	6.7	221	1519	67.6
0.44	8.0	21.2	128	0.3	1522	1.7	14.5	1270	15.3
0.54	7.6	22.0	126	0.2	1384	1.5	4.5	915	12.5
0.64	7.4	20.4	120	<0.1	1170	1.3	2.9	773	11.2
0.74	7.2	17.6	103	<0.1	1147	1.3	1.6	691	9.8
0.84	7.2	18.3	77.9	0.1	1022	1.1	2.7	525	8.4
0.96	7.3	17.1	42.5	0.2	943	1.0	<1.0	442	6.9
1.21	7.2	15.6	10.5	0.1	894	0.9	1.5	329	6.6
1.48	6.9	14.9	5.6	0.1	850	0.9	2.4	249	5.6
1.68	6.6	17.0	3.9	0.1	709	0.7	4.7	193	5.2
1.88	7.0	14.4	10.0	0.3	777	0.8	5.9	193	5.3
2.18	7.0	22.1	7.8	0.1	784	0.8	7.9	144	5.4
2.27	7.0	22.7	2.1	0.2	605	0.6	5.5	102	4.0
2.50	6.9	17.0	0.5	<0.1	498	0.5	8.2	67.3	2.8
2.70	6.9	17.8	0.7	0.3	430	0.4	11.0	38.8	2.2

Table A-19. Pen 1A clay, silt, and sand particle size analysis and soil texture class.

Pen 1A				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.10 0.18	16	25	59	sandy loam
0.30	5	10	84	loamy sand
0.40 0.50 0.60 0.70	8	9	84	loamy sand
0.80 0.90 1.00 1.10	5	6	88	sand
1.20 1.30 1.40 1.49	5	6	88	sand
1.56	NS	NS	NS	NS
1.66	8	3	89	sand
1.76 1.94	21	15	64	sandy clay loam
2.14 2.31	8	8	85	loamy sand
2.51 2.70	5	4	91	sand

NS = No Sample

Table A-20. Pen 2A clay, silt, and sand particle size analysis and soil texture class.

Pen 1B				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.15	15	14	71	sandy loam
0.34	20	33	47	loam
0.44 0.54 0.62	8	13	79	loamy sand
0.72 0.92 1.02 1.18	8	13	79	loamy sand
1.28 1.38 1.48 1.56	4	6	90	sand
1.66 1.76 1.89	6	7	87	loamy sand
2.09 2.29 2.43	6	7	86	loamy sand
2.66	6	11	82	loamy sand

Table A-21. Pen 1C clay, silt, and sand particle size analysis and soil texture class.

Pen 1C				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.12	10	43	47	loam
0.23	12	29	59	sandy loam
0.33 0.44	13	10	77	sandy loam
0.54 0.64 0.75	18	12	70	sandy loam
0.95 1.05 1.14	11	13	77	sandy loam
1.24 1.33	13	14	74	sandy loam
1.43 1.53 1.63	13	9	78	sandy loam
1.73 1.83 1.93 2.03	6	15	79	loamy sand
2.23 2.43 2.63	6	1	93	sand
2.83 3.03 3.23 3.43 3.68	5	0	94	sand
3.88 4.08 4.35 4.66	4	6	90	sand

Table A-22. Pen 1D clay, silt, and sand particle size analysis and soil texture class.

Pen 1D				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.12 0.24	12	28	60	sandy loam
0.34	6	12	82	loamy sand
0.48	9	14	77	sandy loam
0.61	13	19	68	sandy loam
0.74	15	22	63	sandy loam
0.84 1.04 1.14 1.24 1.34 1.44 1.54 1.66	11	18	71	sandy loam
1.76 1.86 1.96 2.13	11	12	77	sandy loam
2.38	6	11	83	loamy sand
2.68	6	7	87	loamy sand

Table A-23. Pen 1E clay, silt, and sand particle size analysis and soil texture class.

Pen 1E				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.14	15	35	49	loam
0.24 0.34 0.43	9	10	82	loamy sand
0.53 0.63 0.73 0.83 1.03 1.13 1.24	9	11	80	loamy sand
1.34 1.44 1.54 1.70	9	11	80	loamy sand
1.90 2.05	4	14	82	loamy sand
2.25 2.38	6	9	85	loamy sand
2.58 2.67	6	9	85	loamy sand

Table A-24. Pen 2A clay, silt, and sand particle size analysis and soil texture class.

Pen 2A				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.02	NS	NS	NS	NS
0.07	NS	NS	NS	NS
0.12	27	62	11	silty clay loam
0.22	25	57	18	silt loam
0.32 0.42 0.52 0.62 0.72	32	50	18	silty clay loam
0.83 1.04 1.14	34	51	15	silty clay loam
1.24 1.34	27	55	18	silty clay loam
1.44 1.54 1.64	30	48	22	clay loam
1.74 1.84 1.94	29	47	23	clay loam
2.14 2.33	30	45	25	clay loam
2.96 3.16	30	35	35	clay loam
3.36	37	27	36	clay loam
3.56	25	29	46	loam

NS = No sample

Table A-25. Pen 2B clay, silt, and sand particle size analysis and soil texture class.

Pen 2B				
Lower	Clay	Silt	Sand	Texture
m	%	%	%	
0.10 0.26	41	40	19	clay loam
0.36	23	58	19	silt loam
0.46 0.56 0.66	25	52	23	silt loam
0.76	30	40	30	loam
1.05 1.15	29	35	36	clay loam
1.25 1.35 1.45 1.55 1.65 1.70 1.96 2.00	20	35	46	sandy loam
2.10	15	21	64	sandy loam

Table A-26. Pen 2C clay, silt, and sand particle size analysis and soil texture class.

Pen 2C				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.10	25	42	33	loam
0.18	16	46	38	loam
0.28	29	43	28	clay loam
0.38				
0.48	29	40	31	clay loam
0.58	NS	NS	NS	NS
0.68	31	47	23	clay loam
0.81	27	52	21	silt loam
1.05	27	48	25	clay loam
1.15	29	46	24	clay loam
1.25	32	51	17	silty clay loam
1.35				
1.45	33	49	18	silty clay loam
1.55				
1.65				
1.74				
1.96	30	52	18	silty clay loam
2.16				
2.36				
2.55				
2.98				
3.18				
3.44				

NS = No sample

Table A-27. Pen 2D clay, silt, and sand particle size analysis and soil texture class.

Pen 2D				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.11 0.21	16	50	34	silt loam
0.31	33	29	37	clay loam
0.41 0.51 0.61 0.75	23	53	24	silt loam
0.86 1.07 1.17 1.22 1.37	32	35	33	clay loam
1.47 1.57	22	43	35	loam
1.72 1.98	22	46	32	loam
2.18 2.38	29	46	24	loam

Table A-28. Pen 3A clay, silt, and sand particle size analysis and soil texture class.

Pen 3A				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.16	6	68	26	silt loam
0.29	8	39	52	silt loam
0.39 0.45	9	41	49	loam
0.55 0.61	10	33	57	sandy loam
0.71 0.77	2	25	72	sandy loam
1.01	3	36	62	sandy loam
1.11 1.21 1.31 1.41 1.52	14	23	62	sandy loam
1.69	14	12	74	sandy loam
1.79 1.89 1.99 2.23	17	21	62	sandy loam
2.43 2.53	18	23	59	sandy loam
2.71	13	16	71	sandy loam

Table A-29. Pen 3B clay, silt, and sand particle size analysis and soil texture class.

Pen 3B				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.1 0.23	9	74	17	silt loam
0.33 0.45	13	41	45	loam
0.55 0.63	21	48	31	loam
0.73 0.83 0.93 1.03 1.18	20	39	41	loam
1.28 1.38 1.47	21	43	36	loam
1.57 1.67 1.77 1.87 2.04	11	19	70	sandy loam
2.28	13	25	62	sandy loam
2.48 2.65	6	15	79	loamy sand

Table A-30. Pen 3C clay, silt, and sand particle size analysis and soil texture class.

Pen 3C				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.1	13	65	22	silt loam
0.2 0.3	9	48	44	loam
0.45	30	45	25	clay loam
0.55 0.63	28	35	37	clay loam
0.73 0.83 0.93 1.03 1.13 1.23 1.33 1.43 1.53 1.63 1.87	18	25	57	sandy loam
1.97 2.06	18	16	66	sandy loam
2.26 2.46 2.64	6	7	87	loamy sand
2.73	4	7	88	sand

Table A-31. Pen 3D clay, silt, and sand particle size analysis and soil texture class.

Pen 3D				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.14	13	39	48	loam
0.24 0.32	17	41	42	loam
0.42 0.53	27	42	31	clay loam
0.63 0.73 0.83 0.93 1.08	21	33	46	loam
1.18 1.28 1.38 1.45	9	20	71	sandy loam
1.55 1.65	0	8	92	sand
1.72	2	16	82	loamy sand
1.99	1	5	94	sand
2.25	1	3	96	sand
2.31	11	6	83	loamy sand
2.48	6	7	86	loamy sand
2.64	2	3	95	sand

Table A-32. Pen 3E clay, silt, and sand particle size analysis and soil texture class.

Pen 3E				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.1 0.25	14	50	36	loam
0.39	25	41	34	loam
0.49 0.6	18	31	51	loam
0.7 0.92	18	35	46	sandy clay
1.02 1.12 1.19	13	19	68	sandy loam
1.29 1.41	11	13	76	sandy loam
1.51 1.61 1.87	6	14	79	loamy sand
1.97 2.07 2.27 2.55	9	15	77	sandy laoam
2.73	5	0	96	sandy loam
2.95	25	38	37	loam
3.11	16	31	52	sandy loam
3.25	39	2	59	sandy clay loam
3.31	10	39	51	sandy clay loam
3.45	7	29	64	sandy loam
3.52	20	29	51	sandy clay loam

Table A-33. Pen 4A clay, silt, and sand particle size analysis and soil texture class.

Pen 4A				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.02	NS	NS	NS	NS
0.11 0.21	31	51	18	silty clay loam
0.30 0.40	38	55	6	silty clay loam
0.54 0.66	56	30	14	clay
0.80 0.97	54	36	10	clay
1.21 1.46	51	40	8	clay
1.66 1.85 2.00 2.31	38	56	6	silty clay loam
2.51 2.68	42	54	4	silty clay

NS = No sample

Table A-34. Pen 4B clay, silt, and sand particle size analysis and soil texture class.

Pen 4B				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.04	NS	NS	NS	NS
0.10	34	33	33	clay loam
0.20	39	28	32	clay loam
0.30				
0.43	31	23	46	sandy clay loam
0.53	36	34	31	clay loam
0.60				
0.73	43	44	12	silty clay
0.96	42	42	16	silty clay
1.06	46	41	13	silty clay
1.16				
1.26				
1.36				
1.46				
1.56				
1.66				
1.80				

NS = No Sample

Table A-35. Pen 4C clay, silt, and sand particle size analysis and soil texture class.

Pen 4C				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.06	16	67	16	silt loam
0.22	26	58	16	silt loam
0.36 0.45 0.55	20	60	21	silt loam
0.70 0.81	26	54	20	silt loam
0.96	26	54	20	silt loam
1.16 1.38	28	54	19	silt loam
1.60 1.89	23	64	14	silt loam
2.10 2.33	24	63	13	silt loam
2.57 2.77	28	62	10	silty clay loam

Table A-36. Pen 4D clay, silt, and sand particle size analysis and soil texture class.

Pen 4D				
Lower Depth	Clay	Silt	Sand	Texture
m	%	%	%	
0.08	54	5	41	clay
0.14	NS	NS	NS	NS
0.21	56	29	15	clay
0.30	35	42	23	clay loam
0.44	46	45	9	silty clay
0.54 0.64 0.74 0.84	45	47	8	silty clay
0.96 1.21 1.48	44	51	6	silty clay
1.68 1.88 2.18 2.27	38	59	3	sandy clay
2.50 2.70	29	53	18	sandy clay loam

NS = No Sample

Table A-37. Table of soil textures by horizon for each pen at Feedlot 1, Feedlot 2, Feedlot 3, and Feedlot 4. The abbreviated soil texture names are s = sandy, sl = sandy loam, ls = loamy sand, l = loam, sil = silty loam, sicl = silty clay loam, cl = clay loam, sc = sandy clay, sic = silty clay, c = clay.

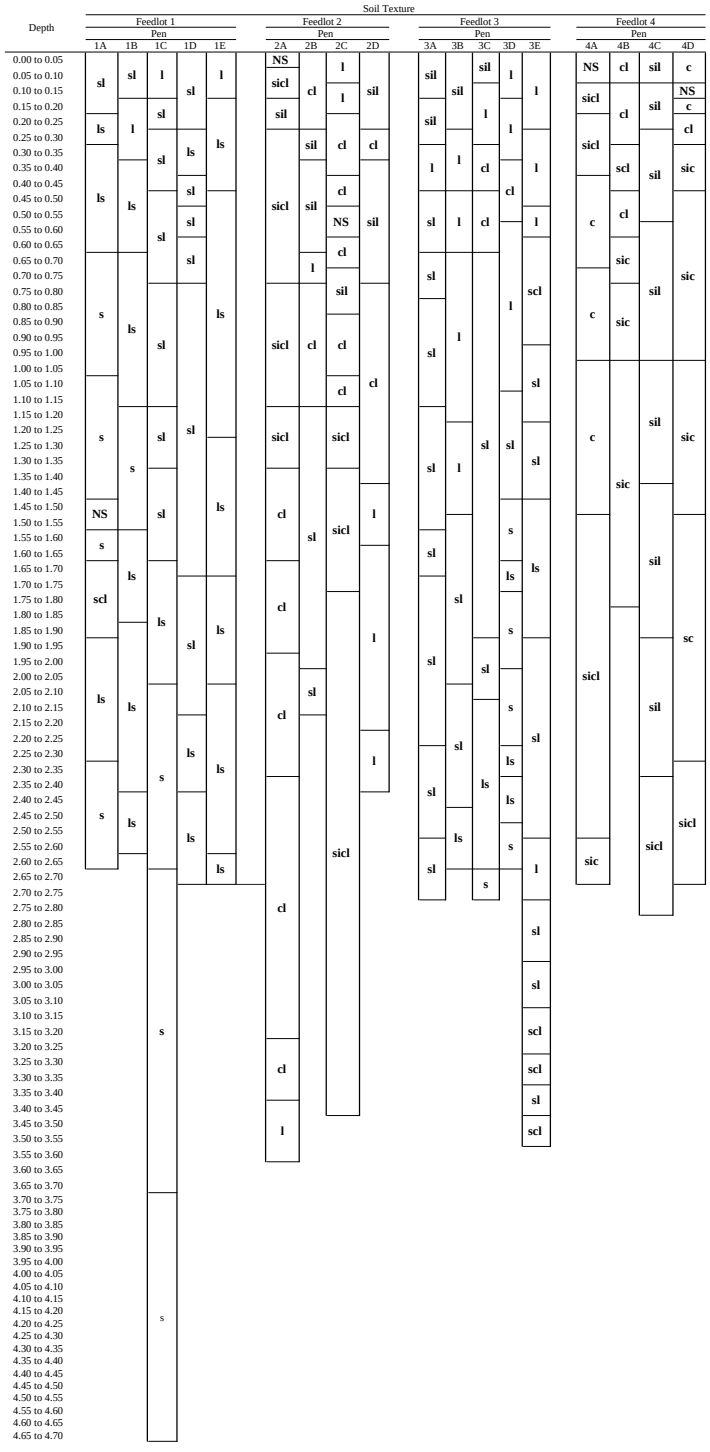

Table A-38. Notes from soil core description for Pen 1A.

Pen 1A							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 18	L1	7.5YR 4/2	pl	sandy loam			
18 - 30	A	7.5YR 4/4	m	loamy sand			
30 - 70	Bt1	7.5YR 4/6	m	loamy sand			
70 - 110	Bt2	7.5YR 4/4	m	sand			
110 - 149	BE1	7.5YR 5/4	m	sand			
149 - 156	BE2	7.5YR 6/4	sg	NS			
156 - 166	BE3	7.5YR 5/6	m	sand			
166 - 184	2Bt	7.5YR 4/4	m	sandy clay loam			
184 - 231	C1	7.5YR 5/6	sg	loamy sand			
132 - 270	C2	7.5YR 6/6	sg	sand			
Date Sampled		3/17/10					
Date Described		6/24/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-39. Notes from soil core description for Pen 1B.

Pen 1B							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 15	L1	10YR 4/4	pl	sandy loam			
15 - 34	L2	10YR 4/2	pl, abk	loam			
		10YR 4/6					
34 - 62	L3	10YR 4/2	m	loamy sand			
		10YR 4/6					
62 - 118	Bw	10YR 4/6	csbk	loamy sand			
118 - 156	C	10YR 4/4	m	sandy loam			
156 - 189	2Ab	10YR 3/3	csbk	loamy sand			
189 - 243	2C1	10YR 4/4	sg	loamy sand			
243 - 266	2C2	10YR 4/4	sg	loamy sand			
Date Sampled		3/17/10					
Date Described		4/20/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-40. Notes from soil core description for Pen 1C.

Pen 1C							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 12	L1	10YR 2/1	plδ	loam			
12 - 33	L2	10YR 2/2	mε	sandy loam			
33 - 44	L3	10YR 4/1	m	sandy loam			
44 - 75	1Bt1	10YR 4/2	pl	sandy loam			
75 -114	1Bt2	10YR 4/4	pl	sandy loam			
114 -133	2Bt1	10YR 4/6	m	sandy loam			
133 - 163	2Bt2	7.5YR 4/6	m	sandy loam			
163 - 203	3Bt1	7.5YR 5/6	m	loamy sand			
203 - 263	3Bt2	7.5YR 6/6	m	sand			Lamelle, 7.5YR 4/6, 210-211, 216-217, 221-222, 229-230, 226-227, 241-241, 243-244, 250-251, and 253-254
263 - 343	3Bt3	7.5YR 6/6	m	sand			Lamelle, 7.5YR 4/6, 271-272, 2278-279, 290-291, 298-299, 310-311, 321-322, and 328-329
343 - 466	C	10YR 5/6	m	sand			
Date Sampled		3/17/10					
Date Described		7/17/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-51. Notes from soil core description for Pen 1D.

Pen 1D							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 24	L1	10YR 2/2	plδ	sandy loam			
24 - 34	L2	10YR 4/2	pl	loamy sand			
34 - 48	A	10YR 4/3	sbkη	sandy loam			
48 - 61	AB/BA	10YR 4/4	sbk	sandy loam			
61 - 74	Bt1	10YR 4/4	sbk	sandy loam			
74 - 166	Bt2	7.5YR 4/6	sbk	sandy loam			
166 - 213	Bt3	7.5YR 4/6	sbk	sandy loam			
213 - 238	C1	7.5YR 5/6	m	loamy sand			
238 - 268	C2	7.5YR 5/6	mε	loamy sand			
Date Sampled		3/17/10					
Date Described		4/15/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer

β: Moist

γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain

δ: Particle Size Analysis

ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-52. Notes from soil core description for Pen 1E.

Pen 1E							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 14	L1	10YR 3/1	pl	loam			
14 - 43	A	10YR 4/4	m	loamy sand			
43 - 124	Bt1	10YR 5/3	m	loamy sand			Lamelle, 10YR 2/1, 49-51, 67-69, 97-99, 106-108
124 - 170	Bt2	7.5YR 4/4	m	loamy sand			Lamelle, 7.5YR 4/3, 149-151, 157-159, 164-166
170 - 205	C1	2.5Y 4/2	m	loamy sand			
205 - 2038	C2	2.5Y 3/2	m	loamy sand			
238 - 267	C3	2.5Y 3/3	m	loamy sand			
Date Sampled		3/17/10					
Date Described		6/30/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer

β: Moist

γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain

δ: Particle Size Analysis

ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-53. Notes from soil core description for Pen 2A.

Pen 2A							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 2	L1	-	-	NS			
2 - 7	L2	5YR 3/1	-	NS			
7 - 12	L3	5YR 3/2	-	silty clay loam			
12 - 22	Bt1	10YR 4/4	-	silt loam			
22 - 72	Bt2	10YR 3/3	-	silty clay loam			
72 - 114	Bt3	10YR 4/4	-	silty clay loam			
114 - 134	BCk	10YR 4/4	-	clay loam		yes	
134 - 164	Ck	10YR 4/3	-	clay loam		yes	
164 - 194	Ck	7.5YR 3/2	-	clay loam		yes	
194 - 233	Ck	10YR 3/3	-	clay loam		yes	
233 - 316	Ck	7.5YR 4/4	-	clay loam		yes	
316 - 336	Ck	7.5YR 7/3	-	clay loam		yes	
336 - 356	Ck	7.5YR 6/2	-	loam		yes	
Date Sampled		7/13/09					
Date Described		8/16/09					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-54. Notes from soil core description for Pen 2B.

Pen 2B							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 26	L1γ	10YR 3/1	-	clay loam			
26 - 36	A	10YR 3/2	-	silt loam			
36 - 66	AB	10YR 2/2	-	silt loam			
66 - 76	Bt	10YR 3/3	-	loam			
76 - 115	BCk	10YR 5/4	-	clay loam		yes	
115 - 200	Ck	10YR 5/6	-	sandy loam		yes	
200 - 210	Ck	10YR 6/4	-	sandy loam		yes	
Date Sampled		7/13/10					
Date Described		8/16/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-55. Notes from soil core description for Pen 2C.

Pen 2B							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 26	L1γ	10YR 3/1	-	clay loam			
26 - 36	A	10YR 3/2	-	silt loam			
36 - 66	AB	10YR 2/2	-	silt loam			
66 - 76	Bt	10YR 3/3	-	loam			
76 - 115	BCk	10YR 5/4	-	clay loam		yes	
115 - 200	Ck	10YR 5/6	-	sandy loam		yes	
200 - 210	Ck	10YR 6/4	-	sandy loam		yes	
Date Sampled		7/13/10					
Date Described		8/16/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ = Particle Size Analysis
ε = F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-56. Notes from soil core description for Pen 2D.

Pen 2D							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 21	L1	10YR 4/3	-	silt loam			
21 - 31	Ab	10YR 4/3	-	clay loam		yes	
31 - 75	Bw1	7.5YR 4/4	-	silty loam		yes	
75 - 137	Bw2	10YR 6/4	-	clay loam		yes	
137 - 157	Bw3	2.5YR 6/4	-	loam		yes	
157 - 198	Ck1	10YR 6/6	-	loam		yes	
198 - 238	Ck2	10YR 6/4	-	loam		yes, rocky	
Date Sampled		7/13/10					
Date Described		8/19/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-57. Notes from soil core description for Pen 3A.

Pen 3A							
Depth (cm)	Horizonα	Colorβ	Structureγ	Textureδ	Redoximorphic Featuresε	$CaCO_3$	Notes
0 - 16	L1	10YR 2/1	pl	silt loam			
16 - 29	L2	10YR 2/1	pl	silty loam			
29 - 45	A	10YR 4/6	pl	loam			
		10YR 3/2					
45 - 61	B1	10YR 3/1	sbk	sandy loam			
61 - 77	B2	10YR 2/1	sbk	sandy loam			
77 - 101	B3	10YR 3/1	sbk	sandy loam			
101 - 152	B4	10YR 4/2	sbk	sandy loam			
		10YR 3/1					
152 - 169	BC	10YR 4/3	sbk	sandy loam			
		10YR 3/1					
169 - 223	C1	10YR 3/1	sbk	sandy loam			
		10YR 3/2					
223 - 253	C2	10YR 2/1	sbk	sandy loam			
253 - 271	C3	10YR 3/2	sbk	sandy loam	7.5YR 4/4, FMM 5YR 3/3, FMM 5G 6/6, F3M		
Date Sampled		9/21/10					
Date Described		10/21/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-58. Notes from soil core description for Pen 3B.

Pen 3B							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 23	L1	10YR 2/1	pl	silt loam	10YR 2/1, MNF		
23 - 45	L2	10YR 2/1	pl	loam	10YR 2/1, MNM		
45 - 63	BA	7.5YR 5/4	pl	loam	10YR 2/1, MNM		
63 - 118	Bt1	5YR 5/4	pl	loam	10YR 2/1, MNM	yes	
118 - 147	Bt2	5YR 4/4	pl	loam	10YR 2/1, MNM	yes	
147 - 204	Bt3	7.5YR 4/6	pl	sandy loam	10YR 2/1, MNM		
204 - 228	Bt4	7.5YR 4/6	pl	sandy loam	10YR 2/1, MNM 5YR 4/6, FEF		
228 - 265	C	7.5YR 5/6	m	loamy sand	10YR 2/1, MNM 5YR 4/6, FEF	yes	
Date Sampled		9/21/10					
Date Described		9/22/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-59. Notes from soil core description for Pen 3C.

Pen 3C							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 10	L1	10YR 3/2	pl	silt loam			
10 - 30	L2	N 2.5/	pl	loam			
30 - 45	L3	10YR 3/4	pl	clay loam	10YR 3/1, MNF		
45 - 63	Bt1	7.5YR 4/6	pl	clay coam	10YR 3/1, MNF		
63 - 187	Bt2	7.5YR 4/6	pl	sandy loam	10YR 3/1, MNF and MNM	yes	
187 - 206	Bt3	7.5YR 5/6 7.5YR 5/8	m	sandy loam	10YR 3/1, MNF 5YR 3/3, FMM	yes	
206 - 264	Bt4	7.5YR 4/4	m	loamy sand	10YR 3/1, MNF 5YR 3/3, FMM	yes	Lamelle, 5YR 3/3, at 212-213, 214-215, 218-220, 226-227, 228-229, 233-235, 237-238, 240-241, 244-245, 249-250, and 253-258
264 - 273	C	5YR 3/3 10YR3/1 5G 5/5	m	sand	10YR 3/1, MNF 5YR 3/3, FMM 5G 5/5		
Date Sampled		9/21/10					
Date Described		9/28/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-50. Notes from soil core description for Pen 3D.

Pen 3D							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 14	L1	10YR 2/1	pl	loam			
14 - 32	L2	10YR 2/2	pl	loam			
32 - 53	A	10YR 2/1	sbk	clay loam			
		10YR 4/2					
53 - 108	BA	10YR 4/3	pl	loam			
108 - 145	Bt1	7.5YR 4/4	pl	sandy loam			
145 - 165	Bt2	10YR 4/6	sbk	sand			
165 - 172	Bt3	7.5YR 4/4	gr	loamy sand			
172 - 199	Bt4	7.5YR 7/3	sbk	sand			
199 - 225	Bt5	7.5YR 5/6	gr	sand			
225 - 231	Bt6	10YR 4/3	gr	loamy sand			
231 - 248	Bt7	10YR 4/4	sbk	loamy sand			
248 - 264	C	7.5YR 5/4	sbk	sand	10YR 3/1, MNF	yes	
Date Sampled		9/21/10					
Date Described		10/10/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-51. Notes from soil core description for Pen 3E.

Pen 3E							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 25	L1	10YR 2/1	pl	loam			
25 - 39	L2	10YR 2/1 10YR 3/2	pl	loam			
39 - 60	L3	10YR 2/1 10YR 4/2	pl	loam			
60 - 92	BA	2.5Y 2.5/1	pl	sandy clay			
92 - 119	Bt1	10YR 4/3	pl	sandy loam			
119 - 141	Bt2	7.5YR 4/4	sbk	sandy loam	10YR 2/1, MNF		
141 - 187	Bt3	7.5YR 4/6	sbk	loamy sand		yes	
187 - 255	Bt4	7.5YR 4/6	mε	sandy loam		yes	Lamelle, 211-219 cm, 7.5YR 3/3, at 230-231 and 237-242
255 - 273	Bt5	7.5YR 5/6	m	sandy loam			
273 - 295	Bt6	7.5YR 4/6	sbk	loam	10YR 2/1, MNF		
295 - 311	BC	7.5YR 4/4	m	sandy loam			
311 - 325	C1	5PB 7/6	sbk	sandy clay loam	7.5YR 4/4, MNM		
325 - 331	C2	5PB 7/5	sbk	sandy clay loam	2.5YR 4/8, FMM		
331 - 345	C3	5PB 6/6	sbk	sandy loam	5YR 4/6, FMM 7.5YR 4/6, FMM		
345 - 352	C4	5PB 5/6	sbk	sandy clay loam	10YR 5/4, FMM 5YR 5/8, FMM		
Date Sampled		9/21/10					
Date Described		9/28/10					
Describers		Grace Vaillant					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-52. Notes from soil core description for Pen 4A.

Pen 4A							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 2	L1	10YR 4/2	pl	NS			
2 - 21	L2	10YR 4/2	sbkη	silty clay loam		yes	
		5YR 4/6					
		10YR 3/1					
21 - 40	L3	10YR 5/2	pl	silty clay loam		yes	
		10YR 3/3					
40 - 66	Ab	2.5Y 2.5/1	sbk	clay		yes	
66 - 97	Btb	10YR 3/2	pr	clay		yes	
97 - 146	2Btssb	10YR 4/2	pr, abk	clay	7.5YR 4/6, FEF	yes	
146 - 200	2Btkb	10YR 4/3	pr	silty clay loam		yes	
200 - 231	2Btb	10YR 5/3	pr	silty clay loam			
231 -268	3Btkb	10YR 5/4	sbk	silty clay			
Date Sampled		2/24/10					
Date Described		3/3/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-53. Notes from soil core description for Pen 4B.

Pen 4B							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 4	L1	10YR 3/2	pl	NS			
4 - 10	L2	5YR 4/6	pl	clay loam			
		7.5YR 3/1					
10 - 30	L3	2.5Y 5/2	sbk	clay loam		yes	
		10YR 4/1					
		10YR 3/1					
30 - 43	L4	10YR 2/1	sbk	sandy clay loam		yes	
43 - 60	Ab	10YR 2/1	sbk	clay loam			
		10YR 4/2					
60 -73	Btkb1	10YR 3/1	sbk	silty clay		yes	
73 - 96	Btkb2	10YR 3/3	pr	silty clay		yes	
96 - 180	Btkb3	10YR 3/6	pr	silty clay		yes	
		10YR 3/2					
Date Sampled		2/24/10					
Date Described		3/28/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-54. Notes from soil core description for Pen 4C.

Pen 4C							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 6	L1	10YR 5/3	pl	silty loam			
6 - 22	L2	10YR 6/8 10YR 3/2	abk	silty loam			
22 - 55	L3	10BG 2.5/1	abk	silty loam			
55 - 81	Ab	10YR 2/1	sbk	silty loam			
81 - 96	Btb	10YR 3/2	pr	silty loam			
96 - 138	Btkb	10YR 3/4	pr	silty loam			
138 - 189	2Btb1	10YR 3/4	pr	silty loam			
189 -233	2Btb2	10YR 4/3	pr	silty loam	10YR 7/1, FEF		
233 - 277	2Btb3	10YR 4/3	pr	silty clay loam	10YR 5/8, FEF		
Date Sampled		2/24/10					
Date Described		3/3/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ = Particle Size Analysis
ε = F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Table A-55. Notes from soil core description for Pen 4D.

Pen 4D							
Depth (cm)	Horizon[α]	Color[β]	Structure[γ]	Texture[δ]	Redoximorphic Features[ε]	$CaCO_3$	Notes
0 - 8	L1	2.5Y 2.5/1	pl	clay			
8 - 14	L2	N 2.5/1	abk	NS			
14 - 21	L3	10YR 4/2	abk	clay			
21 - 30	L4	2.5Y 2.5/1	sbk	clay loam			
30 - 44	Ab	10YR 2/1	pr	silty clay			
44 - 96	Btb	10YR 3/2	pl	silty clay			
96 - 148	2Btb1	10YR 3/2	pr	silty clay			
148 - 227	2Btb2	10YR 3/3	pr	sandy clay			
227 - 270	3Btb	10YR 4/3	sbk	sandy clay loam	10YR 5/8, FEF 10YR 2/1, MNF		
Date Sampled		2/24/10					
Date Described		3/4/10					
Describers		Grace Vaillant and DeAnn Presley					
Observation Method		Push Tube					

α: L = Layer
β: Moist
γ: ang = angular blocky, csbk = columnar subangular blocky, g = granular, m = massive, pl = platey, pr = prismatic, sbk = subangular blocky, sg = single grain
δ: Particle Size Analysis
ε: F3M = Fe (III) masses, FMM = iron-manganese masses, MNM = manganese masses, FEF = Fe (III) films, MNF = manganese films

Appendix B - Data From Ammonia Chamber Experiments

Table B-1. Data from aerodynamic conductance test.

Air Flow	Air Exchange Rate	$\sqrt{Air\ exchange\ rate}$	Average g_a	SD g_a
L min^{-1}	ex min^{-1}	$\sqrt{ex\ \min^{-1}}$	mm s^{-1}	mm s^{-1}
0.01	0.01	0.10	0.00	0.00
1.90	2.68	1.64	7.37	0.00
3.10	4.37	2.09	9.80	0.44
4.70	6.62	2.57	12.36	0.23
6.10	8.59	2.93	14.66	0.26
10.00	14.08	3.75	18.26	0.35
14.00	19.72	4.44	20.94	1.01
16.70	23.52	4.85	22.30	2.39

Table B-2. Summary of %N recovered from the mass balance. Treatment 1 had no media and Treatment 2 had glass beads. Three chambers were at 0% RH and three chambers were at 75% RH. Treatment 1 and Treatment 2 were found to be significantly different than each other at alpha = 0.05. However, in each treatment, there was no difference between RH treatments or between chambers in each RH treatment at alpha = 0.05.

% N Recovered										
	Liquid					Glass Beads				
	Chamber (0% RH)					Chamber (0% RH)				
Trail	1	2	3	Average	Stdev	1	2	3	Average	Stdev
1	88.9	91.0	85.7	88.5	2.7	94.4	96.9	95.4	95.5	1.3
2	83.7	86.8	90.3	86.9	3.3	94.6	98.1	96.9	96.5	1.8
3	99.7	72.9	88.5	87.1	13.5					
Average	90.8	83.6	88.1	87.5	7.1	94.5	97.5	96.1	96.0	1.5
Stdev	8.2	9.5	2.3			0.2	0.8	1.1		
	Chamber (75% RH)					Chamber (75% RH)				
Trail	4	5	6	Average	Stdev	4	5	6	Average	Stdev
1	92.5	96.3	81.4	90.1	7.7	97.8	95.8	92.8	95.5	2.5
2	89.7	89.3	78.8	85.9	6.2	98.4	99.7	100.1	99.4	0.9
3	98.4	93.7	96.9	96.3	2.4					
Average	93.5	93.1	85.7	90.8	6.8	98.1	97.8	96.5	97.4	2.7
Stdev	4.5	3.5	9.8			0.4	2.8	5.2		

RH = Relative Humidity

Table B-3. Summary of data from Trial 1 of humidity tests. Chambers 1 thru 3 were at 75% RH and Chambers 4 thru 6 were at 0% RH.

Time	Chamber (75% RH)						Average	S.D.
	1		2		3			
	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)
2	0.04	0.04	0.03	0.03	0.03	0.03	0.04	0.00
6	0.08	0.12	0.07	0.10	0.05	0.08	0.10	0.02
24	0.20	0.32	0.15	0.24	0.18	0.27	0.28	0.04
49	0.11	0.43	0.10	0.34	0.11	0.38	0.39	0.05
73	0.09	**0.52**	0.09	**0.44**	0.11	**0.49**	**0.48**	**0.04**

Time	Chamber (0% RH)						Average	S.D.
	4		5		6			
	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)
2	0.05	0.05	0.07	0.07	0.05	0.05	0.06	0.01
6	0.08	0.13	0.13	0.20	0.08	0.13	0.15	0.04
24	0.61	0.74	0.70	0.90	0.56	0.68	0.77	0.11
48	1.56	2.30	1.79	2.69	1.21	1.89	2.29	0.40
72	0.85	**3.15**	0.95	**3.64**	0.62	**2.51**	**3.10**	**0.57**

Numbers bolded indicate total loss of NH_4^+ from each chamber. Areas highlighted in gray indicate mean and S.D. total loss of NH_4^+ from among designated chambers

Table B-4. Summary of data from Trial 2 of humidity tests. Chambers 1 thru 3 were at 75% RH and Chambers 4 thru 6 were at 0% RH.

Time	Chamber 1		Chamber 2		Chamber 3		Average	S.D.
	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)
2	0.06	0.06	0.04	0.04	0.03	0.03	0.04	0.01
6	0.06	0.12	0.07	0.11	0.06	0.09	0.10	0.01
24	0.20	0.31	0.16	0.26	0.19	0.28	0.28	0.02
48	0.09	0.40	0.06	0.32	0.07	0.35	0.36	0.04
72	0.07	0.47	0.06	0.38	0.06	0.41	0.42	0.05
92	0.09	**0.56**	0.07	**0.45**	0.09	**0.50**	**0.50**	**0.06**

Time	Chamber 4		Chamber 5		Chamber 6		Average	S.D.
	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	NH_4^+ captured (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)	Cumulative NH_4^+ (mg)
2	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.00
6	0.08	0.11	0.12	0.16	0.07	0.09	0.12	0.03
24	0.67	0.78	0.64	0.79	0.36	0.46	0.68	0.19
48	1.30	2.09	0.99	1.78	0.81	1.27	1.71	0.41
72	0.73	2.81	0.77	2.56	0.44	1.70	2.36	0.58
92	0.53	**3.35**	0.42	**2.98**	0.37	**2.07**	**2.80**	**0.66**

Numbers bolded indicate total loss of NH_4^+ from each chamber. Areas highlighted in gray indicate mean and S.D. total loss of NH_4^+ from among designated chambers

Table B-5. Means from Trail 1 and Trial 2 of Soil Media – Effect on Humidity. The RH treatments are statistically different than each other at alpha = 0.05 as indicated by the capital letters. For the 0% RH treatment, chamber 1 is different than chamber 2, but is not biologically significantly different. For the 75% RH treatment the chambers are not different than each other at alpha = 0.05.

	Cumulative NH_4^+ (mg)			
RH Treatment	Chamber			
	1	2	3	Average
0%	0.54 [a]	0.45 [b]	0.50 [ab]	0.49 [A]
			Chamber	
75%	4	5	6	Average
	3.25	3.31	2.29	2.95 [B]

Lower case letters indicate significant difference between chambers at alpah = 0.05
Upper case letters indicate difference between RH treatments at alpha = 0.05.

Table B-6. Summary of NH_3 captured from two soil moisture treatments using the Tully soil at 75% RH.

Time	Chamber (90 mL application rate)						Average	S.D.
	1		2		3			
	NH_4^+ captured	Cumulative NH_4^+	NH_4^+ captured	Cumulative NH_4^+	NH_4^+ captured	Cumulative NH_4^+	Cumulative NH_4^+	Cumulative NH_4^+
1	4.6	4.6	4.2	4.2	3.7	3.7	4.2	0.5
5	9.2	13.8	9.4	13.7	9.4	13.1	13.5	0.4
24	13.2	27.0	16.2	29.9	13.5	26.6	27.9	1.8
49	13.3	40.4	14.5	44.4	11.4	38.1	41.0	3.2
72	23.1	63.5	21.0	65.4	22.6	60.7	63.2	2.4
186	12.5	**75.9**	9.5	**74.9**	13.0	**73.7**	**74.9**	**1.1**

Time	Chamber (45 mL application rate)						Average	S.D.
	4		5		6			
	NH_4^+ captured	Cumulative NH_4^+	NH_4^+ captured	Cumulative NH_4^+	NH_4^+ captured	Cumulative NH_4^+	Cumulative NH_4^+	Cumulative NH_4^+
1	2.9	2.9	2.4	2.4	2.3	2.3	2.5	0.3
5	4.3	7.2	4.0	6.3	3.4	5.7	6.4	0.8
24	8.0	15.3	7.0	13.3	5.7	11.4	13.3	1.9
49	4.4	19.6	4.1	17.4	3.2	14.6	17.2	2.5
72	4.3	24.0	3.9	21.3	3.2	17.8	21.0	3.1
186	9.3	**33.3**	9.9	**31.2**	7.2	**25.0**	**29.8**	**4.3**

Numbers bolded indicate total loss of NH_4^+ from each chamber. Areas highlighted in gray indicate mean and S.D. total loss of NH_4^+ from among designated chambers

Table B-7. Summary of NH_3 captured from two soil moisture treatments using Haynie soil at 75% RH.

	Chamber (90 mL application rate)							
	1		2		3		Average	S.D.
Time	NH_4^+ captured (mg)	Cumulative NH_4^+(mg)	NH_4^+ captured (mg)	Cumulative NH_4^+(mg)	NH_4^+ captured (mg)	Cumulative NH_4^+(mg)	Cumulative NH_4^+(mg)	Cumulative NH_4^+(mg)
2	4.1	4.1	4.4	4.4	4.4	4.4	4.3	0.1
6	12.0	16.1	10.1	14.4	11.4	15.7	15.4	0.9
24	32.8	48.9	28.7	43.2	39.6	55.3	49.1	6.1
52	28.1	77.0	27.7	70.8	28.3	83.7	77.1	6.4
72	19.0	95.9	19.9	90.7	20.1	103.8	96.8	6.6
119	64.3	160	70.1	161	60.8	165	162	2.4
168	83.8	244	83.7	244	93.0	258	249	7.7
194	39.8	**284**	47.4	**292**	50.9	**309**	**295**	**12.6**

	Chamber (45 mL application rate)							
	4		5		6		Average	S.D.
Time	NH_4^+ captured (mg)	Cumulative NH_4^+(mg)	NH_4^+ captured (mg)	Cumulative NH_4^+(mg)	NH_4^+ captured (mg)	Cumulative NH_4^+(mg)	Cumulative NH_4^+(mg)	Cumulative NH_4^+(mg)
2	6.4	6.4	5.7	5.7	5.9	5.9	6.0	0.3
6	9.7	16.1	8.8	14.6	9.3	15.2	15.3	0.8
24	26.2	42.3	25.2	39.7	22.6	37.8	39.9	2.2
52	32.6	74.8	35.1	74.8	28.8	66.6	72.1	4.7
72	20.7	95.5	23.1	98.0	22.9	89.5	94.3	4.3
119	48.7	144	39.6	138	46.6	136	139	4.3
168	43.0	187	46.8	184	41.8	178	183	4.8
194	22.3	**210**	23.4	**208**	22.1	**200**	**206**	**5.1**

Numbers bolded indicate total loss of NH4+ from each chamber. Areas highlighted in gray indicate mean and S.D. total loss of NH4+ from among designated chambers