NUTRIENT DYNAMICS IN BAHIAGRASS SWARDS IMPACTED BY CATTLE EXCRETA

By

UNA RENEE WHITE

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To Jacob.

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Una Renee White

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Most nutrients consumed by grazing livestock are returned to pasture in excreta, but excreta effects on forage responses, plant nutrient recovery, and shallow soil water quality are not well defined. The objective was to determine the effect of management intensity, excreta type, and number of excreta applications on bahiagrass (*Paspalum notatum* Flügge) herbage dry matter (DM) harvested and nutritive value, excreta nutrient recovery in harvested herbage, and nutrient concentration in shallow soil water. Treatments were the factorial combinations of two management intensities (Average and High, 60 and 120 kg N ha^{-1}, respectively), two excreta types (dung and urine), and three application frequencies (1, 2, or 3 $season^{-1}$). Three control treatments received no excreta and 0, 60, or 120 kg N ha^{-1}. Dung and urine were collected from animals grazing bahiagrass pasture and applied to ungrazed bahiagrass plots. A urine application was 2 L distributed to a 60-cm diameter circle, and a dung application was 2 kg fresh weight applied to a 30-cm diameter circle. Concentric rings (radii of 0-15, 15-30, 30-45, and for urine plots, 45-60 cm from the center of excreta application) were clipped monthly from July through October 2006 to measure forage responses, and lysimeters were placed 1.3 m below soil level directly under the excreta application to measure nutrient concentrations in soil water. Herbage data are reported for a circle of radius 45 cm from the center of the excreta deposit and also by ring to show spatial patterns of response. Herbage response for the circle of 45-cm radius was affected to the greatest extent by application frequency X excreta type interaction. Interaction occurred because dung application had no effect on most herbage responses, whereas responses to urine were consistently significant. In urine-treated plots, herbage DM harvested increased from 2760 at zero applications to 4670 kg ha^{-1} with three, while over the same application frequency herbage N concentration increased from 13.3 to 16.2 g kg^{-1}, P concentration from 3.45 to 3.87 g P kg^{-1}, in vitro digestible organic matter concentration from 569 to 588 g kg^{-1}, N harvested from 37 to 75 kg ha^{-1}, and P harvested from 9 to 18 kg ha^{-1}. Excreta N recovery was greater from urine than dung and decreased as application frequency increased from one to three (28 to 18% for urine and 4 to < 1% for dung). Spatial characteristics of response were assessed within excreta type and were consistently affected by application frequency X ring number interaction. In urine-treated plots, herbage response generally was greatest near the center of the urine deposit and decreased as distance from center of excreta application increased. In dung-treated plots, physical interference by dung resulted in decreased herbage DM, N, and P harvested in the area under the dung deposit. Urine affected DM harvested and herbage P concentration up to 15 cm and N concentration and N harvested up to 30 cm beyond the edge of the urine application. Dung had no effect on any response outside the area physically impacted by dung. Shallow soil water was affected by treatment at only one sampling date, and NO_3-N concentration was > 10 mg L^{-1} in only three samples during the entire study. In conclusion, urine has much greater impact on herbage response than dung, both in the area impacted physically by the excreta and beyond that area. Greater N recovery following single vs. multiple excreta events per site per year emphasizes the importance to sustainable grassland management of grazing practices that increase uniformity of excreta deposition.

CHAPTER 1
INTRODUCTION

Rotz et al. (2005) define grassland agriculture as "a farming system that emphasizes the importance of grasses and legumes in livestock and land management." Planted grasslands and non-forested rangeland comprise nearly 30% of the USA land area (Barnes and Nelson, 2003) and occupy more than 4 million ha in Florida (Dubeux et al., 2007). Because of the amount of area involved, the fate of nutrients within these agroecosystems has important implications for agricultural production and the environment.

Nutrient management in grasslands has received greater attention in recent years due to soil nutrient insufficiency and associated pasture degradation in some areas (e.g., Brazil; Boddey et al., 2004) and excessive applications of nutrients and negative environmental impact in others (e.g., USA; Woodard et al., 2003). The major nutrient pools in grassland systems are soil, atmosphere, live and dead plant material, and animals (Mathews et al., 2004; Dubeux et al., 2007). Addition of livestock to grasslands increases the complexity of the nutrient cycle and the rate of fluxes among nutrient pools; the latter increases the potential for nutrient loss to the environment (Boddey et al., 2004). This is due to chemical and biological transformations that occur during forage digestion, making the forms of nutrients in excreta more readily available for uptake or loss than those occurring in live plants or plant litter (Jarvis et al., 1995; Rotz et al., 2005).

In pasture-based livestock production systems, animals gather herbage, utilize a small proportion of the nutrients and excrete the remaining nutrient compounds in patches (Rotz et al., 2005). Efficient recovery of these nutrients is hindered by the large quantity of nutrients in a single dung or urine event and because a disproportionately large number of excreta events occur in small areas where cattle congregate, e.g., near to shade, water, and supplemental feed sources (Mathews et al., 2004; Sollenberger et al., 2002).

It has been suggested that rotational stocking with short grazing periods, i.e., many paddocks per pasture, decreases the opportunity and tendency of animals to congregate in lounging areas by intensifying competition for feed and shortening residency periods (Haynes and Williams, 1993). In Florida, it was found that rotationally stocked pastures where grazing periods were short (1 to 7 d) had greater spatial uniformity in time spent by cattle, excreta deposition, and soil nutrient concentration than continuously stocked pastures (Dubeux, 2005). Thus, it is likely that greater uniformity of excreta deposition can be achieved by imposing rotational stocking with short grazing periods. Whether this intensification of grazing management results in more efficient nutrient cycling may depend on the degree to which more uniform excreta deposition enhances nutrient recovery by grassland plants and avoids excessive nutrient accumulation in soils or nutrient loss to surface or ground water.

There is little information in the literature evaluating the impact of type and number of excreta applications to pasture on leaching of N, changes in soil nutrient concentration, and herbage growth and nutritive value. The objective of the reported research in this thesis is to characterize the effects of cattle excreta application on 1) bahiagrass (*Paspalum notatum* Flügge) herbage accumulation, chemical composition, and nutrient recovery and 2) nitrate leaching to shallow ground water under a bahiagrass sod. Companion studies not reported in this document will assess the effect of these factors on changes in soil nutrient concentration over time. Bahiagrass was chosen for this research because it is the most widely used of the planted pasture species in Florida.

CHAPTER 2
LITERATURE REVIEW

Introduction

Bahiagrass (*Paspalum notatum* Flügge) is a warm-season perennial pasture grass that is important in Florida and throughout the Gulf Coast Region of the southern USA (Chambliss and Adjei, 2006). It is growing on approximately 1.1 million ha in Florida where it is used as the primary feed for the nearly 1 million head of beef cows (NASS: Florida, 2006).

Due to the quantity of land area occupied and the number of animals supported on bahiagrass pasture, nutrient management is a key issue. One of the many challenges faced by livestock producers utilizing pasture as a feed resource is avoidance of over accumulation of livestock wastes in certain areas of the pasture. Uneven distribution of soil nutrients, due to non-uniform spatial deposition of excreta, is thought to lead to leaching and volatilization of N and runoff of P and other nutrients from so-called nutrient hot spots in pastures, yet the effect of in situ excreta deposition on plant, soil, and water responses has not been studied in detail. The reported research objectives were to characterize the impact of frequency and type of excreta application on bahiagrass herbage production, chemical composition, and nutrient recovery, and to measure the nitrate-N concentration in shallow ground water under excreta applications.

This literature review will focus on a description of bahiagrass and its growth characteristics. Subsequently, excreta quantity, composition, deposition patterns, and effects on herbage productivity and nutritive value will be described. Finally, nutrient release from excreta and its impact on plant, water, and soil will be explored.

Bahiagrass and Its Use in Florida

Center of Origin and Introduction to Florida

Bahiagrass is native to South America and was described in 1810 using a plant collected from St. Thomas Island by Schrader and Ventenat (Gates et al., 2004). Common bahiagrass is particularly abundant in Brazil, eastern Bolivia, Paraguay, and northeastern Argentina, but the original distribution of the races of var. *saurae* was confined to Corrientes, Entre Rios, and the eastern edge of Santa Fe Provinces in Argentina (Gates et al., 2004). 'Pensacola' bahiagrass belongs to the var. *saurae*. Scott (1920) reported that bahiagrass was first introduced into the USA by the Bureau of Plant Industry and grown by the Florida Agricultural Experiment Station in 1913 (Gates et al., 2004). Currently, bahiagrass is widespread throughout the southern USA and Central and South America (Skerman and Riveros, 1989; Hirata et al., 2006; Chambliss and Adjei, 2006).

Morphological Characteristics

Bahiagrass is a sod forming, warm-season perennial (Skerman and Riveros, 1989; Hirata et al., 2006; Gates et al., 2004). It has strong, shallow, horizontal rhizomes formed by short internodes (Gates et al., 2004). Pensacola bahiagrass has a decumbent growth habit with most leaves originating from rhizomes near the soil surface (Beaty et al., 1968). Approximately 40% of Pensacola biomass is within 3 cm of the soil surface (Beaty et al., 1968). Bahiagrass leaves are attached to growing rhizomes which are produced continuously as long as leaves are being produced (Beaty and Powell, 1978). Upon death of leaves, soluble constituents such as N are translocated from the aging leaf to the rhizome, root, or young phytomers (Beaty and Powell, 1978).

Bahiagrass allocates significant mass to rhizomes and roots (Pedreira and Brown, 1996a). Bahiagrass plots were fertilized with either a low N (LN: 0 and 5 g N m^{-2} in Years 1 and 2), medium N (MN; 40 and 10 g N m^{-2} in Years 1 and 2), or high N rate (HN: 80 and 20 g N m^{-2} in Years 1 and 2) and were clipped every 10 (short interval; SI) or 21 d (long interval; LI) (Hirata, 1996). Root mass averaged across the 2-yr period was greatest with greatest N rate and longest cutting interval (LN/LI: 595 g m^{-2}; MN/LI: 597 g m^{-2}; HN/LI: 613 g m^{-2}). There also were effects of N rate and cutting interval on leaf mass. Specifically, as N rate and cutting interval increased so did leaf mass (LN/SI: 81 g m^{-2}; LN/LI: 89 g m^{-2}; HN/SI: 148 g m^{-2}; HN/LI: 288 g m^{-2}), but leaf mass was relatively small compared to root mass.

Adaptation to Environments

Bahiagrass is grown throughout Florida due to its tolerance of a wide range of soil conditions, including low fertility, drought, and short-term flooding (Gates et al., 2004), pH up to 6, and its ability to withstand close grazing (Burson and Watson, 1995; Williams and Hammond, 1999). Following its introduction to Florida, it spread to the Gulf Coast and Coastal Plains of the Southeast USA and has become naturalized in these regions (Gates et al., 2004). Its area of growth extends north to North Carolina and west to Texas and southeastern Oklahoma (Gates et al., 2004).

Use in Production Systems

Approximately 75% of the 1.4 million ha of planted pasture in Florida are dominated by bahiagrass which supports ~ 1 million head of beef cows (Gates et al., 2004; Mislevy et al., 2005). Bahiagrass is also used for hay, although in the Lower South, most hay is produced from higher yielding warm-season perennial grasses such as bermudagrass [*Cynodon dactylon* (L.) Pers.], dallisgrass (*Paspalum dilatatum* Poir.), and stargrass (*Cynodon nlemfuensis* Vanderyst) (Robinson, 1996; Taliaferro et al., 2004). Bahiagrass is widely used for low maintenance turf, especially in highway rights-of-way throughout the Southeast (Gates et al., 2004).

Pensacola Bahiagrass

Pensacola bahiagrass belongs to *P. notatum* var. *saurae* and was first discovered growing near docks in Pensacola, FL; it is assumed that the seed arrived on a ship from Argentina prior to 1926 (Finlayson, 1941; Burton, 1967; Gates et al., 2004). Hoveland (2000) stated that the introduction and release of Pensacola bahiagrass was a major achievement in the development of grasslands in the southern USA. Pensacola, a diploid, is more cold tolerant than the tetraploid bahiagrasses, including Argentine (Gates et al., 2004). Pensacola is the most widely grown of the bahiagrass cultivars and is very drought tolerant, although growth during dry periods is minimal. Its winter hardiness and survival under heavy grazing are due to its prostrate and rhizomatous nature (Pedreira and Brown, 1996a). These traits also contribute to its tolerance of continuous stocking (Pedreira and Brown, 1996b).

Bahiagrass Response to Nitrogen and Phosphorus

Herbage Accumulation

Plant production responses are affected by species, stage of growth, amount and time of N applied, and environmental conditions following fertilizer application (Crowder and Chheda, 1982). The addition of N influences yield as long as no other element is limiting (Crowder and Chedda, 1982). Without adequate P or other nutrients, plant growth is restricted, yields are lower, use efficiency of N is affected, and lower profits result (Griffith and Murphy, 1996).

Dry matter accumulation of planted warm-season perennial grasses, like bahiagrass, depends on the amount of N applied and has pronounced seasonal characteristics. Dry matter yields of Pensacola bahiagrass were 3000 to 4000 kg ha^{-1} without applied N (Blue, 1970) and 12 000 kg ha^{-1} or more when 224 kg N ha^{-1} was applied (Sigua et al., 2004). Beaty et al. (1975) showed that Pensacola herbage accumulation increased from 3700 to 4360 kg ha^{-1} when N fertilization increased from 0 to 224 kg ha^{-1}. Herbage accumulation was not different when N fertilization increased from 224 to 672 kg ha^{-1}.

Mislevy et al. (2005) found that Pensacola produced 50 to 60% of its total seasonal yield during long days of June, July, and August, and average annual yield was between 10 000 and 12 000 kg ha^{-1} when 112 kg N ha^{-1} yr^{-1} was applied. Total seasonal yield was 13 400 kg ha^{-1} in the first year of the 3-yr study, while yields in the second and third years were 11 000 and 6300 kg ha^{-1}. The reason for this drastic decrease in Year 3 was drought. Total rainfall for the 1st, 2nd, and 3rd years was 1740, 1270, and 813 mm, respectively.

Burton et al. (1997) fertilized Pensacola bahiagrass at differing rates of N, P, and K, the lowest being 56 kg N, 24 kg P, and 46 kg K ha^{-1}; the highest was 448 kg N, 49 kg P, and 278 kg K ha^{-1}. Average dry matter harvested over the 3-yr period was 10 620 kg ha^{-1}, with the highest yield of 15 070 kg ha^{-1} from the greatest fertilizer amount. In Louisiana, Twidwell et al. (1998) found that a single application of 224 kg N ha^{-1} to bahigrass increased annual yield from 4040 kg ha^{-1} for the zero control to 11 900 kg ha^{-1}.

Bahiagrass response to P fertilization has been less consistent than to N, due in part to bahiagrass' ability to access soil P from below the depth sampled for soil analysis (Mylavarapu et al., 2007), especially when growing in Spodosols. In a study conducted in South Central Florida, bahiagrass herbage yield increased 12% above the zero control when fertilized with 15 kg P ha^{-1} (Ibrikci et al., 1999). Burton et al. (1997) found bahiagrass P rates had no effect on DM yield across a range of N and P rates. In that study, bahiagrass was fertilized with varying rates of N, P, and K (from 56 kg N, 24 kg P, and 46 kg K ha^{-1} as the lowest fertilizer rate, to the highest of 448 kg N, 49 kg P, 279 kg K ha^{-1}). McCaleb et al. (1966) found that Pensacola bahiagrass yield was affected by P fertilization only for an initial increment of 6 kg P ha^{-1} yr^{-1}.

Rhoads et al. (1997) found similar results but with different rates of P (0, 84, and 168 kg ha^{-1}). In this study, they found that increasing P fertilizer from 0 to 84 kg ha^{-1} increased yield from 9.8 to 10.7 Mg DM ha^{-1} in the first year and 7.3 to 8.8 Mg DM ha^{-1} in the second year.

Herbage Nutritive Value

There is extensive literature on the effects of N fertilization on the chemical composition and digestibility of Pensacola bahiagrass herbage (Beaty et al., 1975; Burton et al., 1997; Twidwell et al., 1998; Newman et al., 2006; Stewart et al., 2007). Similar to many other C_4 grasses, Pensacola bahiagrass crude protein (CP) increases with increasing N fertilization, while the response of herbage in vitro digestible organic matter (IVDOM) is less clear.

Beaty et al. (1975) showed that Pensacola bahiagrass N concentration increased significantly when N fertilization increased from 0 to 224 and again from 224 to 672 kg N ha^{-1}. Newman et al. (2006) fertilized bahiagrass with two levels of N fertilizer, 80 and 320 kg N ha^{-1}, and harvested them by clipping to a 5-cm stubble height every 7 wk. Bahiagrass fertilized with 320 kg N ha^{-1} had greater IVDOM than bahiagrass fertilized with 80 kg N ha^{-1} (471 and 432 g kg^{-1}, respectively). Herbage CP was 79 and 58 g kg^{-1} for the 320 and the 80 kg N ha^{-1} treatments, respectively. Burton et al. (1997) found bahiagrass N concentrations increased from 10.6 to 17 g N kg^{-1} as fertilizer N applications increased from 56 to 448 kg N ha^{-1}. Stewart et al. (2007) found that bahiagrass herbage CP increased as amount of N fertilizer increased from 40 to 120 kg N ha^{-1} (99 to 113 g CP kg^{-1}), and from 120 to 360 kg N ha^{-1} (113 to 140 g CP kg^{-1}).

In Florida, bahiagrass was fertilized with 112 kg N, 30 kg P, and 52 kg K ha^{-1} yr^{-1}, and this resulted in average CP and IVDOM concentrations from April through December of 142 and 563 g kg^{-1}, respectively, in Year 1, 140 and 510 g kg^{-1} in Year 2, and 163 and 485 g kg^{-1} in Year 3 (Mislevy et al., 2005). These authors characterized seasonal changes in bahiagrass nutritive value. Pensacola's greatest CP (186 g kg^{-1}) occurred in April 1998 and then decreased from June through December. The greatest IVDOM for Pensacola was 623 g kg^{-1} in December 1998 and the lowest occurred in August and was 467 g kg^{-1}. All genotypes of bahiagrass tended to drop in IVDOM during June to August due to a low soluble carbohydrate concentration in above-ground plant parts.

In comparison to N fertilization, there are relatively few papers that address the effect of P fertilization on Pensacola bahiagrass nutritive value. However, there has been increasing interest in P nutrition of bahiagrass because of the role of P in water quality, and this has stimulated greater research emphasis in recent years.

Ibrikci et al. (1999) found that when triple superphosphate was applied at rates of 0, 17, 34, 51, and 68 kg P ha^{-1}, there was no change in bahiagrass herbage P concentration in the first year, but in the second year the uptake of inorganic P increased significantly and P concentration increased with P fertilization. Sumner et al. (1992) found when bahiagrass was fertilized with P it resulted in increased P concentration and the increase was related to the amount of P applied. Phosphorus concentration of Pensacola bahiagrass averaged 1.5 g kg^{-1} when fertilizer rate was 24 kg P, but when P fertilizer rate increased to 49 kg P ha^{-1} forage P concentration increased to 3.0 g kg^{-1} (Burton et al., 1997).

Tiffany et al. (1999) sampled three grazed bahiagrass pastures that were growing on different soils in Florida. Pastures were fertilized with 40 kg N ha^{-1}. Forage P concentrations in the first (3.0 g kg^{-1}) and second years (3.1 g kg^{-1}) were similar early in the season. There was a decrease in P concentration from June to November in both years from approximately 3.0 to 1.3 g kg^{-1}. The forage P concentration in October and November were below the 1.8 g kg^{-1} requirement for growing beef cattle (NRC, 1996).

Characteristics of Cattle Excreta

A large proportion of the nutrients consumed by grazing livestock are returned to the pasture in animal excreta (Sollenberger et al., 2002). In grazed pastures, soil nutrient redistribution occurs as animals consume forage from throughout the pasture but concentrate excreta return in areas around water and shade where they spend more time (Mathews et al., 1994). Nutrients in excreta are much more readily available for plant uptake or loss to the environment than nutrients in plant matter. Nitrogen losses from dung and urine are particularly sensitive to climatic and edaphic conditions (Boddey et al., 2004), thus excreta deposition can hasten N depletion in extensively managed grasslands. Leaching of nitrate N is a major pathway of N loss, while gaseous N emissions from dung and urine occur mainly in the form of NH_3 and only a small portion of N_2O and NO is emitted (Pineiro et al., 2006).

Urine

Quantity and distribution in grazed pasture

Cattle urinate approximately 8 to 10 times d^{-1} (Carran and Theobald, 1999; Peterson and Gerrish, 1996) with a volume of 10 to 25 L d^{-1} (Mathews et al, 1996). A given urine spot covers 0.28 to 0.37 m^2 (Haynes and Williams, 1993). The literature on frequency, amount, and area impacted by excreta was summarized (Table 2-1) by Haynes and Williams (1993). The quantity and distribution of urine will vary depending on the season; during warmer weather cattle will consume more water which will increase frequency of urination and dilute the concentration of nutrients. Also during warmer weather, cattle will seek shade and water causing more urine to be deposited there (Sugimoto et al., 1987). Soil P and K concentrations of 100 and 1000 mg kg^{-1}, respectively, in the upper 7.5 cm of the soil profile were reported in a zone 10 to 20 m from the water source for cattle grazing in a three-paddock rotational system (West et al., 1989; Peterson and Gerrish, 1996). Nitrogen loading in a urine patch can reach up to the equivalent of 1000 kg

N ha^{-1} (Haynes and Williams, 1993; Clough et al., 2004). Pakrou and Dillon (1995) collected fresh urine from dairy cows grazing clover (*Trifolium* spp.)-perennial ryegrass (*Lolium perenne* L.) pastures. The N loading under the urine patches ranged between 650 (autumn) and 1370 kg N ha^{-1} (summer) in the soil. Applying this much N increases the likelihood of nutrient losses.

Table 2-1. Number and weight or volume of dung or urine events per day and surface area covered (adapted from Haynes and Williams, 1993).

Reference	Stock type	Mean number of defecations per day	Weight of single defecation (kg wet wt)	Area covered by defecation (m^2)	Mean number of urinations per day	Volume of single urination (L)	Area covered by urination (m^2)
Johnstone-Wallace and Kennedy (1994)	Beef cow	11.8	1.77	0.06	8.5	--	--
Castle et al. (1950)	Dairy cow	11.6	--	--	9.8	--	--
Hancock (1950)	Dairy cow	12.2	--	--	10.1	--	--
Goodall (1951)	Dairy cow	12	1.48	--	11	--	--
Waite et al. (1951)	Dairy cow	--	2.27	--	--	--	--
Doak (1952)	Dairy cow	--	--	--	--	1.6	--
Hardison et al. (1956)	Dairy cow	15.4	--	0.09	9.4	--	--
Petersen et al. (1956)	Dairy cow	12	--	--	8	--	0.28
MacLusky (1960)	Dairy cow	11.6	--	0.05	--	--	--
Davies et al. (1962)	Dairy cow	12	--	0.07	10	2.2	0.19
Wardrop (1963)	Dairy cow	16.1	--	--	12.1	--	--
Hogg (1968)	Dairy cow	--	--	--	--	--	0.18
Weeda (1967)	Beef steer	10.5	--	--	--	--	--

Table 2-1. Continued

Reference	Stock type	Mean number of defecations per day	Weight of single defecation (kg wet wt)	Area covered by defecation (m^2)	Mean number of urinations per day	Volume of single urination (L)	Area covered by urination (m^2)
Frame (1971)	Dairy cow	11	2.7	--	11	1.9	--
MacDiarmid and Watkin (1972)	Dairy cow	13.9	1.82	0.07	--	--	--
Robertson (1972)	Dairy cow	--	--	--	10	2	--
During and Weeda (1973)	Beef steer	--	--	0.05	--	--	--
Richards and Wolton (1976)	Dairy cow	--	--	0.05	--	--	0.49
Weeda (1979)	Beef steer	10.5	--	--	--	--	--
Williams et al. (1990)	Dairy cow	--	--	--	--	--	0.16

Chemical composition

Nutrients in urine are in plant-available forms or are rapidly mineralized within a few days (Mathews et al., 1996). Because urine is 500 to 800 g urea-N kg^{-1} of total-N, it is hydrolyzed very rapidly (Rotz et al., 2005), resulting in a release of available nutrients. The urea in the urine is broken down by urease which is an enzyme produced by microbes in the soil. Urine contains many amino acids, such as hippuric acid. The hippuric acid in urine was reported to have a controlling effect on both hydrolysis of urine N and on NH_3 volatilization (Doak, 1952; Whitehead et al., 1989). When urine-N concentrations are lowered or the amount of urine N is affected by altering forage source, feed additives, or grazing regimes, there may be a significant effect on N_2O emissions, due to lower amounts of N being applied to the soil (Oenema et al., 1997). Potassium in urine may be leached or converted to less available forms, which affect supply (Carran and Theobald, 1999).

Livestock on forage diets have a urine pH of approximately 7.4 (Rotz et al., 2005). The specific concentrations of N in cattle urine depend on factors such as diet and water consumption but normally range from 8 to 15 g N L^{-1} (Whitehead, 1970; Clough et al., 2004). Reducing cattle N intake by changing diet composition can lead to lower N concentration in urine with the volume of urine unchanged, fewer urinations of the same volume but with unchanged N concentration, or an unchanged number of urinations but with a smaller volume of urine and unchanged N concentration (Bussink and Oenema, 1998; van Groenigen et al., 2005a). Salts and other feed additives will dilute the concentration of N in urine through more water consumption (van Groenigen et al., 2005a).

Effect on herbage production and nutritive value

Nutrients in urine enhance overall pasture productivity disproportionately to the area physically covered by the excreta site (Peterson and Gerrish, 1996). Recycled nutrients can account for up to 70% of annual pasture production in low-input systems (Mathews et al., 1996). Short-term effects of urine have a greater impact on productivity than dung (Carran and Theobald, 1999). When cattle and sheep were corralled and combined dung and urine applied to pearl millet (*Pennisetum glaucum* L.), the millet plots had an average of 53% greater seasonal yield than where only dung was applied (Powell et al., 1998).

Decau et al. (2003) conducted an experiment using perennial ryegrass planted in three types of soil. Cow urine spiked with ^{15}N was applied to the plots at a rate of 7 mg N L^{-1} (urea N = 4.61 mg L^{-1}, and ^{15}N = 2.47 mg L^{-1}) and top dressed with 15 g N m^{-2} yr^{-1} of ammonium nitrate. The controls, which did not receive any form of N in Year 1, had a forage dry matter production of 5 to 6 Mg ha^{-1}. Application of urine in the spring increased DM yields by 17 to 33%, but the summer application increased yield only 10 to 15%, probably due to greater volatilization losses in summer. Total N uptake for the spring and summer applications was greater than the fall. Average urinary N uptake in the harvested herbage over the 2-yr period was approximately 40%; for the spring harvest urinary N uptake ranged from 52 to 60% across soil types. The fall uptake of urinary N was poor compared to the spring and ranged from 16 to 41%.

Silva et al. (2005) applied dairy cow urine to perennial ryegrass-white clover plots. Plots received urine+urea (1000 + 4000 kg N ha^{-1} yr^{-1}), urine alone (1000 kg N ha^{-1} yr^{-1}), or a control with no N applied. Dry matter production over a 2-yr period was 10 700 kg ha^{-1} yr^{-1} (control), 19 415 kg ha^{-1} yr^{-1} (urine), and 20 000 kg ha^{-1} yr^{-1} (urine+urea). Uptake of N by the control treatment was approximately half that (364 kg ha^{-1} yr^{-1}) of the urine (610 kg ha^{-1} yr^{-1}) and urine+urea (705 kg ha^{-1} yr^{-1}) treatments.

In another study, perennial ryegrass cv. Concord and white clover cv. Grasslands Huia were used in short-term pasture rotations (Williams and Haynes, 2000). The pasture had been planted previously to cereal and grain crops for ~ 20 yr and then planted to grass-clover 2 yr before start of the experiment. Nitrogen concentration in herbage was measured 14, 33, 77, and 133 d after application of sheep urine. Resulting concentrations were 46, 31, 29, and 22 g N kg^{-1}, respectively. In the long-term pasture, a pasture that was sown ~25 yr prior to the experiment and rotationally stocked by sheep, N concentration in herbage decreased slightly compared to the short-term pasture and was 33, 28, 24, and 24 g kg^{-1}, respectively, for the four time periods after urine application. Clearly the impact of urine is greatest soon after application and diminishes with time.

Dung

Quantity and distribution in grazed pasture

Cattle defecate approximately 12 times d^{-1} (Peterson and Gerrish, 1996), with the reported range from 8 to 16 times d^{-1} (Barrow, 1967; Wilkinson and Lowrey, 1973; Peterson and Gerrish, 1996) and an average wet weight of 1.5 to 2.7 kg per defecation (Haynes and Williams, 1993; Table 2.1). The area covered by a single dung pat is generally from 0.05 to 0.09 m^2. Like urine, dung deposition is often not uniform across the pasture and is concentrated in high traffic areas.

Chemical composition

Dung contains undigested herbage residues, products of animal metabolism, ingested soil, and a large biomass of microorganisms (Rotz et al., 2005). Most of the nutrients in dung are not immediately plant available; the main factors affecting decomposition and disappearance of dung are microbial decomposition, weathering, disintegration of pats due to invertebrates, and consumption and removal of dung by insects and lumbricids (Holter, 1979; Lee and Wall, 2006). Holter (1979) found hot and dry summers slowed dung disappearance, resulting in 65% of the dung pat remaining after 65 d compared to other years with pat disappearance (only small particles or "soil-like material" left) in 50 d. Lee and Wall (2006) estimated that complete disappearance for dung pats can take 57 to 78 d and 88 to 111 d in spring and summer, respectively.

Almost all P excreted is in the feces, and more than 70% of P in manure is inorganic P (Eghball et al., 2005). Nitrogen is also excreted through dung at about 8 g kg^{-1} of feed consumed. Nitrogen in dung is only 20 to 25% water soluble, and volatile loss of NH_3 is less than 5% (Rotz et al., 2005). About 10 to 20% is undigested dietary N and the remaining 60% is in bacterial cells (Whitehead, 1986). On average, "as excreted" cattle feces is 5.2 g N kg^{-1}, 1.9 g P kg^{-1}, and 4.1 g K kg^{-1}, for an N:P:K ratio of 2.7:1:2.2 (Edwards, 1996).

Powell et al. (2006) describe fecal N pools as being either endogenous N or undigested feed N. The endogenous N pool consists of organic N forms which are readily available and contributes to crop N requirements the year of application. The undigested feed N mineralizes slowly in soil and is plant unavailable until broken down by microorganisms.

Effect on herbage production and nutritive value

Studies have evaluated the impact of cattle dung on herbage production (Williams and Haynes, 1995). Dung deposits initially reduced herbage yield owing to smothering. However, after 40 d, herbage around the edges of the dung patch responded positively to the dung and more dry matter was produced in this patch than in the control patch during the first 12 mo. Dung applied to pearl millet resulted in lower yields than excreta including both dung and urine that was collected from a corral where cattle and sheep were penned. This is due to the more readily available nutrients in the urine compared to the dung (Powell et al., 1998).

Hirata et al. (1990) studied the effect of dung on bahiagrass herbage growth when dung pats from dairy cows were applied in June and August; there was also a control with no dung applied. The herbage dry matter growth rate was 0.2 g (0.04 m^{-2}) d^{-1} from the initial application of the dung pat on 1 June until 29 June. The greatest herbage growth rate was observed from 1 to 12 July and was 0.8 g (0.04 m^{-2}) d^{-1}. The greatest herbage growth rate for the August dung application did not occur until the following year when from 29 June to 12 July growth was 1.2 g (0.04 m^{-2}) d^{-1}. They found that some plants covered by the dung pat were killed, thus explaining the reduced herbage growth.

In a greenhouse trial, feces was added to three different soils (Fine-loamy, mixed, superactive, frigid Oxyaquic Glossudalfs; fine-silty, mixed, superactive, mesic, Typic Argiudolls; coarse-loamy, mixed, superactive, frigid, Haplic Glossudalfs) such that a total of 350 kg N ha^{-1} was mixed with 800 g of soil. Oat (*Avena sativa* L.) and sorghum [*Sorghum bicolor*

(L.) Moench] were planted. Plant dry matter yield and N uptake were more affected by soil type than feces type (diets fed to animals producing feces for the study were corn silage-low CP; corn silage-high CP; alfalfa-low CP; alfalfa-high CP; Powell et al., 2006). Soil type accounted for 67, 65, and 82% of the variability in N uptake by oat and sorghum; feces from the low CP diets decreased oat dry matter production likely due to N immobilization (Powell et al., 2006).

Pearl millet was grown in pots and the soil was amended with fecal material (with fertilizer N or without fertilizer N) or with leaves. Dry matter yield was measured from 60 to 240 d after amendment application. Pearl millet amended with feces accumulated about 37% more P than when amended with leaves (*Acacia trachycarpa*, *Combretum glutinosum*, *Guiera senegalensis*, *Pterocarpus erinaceus*, *Pennisetum glaucum*, and *Vigna unguiculata*), perhaps due to immobilization of P in the leaves. Feces without fertilizer N did not affect pearl millet dry matter yield or N and P uptake, while feces with fertilizer N resulted in a yield response likely due to enhanced N mineralization (Powell et al., 1999).

Cherney et al. (2002) applied three different nutrient treatments (NT) to orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.). Treatments were inorganic N fertilization at 196 kg ha^{-1} (NT 1) or dairy cow manure which was applied at two rates (X and 2X and termed NT2 and NT3) in 1995, 1996, and 1997. Rates of N applied in manure were 123 and 246 kg N ha^{-1} in 1995, 134 and 268 kg N ha^{-1} in 1996, and 143 and 286 kg N ha^{-1} in 1997. The relative N recovery in 1995 through 1997 for orchardgrass was 72, 58, and 45%, respectively, for NT1, NT2, and NT3. Tall fescue had a relative N recovery of 76% for NT 1, 58% for NT 2, and 48% for NT 3. They concluded that perennial grasses can utilize large quantities of applied N, even N from dung.

Fate of Nitrogen from Excreta Applied to Grazed Grass Swards

Nitrogen Cycle in Grazed Grasslands

The major N pools in grazed grasslands are the soil, vegetation, grazing animals, and atmosphere. Fluxes among pools are a function of climate, soil microbiota, forage species, and herbivores. Considering all terrestrial ecosystems, the atmospheric N pool is 16 000 times greater than the sum of the soil and biotic N pools (Russelle, 1996); however, it is available to plants only through biological N fixation (Marschner, 1995). In grasslands, the soil is the second largest N reservoir and is affected by soil OM, soil microbial biomass, fixed NH_4^+, and to a lesser extent, plant-available inorganic N (Stevenson and Cole, 1999). The below-ground soil mesofauna are also important components of the soil pool, and the rhizosphere may contain from 4500 to 24 000 kg N ha^{-1} (Henzell and Ross, 1973). These amounts are far greater than the 20 and 400 kg N ha^{-1} reported in live herbage of tropical forages (Dubeux et al., 2007). Litter is another very important N pool, because along with the soil microbiota it constitutes the link between N in metabolically active plant tissues and N available for plant uptake (Thomas and Asakawa, 1993).

Nutrients cycle among pools in the grassland and the rate of flux between pools is associated with fertilization practice, stocking rate, soil microfauna, climate, soil chemical characteristics, and plant species. Biological pathways of N in pasture soils include nitrification and denitrification (Wrage et al., 2004; Clough et al., 2004). Boddey et al. (2004) found when stocking rate increased from 2 to 4 animals ha^{-1}, N deposited as urine and dung in the paddocks increased from 50 to 90 and 37 to 59 kg ha^{-1}, respectively. Some pathways of loss, such as denitrification and volatilization of NH_3, can be reduced by activity of dung beetles and earthworms which incorporate feces into soil and eliminate anaerobic zones around the dung pats

(Dubeux et al., 2007). The different pathways of nitrogen loss will be discussed in greater detail in the following sections.

Pathways of Nitrogen Loss from the Agroecosystem

Loss of nutrients from urine to the environment occurs primarily via volatilization and leaching (Mathews et al., 1996). Urine spots on sandy soils have a lower ammonia loss due to higher infiltration (Rotz et al., 2005). Urine is particularly susceptible to gaseous N losses because urine N is not bound to organic compounds (Sollenberger et al., 2002). Nitrogen loss from urine is typically greater than from dung spots (Rotz et al., 2005). Excreta (especially urine) contains a high concentration of soluble N that is very susceptible to either gaseous (ammonia volatilization, denitrification) or leaching losses. Much excreta N in grazed pasture is deposited in rest areas and around drinking troughs where the vegetation can be so trampled that very little N is recovered in forage production (Boddey et al., 2004). Grazing alters N cycling in ecosystems; it may alter fluxes of N to the atmosphere and change the amount of the different chemical forms released (Pineiro et al., 2006).

Gaseous losses

Concentrations of atmospheric N_2O have increased since pre-industrial times (Rockmann et al., 2003), with one of the main contributions being from agricultural soils (Perez et al., 2003; Clough et al., 2004). Excreta on grasslands represent high, very local additions of N, which creates optimal conditions for N_2O emissions (van Groenigen et al., 2005b). Emissions are typically greater in grazed than ungrazed grasslands (Clough et al., 2004) due to soil compaction by animals. Compaction can reduce water penetration, causing ponding and saturated soils and resulting in reduction of aeration and the increase of anaerobic environments (Smith et al., 1998; van Groenigen et al., 2005b). Severity of compaction is affected by soil texture, and it is limited in sandy-soil environments like Florida. There are several studies which have implicated compacted areas as "hot spots" of N_2O emission from pastures (Anger et al., 2003; Carran et al., 1995; and van Groenigen et al., 2005b). Allen et al. (1996) reported a shift from N_2O consumption to N_2O production during warm conditions. Clough et al. (2004) found when synthetic urine was applied to limed soil cores with different water-filled pore spaces (WFPS) there were significant differences in N_2O emission and soil pH. Soils at field capacity (54% WFPS) that had a pH greater than or equal to 5.9 produced the least amount of N_2O, while the N_2O flux was greatest in saturated (80% WFPS) treatments with a pH of 4.7.

Under suitable conditions, i.e. moisture, temperature, pH, etc., N_2O can be reduced in the soil and released as benign N_2 (Firestone, 1982; Clough et al., 2004). van Groenigen et al. (2005b) evaluated treatments including urine+dry soil, urine+dung, urine+compaction, and dung+soil with different water-filled pore space during an incubation period of 103 d at 16^{o}C. Nitrous oxide fluxes were measured 27 times during the 103 d. They reported a greater emission of N_2O for the urine+dung and urine+compaction treatments, while urine+dry soil had the lowest emissions likely due to greater immediate penetration into the soil.

Ammonia volatilization is another important pathway of N emission from the grassland and will be greatest at high temperatures and high soil pH (Boddey et al., 2004). Yokoyama et al. (1991) found when dung beetles colonized dung pats NH_3 volatilization ceased during the first week; although, denitrification increased 23% and was greater than for the uncolonized dung pats (12.2%). Denitrification increased due to supplies of available energy and NO_3-N and the consumption of O_2 by microorganisms.

It is reported that hippuric acid in urine has a controlling effect on both hydrolysis of urine N and on NH_3 volatilization, which may also have an affect on N_2O emission factors (Doak, 1952; Whitehead et al., 1989; van Groenigen et al., 2005a). van Groenigen et al. (2005a) theorize it is possible to control hippuric acid concentration in urine by changing the diet. Salts and other additives will dilute the N concentration in urine, leading to lower NH_3 volatilization (Bussink and Oenema, 1998; van Groenigen et al., 2005a).

Leaching losses

Nitrogen leaching is a major environmental concern in agroecosystems. Nitrate pollution of groundwater resources affects drinking water quality and the conservation of natural ecosystems (Steenvoorden et al., 1986). Stout et al. (2000) noted the uneven recycling of N through urine could increase N leaching and threaten water quality.

Leaching is rainfall dependent and likely to be greater in free-draining, sandier soils (Boddey et al., 2004). Nitrogen leaching takes place when precipitation exceeds evapotransporation (Steenvoorden et al., 1986). Perennial grasslands efficiently use soil water due to deep root systems and long growing seasons and also protect the soil surface from erosion and runoff minimizing soil and nutrient loss (Kemp and Michalk, 2005). Russelle et al. (2005) noted significant nitrate leaching occurs even in low N input systems because available N from excreta patches often exceeds plant uptake capacity. Hydrolysis is fairly rapid, approximately 1 d, resulting in high concentrations of NH_4^+ followed by the development of NO_3^- approximately 14 d after deposition (van Groenigen et al., 2005a).

Denitrification losses

Dung application may lead to anaerobicity due to high biological activity and subsequent lowering of the redox potential (Monaghan and Barraclough, 1993; van Groenigen et al., 2005b). Manure N in organic form is not lost by denitrification until after oxidation to the NO_3^- form (Edwards, 1996). Denitrification losses will only occur if there are anaerobic sites which will generally occur after heavy rainfall, and loss will be greater in soils with impeded drainage (Boddey et al., 2004). Denitrification is also promoted by high soil temperature, a low rate of oxygen diffusion, as well as the presence of soluble organic matter and nitrate (Luo et al., 1999). Luo et al. (1999) showed that there was no significant difference in denitrification rates between saturated and control cores collected during the cool-wet season, but during the warm season denitrification rates were strongly enhanced by NO_3^- additions. Although the responses to added N in the warm, dry season were not as large as those in other seasons, it may be the lack of soil moisture controlled denitrification.

Nitrification

When urea is applied to soil, it reacts with water in the presence of the urease enzyme and is rapidly converted to NH_4^+, a process called hydrolysis (Griffith and Murphy, 1996). The remaining NH_4^+ is oxidized to NO_2^- (nitrite) through nitrification. Nitrite is either denitrified or lost from the system or oxidized to NO_3^-, the latter being the dominant form of plant-available N in most soils. Nitrate can either be leached from the root zone or lost as N_2O or N_2. The conversion of NH_4^+ to NO_3^- leads to a decrease in pH over a period of approximately 2 wk (Doak, 1952; Haynes and Williams, 1992; van Groenigen et al., 2005a). Nitrite will accumulate under high pH following hydrolysis of urea due to *Nitrobacter* being inhibited (van Groenigen et al., 2005a).

Recovery of Excreta Nitrogen by Grassland Plants

Urine

Leterme et al. (2003) conducted an experiment measuring the fate of urine N over three time periods (spring, summer, and autumn) when applied to perennial ryegrass cv. Belfort plots receiving two N fertilizer rates (100 and 300 kg N ha^{-1} yr^{-1}). Three liters of spiked ^{15}N urine was applied to ryegrass plots, and plant N uptake was determined. They found that ryegrass recovery of N from urine ranged from 30 to 65%. The autumn application resulted in a relatively higher recovery of N, 49%, for the 100 kg N ha^{-1} yr^{-1} fertilizer treatment. The higher level of N fertilizer resulted in a decrease of urine N uptake in above-ground parts of ryegrass.

Ball et al. (1979) applied 300 (N300) and 600 kg N ha^{-1} (N600) as a mixture of urea and urine to perennial ryegrass-white clover plots in New Zealand. The urine was obtained from beef cattle fed pasture clippings in a barn. The ryegrass-white clover sward had an apparent N recovery of 37 and 23% for N300 and N600, respectively. Total herbage N yields increased with increasing N application, 143 to 202 kg N ha^{-1} as amount of N applied increased from 300 to 600 kg.

Thompson and Fillery (1998) conducted three experiments applying sheep urine spiked with ^{15}N at different times of the year to a rotation system including wheat (*Triticum aestivum* L.) pasture. Applications were either to pasture residues (Experiments 1 and 2), which were sown to wheat, or to growing pasture in winter-spring (Experiment 3). In Experiments 1 and 2, urine was applied in November 1990, April 1991, October 1991, January 1992, and March 1992 (9.8 g N m^{-2}, 46.1 g N m^{-2}, 4.6 g N m^{-2}, 15.6 g N m^{-2}, and 13.6 g N m^{-2}, respectively). Wheat recoveries in November 1992 were 4, 7, and 12% of ^{15}N applied. For Experiment 3, the urine was applied in August and September 1992 (12.3 and 25.9 g N m^{-2}, respectively). Nine days after urine application in August, 14% of the applied ^{15}N was taken up by the pasture plants, and after 6 wk 53% had been recovered. In September, 47% of the ^{15}N applied was recovered by the growing plants.

Pakrou and Dillon (1995) collected urine from dairy cows and spiked it with ^{15}N-labelled urea. The urine was applied to either irrigated white clover-perennial ryegrass paddocks, which received 25 to 30 mm of irrigation in a single application per week, or non-irrigated subterranean clover (*Trifolium subterraneum* L.)-based paddocks with annual grasses and weeds. To simulate a urination event, 11 mm of urine was applied in winter, spring, and summer. Paddocks were harvested 7, 28, 56, and 84 d each season after the urine application. In the winter, irrigated white clover-ryegrass total plant N recovered was 1% of applied ^{15}N at 7 d, 2% of applied ^{15}N at 28 d, 5% of applied N^{15} at 56 d, and 3% of applied N^{15} at 84 d. This compares with the non-irrigated subterranean clover plots which had recoveries of 1% at 7 d, 3% at 28 d, 17% at 56 d, and 20% at 86 d. The lower ^{15}N recovery in the irrigated paddocks can be attributed to the loss of ^{15}N in leachate. In spring there was no difference in plant uptake of ^{15}N among paddocks because sufficient soil moisture and active plant growth during spring and summer resulted in greater recovery of ^{15}N from the spring application.

Dung

Dairy manure (dung + urine) was applied annually at four different rates over 2 yr (0, 75, 150, 300 kg N ha^{-1} in 1990 and 0, 150, 300, and 600 kg N ha^{-1}) to orchardgrass managed for hay (Kanneganti and Klausner, 1994). Over the 2 yr, average N recovery was 40%. In a single cutting the crop removed as much as 200 kg N ha^{-1} when 600 kg N ha^{-1} was applied; and tissue N concentration was 45 g kg^{-1}.

In a dung pat study, Dickenson and Craig (1990) determined that uncovered and covered dung still contained 86 to 95% of their original N content, respectively, over an 85-d period. This has an impact on herbage accumulation under and surrounding dung pats, because most of the N is still in the pats and not available to the plant.

Impact on Soil and Water

Soil

Urine application on pastures can increase soil pH by 3 units within approximately 1 d due to hydrolysis of urea to NH_4^+ (van Groenigen et al., 2005a), although nitrification of the remaining NH_4^+ to NO_3^- leads to a decrease in pH over a 2-wk period (Doak, 1952; Haynes and

Williams, 1992; van Groenigen et al., 2005a). Powell et al. (1998) found that when urine from rams was applied to pearl millet, the urine not only increased soil pH from 4.5 to 9.5, but also increased available P, especially during the first week after application. The pH in the top 15 cm of the soil remained elevated for approximately 128 d, and Bray I-P appeared to decrease compared to the untreated control, perhaps indicating movement downward of P. Not only were there decreases in soil ammonium levels in the urine patches 1 d after urine application, but also a large increase in soil nitrate levels to a depth of 30 to 45 cm.

When plots of 'Nandi' setaria (*Setaria sphacelata* var. sericea) received 1.4 L of urine (37-48 g N m^2), the greatest increase in pH in the 0- to 0.5-cm soil layer occurred 2 to 6 h after urine application from an initial pH of 5 to a pH of 8, and after the second day there was a linear decline from pH of 8 to a pH of 4.5 (Vallis et al., 1982). Mineralization of urea occurred by 2 h after application, with only 200 g kg^{-1} of the original amount remaining, and by 14 h after application there was less than 20 g kg^{-1} present. This caused nitrate to accumulate after the first day, with a maximum NO_3^- concentration in the 0- to 1.5-cm soil layer on the seventh day.

Powell et al. (2006) reported feces applied to silt loams generally increased net soil inorganic N (IN), but when feces was applied to a sandy loam soil it caused net IN to decrease for 112 d followed by a rapid increase. This can be attributed to soil texture and chemical properties which had the greatest impact on soil N mineralization. Another possible reason is when microbial populations are deprived of supplied organic C input, biologically active pools of soil organic matter decline and this leads to a net release of soil nutrients. Also, when fed high protein diets cattle feces produced higher net soil IN than feces from low protein diets. Cows fed different diets (corn silage-low CP; corn silage-high CP; alfalfa-low CP; alfalfa-high CP) had different effects on soil IN, however, all fecal types applied to sandy loam soil had an initial 112 d of N immobilization followed by a gradual N mineralization to 365 d.

Dai (2000) investigated the decomposition of dung over time following deposition by young cows on mixed-species temperate grassland. Total N concentration in the dung, after drying at 40^{o}C for 48 h, was greatest (21 g kg^{-1}) on Day 5; the greatest soil-N concentration occurred on Day 6 (16 g kg^{-1}). Total soil N concentration outside the dung patch was 5 g kg^{-1}. Dickenson and Craig (1990) applied dung pats to plots which were watered and either covered with transparent plastic sheets (250 x 250 mm) stretched horizontally between four pegs at a height of 150 mm or left uncovered (with no plastic over the manure pile). Soil N concentration under the uncovered pats increased initially but then declined. This result could be due to N being removed from the soil by plants at a greater rate than it was being added. The P concentrations in the soils in all three treatments were similar and very little P moved out of the dung pats. The final soil P concentrations remained below initial levels, possibly due to immobilization by microbes.

Water

Pastures reduce N loss in sediment and runoff water compared with annual crops (Rotz et al., 2005), however, the more nutrients added to a system above that which the forage is able to absorb results in build up in the soil and creates risk for runoff and water contamination (Sigua et al., 2004). Low intensity grazing of unfertilized pasture land seldom causes problems in receiving waters, but pastures heavily fertilized with exogenous nutrients can have serious impacts (Correll, 1996). In pasture systems in humid climates, subsurface water usually has larger NO_3-N concentration and transport than surface runoff, and has a greater need for evaluation (Owens et al., 1992).

White (1988) reported that NO_3 leaching losses from intensively managed grazed pastures can be in the range of 100 to 200 kg N ha^{-1} yr^{-1}. Jabro et al. (1997) found during spring, summer, and fall applications of urine leached more NO_3-N below 1 m (19, 15, and 25 g m^{-2}, respectively) than the untreated control (1.7 g m^{-2}). In comparison, when dung was applied in the summer of the first and second year, 2.2 g m^{-2} and 1.8 g m^{-2} were leached, respectively.

Fate of Phosphorus from Excreta Applied to Grazed Grass Swards

Phosphorus Cycle in Grazed Grasslands

The P cycle is much more complex than the N cycle because the availability of P depends not only on biologically mediated processes of organic P but on the chemistry of inorganic P (Dubeux et al., 2007). Phosphorus exists in various chemical forms, inorganic P and organic P, which vary widely in their behavior and fate in soils (Fuentes et al., 2006). The main sources of organic P include manure, crop residues, and sludge. Organic P can be degraded into a long availability form of orthophosphate. Recovery of P in a growing season by plants can be very low; more than 80% may become immobile and unavailable for uptake because of adsorption, precipitation, or conversion to the organic form (Schachtman et al., 1998).

Phosphorus in manure is in various forms but is mostly inorganic, indicating that P availability following application should be high because this P fraction in manure converts to plant-available P in a short period after application (Eghball et al., 2005). Phosphorus is accumulated at low pH mainly into the alkali-extractable Al—P and Fe—P fractions which represent phosphate adsorbed to soil colloids (Haynes and Williams, 1993).

Pathway of Phosphorus Loss from the Agroecosystem

Leaching losses and runoff

Phosphorus loss is much greater in surface runoff than subsurface flow and is dependent on the rate, time, and method of P application; form of fertilizer or manure applied; amount and time of rainfall after application; and vegetation cover of the land (Shigaki et al., 2006). Long-term application of manures and biosolids typically results in soil-P levels in excess of crop needs (Elliot et al., 2002). Phosphorus typically does not leach unless the concentration in the soil is very high or the soil has very low retention capability.

Graetz et al. (1999) measured P accumulation in manure-impacted soils in Florida. Sites were chosen to reflect a wide range of impact and included active dairies, dairies abandoned for years, beef cattle pastures, and areas not significantly impacted by human activities (native areas). Pastures consisted of bahiagrass and bermudagrass. Soil samples were taken of each horizon to a depth of at least 120 cm using a bucket auger. These soil samples were analyzed for water soluble P (WSP), double-acid extractable P (DAP), and total P (TP). Native areas had less WSP in all horizons (1 mg kg^{-1}) compared to the other areas. The high cattle densities in the abandoned dairies had WSP concentrations averaging 45, 13, 16, and 8 mg kg^{-1} for the A, E, Bh, and Bw horizons, respectively. This indicated P movement vertically down the soil profile of high cattle density areas, and part of the P existed in a form readily removed by water. The DAP concentrations of native areas averaged 4 mg kg^{-1} compared to high cattle density areas (active and abandoned dairy) that averaged 707, 63, 238, and 72 mg kg^{-1} for the A, E, Bh, and Bw horizons, respectively. Double acid-extractable concentrations for the low cattle density areas averaged 16, 4, 34, and 18 mg kg^{-1} for A, E, Bh, and Bw horizons, respectively. The P forms (WSP, DAP, TP) in the pastures and forage areas tended to accumulate in the spodic horizon, which indicated vertical P movement in the low cattle density soil area, also. Soil pH in native areas was lowest, and it was the highest in the high cattle density areas, which can be related to high dung and soil Ca and Mg concentrations.

Nair et al. (2007) found that combined root systems of pine (*Pinus elliotti*) and bahiagrass may absorb soil nutrients more completely than grasses alone in a treeless system. This conclusion was based upon the reduction of WSP in tree-based systems. This superior absorption resulted in greater P uptake in the silvopasture system and less loss of nutrients to surface water. The silvopasture received 6 kg P ha^{-1} annually and was grazed; the treeless system was planted to bahiagrass and received a single inorganic P application of 6 kg P ha^{-1} in 2003 and was grazed. Soil samples were taken at a range of depths (0-5, 5-15, 15-30, 30-50, 50-75, and 75-100 cm). The treeless pasture had a greater Melich-1 P as depth increased up to 50 cm. This could be due to the silvopasture having a higher soil Al concentration which ranged from 350 to 1040 mg kg^{-1} compared to the treeless pasture (280-560 mg Al kg^{-1}). This high concentration of Al will adsorb P and form non-available compounds.

Phosphorus can move laterally from agricultural fields either in dissolved or particulate (attached to soil particles) forms (Elliot et al., 2002). When P is lost through runoff it causes negative environmental effects in surface water, such as eutrophication. The eutrophication of freshwater by increased inputs of P from agricultural runoff is a concern in many areas of the USA, particularly Florida (Sarkar and O'Connor, 2004). Arthington et al. (2003) found that using three different stocking rates (1.49, 2.63, and 3.48 ha cow^{-1}) of pregnant Brahman cows did not affect concentrations or loads of total P or N in runoff from planted summer or mixed winter pastures. They also found that control pastures, containing no cattle, provided similar amounts of total P and N in runoff water compared to pastures containing cattle, although it should be noted that these stocking rates are very low. The summer pastures consistently delivered greater P loads (1.28 kg ha^{-1}) in runoff than the winter pastures (0.03 kg ha^{-1}) because of greater P fertilization for at least 15 to 20 yr, even though P fertilization was discontinued in 1987, 12 yr before the start of this study.

In many soils, high P-sorbing oxide components keep leachate P levels well below eutrophication thresholds (0.01 to 0.05 mg L^{-1}); vertical flux of P is potentially significant in areas with shallow ground water and coarse-textured soils with little P-sorbing capacity (Elliot et al., 2002). Phosphorus loss is a concern on sandy, high water table soils with limited P-holding capacity (Mathews et al., 1996), like those in Florida. Phosphorus loss increases with input rate or soil test P level (Rotz et al., 2005). Phosphorus soil test values over 330 kg P ha^{-1} (Mehlich 1) in the upper 20 cm of soil greatly increases the chance for loss from the system, which will affect water quality (Sigua et al., 2004).

Mineralization

Mineralization of organic P compounds represents an important P source for plants, especially in soils with low levels of bioavailable P (Fuentes et al., 2006). Mineralization of organic P in the soil is catalyzed by various enzymes (phosphatases), including phytase (Eghball et al., 2005). These enzymes play a fundamental role in the P cycle allowing orthophosphate to be released from organic and inorganic compounds and increasing the bioavailable P (Fuentes et al, 2006). Mineralization is greatest when soil moisture is near field capacity and declines with soil drying. For P to become available for plants, phosphatase enzymes must breakdown the organic P compound (i.e., phosphate diester-nucleic acids, phosphoprotein, phospholipids, or phosphate monoester-glucose-6-phosphate, nucleotides) into phosphate (Fuentes et al., 2006).

Recovery of Excreta Phosphorus by Grassland Plants

It has been reported that dry beef cattle manure contains between 2.94 (Iyamuremye et al., 1996) and 4.02 g kg^{-1} of P (Griffin et al., 2003). Manure contains significant amounts of P that can be utilized for crop production (Eghball et al., 2005). Wilkinson and Lowrey (1973) reported that P cycling through grazing animals was inefficient in the short term because of negligible return of P through urination, the small area of coverage by manure each grazing season, and the low mobility and spatial unavailability of P in manure (Peterson and Gerrish, 1996).

There have been experiments showing benefits of excreta application to pastures, but these impacts have not exclusively been linked to P addition. One such study by Dalrymple et al. (1994) reported forage yield increases over a no-excreta control of 220 and 880 kg ha^{-1} in areas affected by manure piles and urinations, respectively (Peterson and Gerrish, 1996), although this benefit was not due solely to P addition. During and Weeda (1973; cited by Peterson and Gerrish, 1996) determined that a cattle dung pat affected forage growth in a zone 5-fold larger than the area covered by the pat. Forage P yields around the 0.25-m^2 area increased 23%.

Summary

The southeastern USA is an important area of livestock and bahiagrass production. Because of increasing cost of fertilizer nutrients and growing concern regarding the impact of agricultural systems on the environment, there is a need for greater understanding of nutrient relationships in grazed pasture. There is little information in the literature evaluating the impact of type and number of excreta applications to pasture on leaching of N, changes in soil nutrient concentration, and herbage growth and nutritive value. The objective of the research reported in the chapters that follow is to characterize the effects of cattle excreta application on 1) bahiagrass yield, chemical composition, and nutrient recovery and 2) nitrate leaching to shallow ground water.

CHAPTER 3
BAHIAGRASS HERBAGE DRY MATTER HARVESTED, NUTRIENT CONCENTRATION, AND NITROGEN RECOVERY FOLLOWING EXCRETA DEPOSITION

Introduction

Grazed bahiagrass (*Paspalum notatum* Flügge) pastures comprise approximately 1.1 million hectares and 75% of the planted perennial pasture resource in Florida (Gates et al., 2004; Mislevy et al., 2005). Bahiagrass is adapted to low soil nutrient levels, and limited amounts of fertilizer are applied to grazed swards (Chambliss and Adjei, 2006). Despite this, these areas are heavily scrutinized for their potential environmental impact. This is due to the large land area planted to this forage and to the sensitivity of Florida ecosystems, especially in terms of nutrient impacts on water quality (Nair et al., 2007). On agricultural lands, the lateral flow of P to surface water, particularly in Central and South Florida (Nair et al., 2007), and leaching of nitrates to ground water, more commonly in North Florida, are critical concerns (Woodard et al., 2002).

In low-input bahiagrass pastures in Florida, animal excreta and decaying plant matter (litter) are the major transitory nutrient pools, and the importance of excreta vs. plant litter increases as stocking rate increases (Thomas, 1992). Chemical transformations that occur during digestion and excretion of plant nutrients by herbivores cause nutrients in animal excreta to be more available for subsequent uptake by plants and more susceptible to loss to the environment than those in plant litter (Bardgett and Wardle, 2003; Boddey et al., 2004). Efficient recovery of these nutrients is hindered by the large quantity supplied in a single excreta event and because a disproportionately large number of these events occur in small areas where cattle congregate, e.g., near to shade, water, and supplemental feed sources (Mathews et al., 2004; Sollenberger et al., 2002).

It has been suggested that rotational stocking with short grazing periods, i.e., many paddocks per pasture, decreases the opportunity and tendency of animals to congregate in lounging areas by intensifying competition for feed and shortening residency periods (Haynes and Williams, 1993). In Florida, it was found that rotationally stocked pastures where grazing periods were short (1 to 7 d) had greater spatial uniformity in time spent by cattle, excreta deposition, and soil nutrient concentration than continuously stocked pastures (Dubeux, 2005). Thus, it is likely that greater uniformity of excreta deposition can be achieved by imposing rotational stocking with short grazing periods. Whether this intensification of grazing management results in more efficient nutrient cycling may depend on the degree to which more uniform excreta deposition enhances nutrient recovery by grassland plants and avoids excessive nutrient accumulation in soils or nutrient loss to surface or ground water.

There is little information in the literature evaluating the impact of type and number of excreta applications to pasture on leaching of N, recovery of nutrients in harvested herbage, and changes in herbage growth and nutritive value. The objective of this research was to characterize the effects of cattle excreta application on 1) bahiagrass yield, chemical composition, and nutrient recovery and 2) nitrate leaching to shallow ground water.

Materials and Methods

Experimental Sites

There were two sites used for this study. One location served as the source for excreta and the other site was used for excreta application to bahiagrass. Excreta source pastures were located at the University of Florida Beef Research Unit, northeast of Gainesville, FL (29.72^{o} N latitude, 82.35^{o} W longitude). This site was chosen because well-established ‘Pensacola’ bahiagrass pastures, fencing, and animals were readily available. Soils at this site were classified as Spodosols of the Pomona (sandy, siliceous, hyperthermic Ultic Alaquods) and Smyrna series (sandy, siliceous, hyperthermic Aeric Alaquods). Average soil pH was 5.5, and Mehlich-I extractable P, K, Mg, and Ca were 17, 29, 50, and 392 mg kg^{-1}, respectively.

A long-term, ungrazed stand of Pensacola bahiagrass at the Plant Science Research Unit, Citra, FL (29.41^o N latitude, 82.02^o W longitude) was used for application of excreta. The ungrazed area was used for this purpose so that amount and frequency of excreta applications could be controlled. Also, this location was chosen because the soils are well-drained sands, avoiding potential subsurface lateral flow of water and nutrients that could occur under the Spodosols at the Beef Research Unit. This could result in mixing of nutrients leaching from adjoining plots and preclude the drawing of meaningful conclusions regarding water quality from the treatments imposed. Also, this site had not been fertilized for the past 12 yr, so there was minimal carryover effect of previous treatments. The soils at the application site are classified as Tavares or Candler fine sands (sandy hyperthermic, uncoated Typic Quartzipsamments). Average soil pH was 5.5, and Mehlich-I extractable P, K, Mg, and Ca were 34, 70, 18, and 164 mg kg^{-1}, respectively.

Treatments and Design

Treatments were two excreta sources (from here forward referred to as Average or High pasture management intensity), two types of excreta (dung and urine), and three frequencies of excreta application (one, two, or three times per year). Average and High management intensity were defined based on N fertilizer amount and stocking rate. Average management pastures received 60 kg N ha^{-1} yr^{-1} and were stocked with two yearling heifers ha^{-1}, and High pastures received 120 kg N ha^{-1}yr^{-1} and were stocked with four yearling heifers ha^{-1}. These two management intensities were selected to represent fertilization and stocking regimes that are common in the Florida livestock industry (Average) or represent approximately the most intensive management applied to grazed bahiagrass (High). In addition, based on previous work by Stewart et al. (2007) it is expected that these treatments will result in forage that varies in nutritive value, especially N concentration, and that these differences likely will affect the composition of dung and urine.

The 2 x 2 x 3 factorial resulted in 12 treatments. In addition there were three control treatments that received no excreta and were fertilized with N at 0, 60, or 120 kg ha^{-1} yr^{-1}. The 15 treatments were replicated three times in a randomized complete block design. Plots were 3 x 3 m in area with a 1-m bahiagrass alley surrounding each plot.

Excreta Source Pastures

There were two replicates of each management intensity (Average and High) arranged in completely randomized design. Pastures were stocked continuously and pasture size was 1 ha for Average and 0.5 ha for High. Each pasture was grazed with two crossbred yearling heifers (Angus x Brahman) with average initial weight of 408 kg, and animal care was monitored according to Institutional Animal Care and Use Committee Protocol Number D655. Heifers were provided with access to water, trace mineral mix (minimum concentrations of Ca, 12; P, 6; NaCl, 19; K, 0.8; Mg, 1.0; S, 0.4; and Fe, 0.4 g $[100\ g]^{-1}$), and artificial shade (3.1 x 3.1 m) on all treatments.

All pastures were fertilized with 17 kg P and 66 kg K ha^{-1} on 15 May 2006. The Average treatment received 60 kg N ha^{-1} yr^{-1} in two equal applications of 30 kg ha^{-1} that were made on 15 May and 15 July 2006. On the same days, the High treatment received 60 kg N ha^{-1} for a total of 120 kg N ha^{-1} yr^{-1}. Grazing was initiated on 26 May 2006. Fertilization occurred in advance of initiation of grazing so that bahiagrass herbage would reflect treatment effects by the time cattle first entered the pastures.

The pastures were sampled to characterize herbage mass and nutritive value during each excreta collection period. Herbage mass was quantified using double sampling with the indirect sampling tool being a disk meter (Stewart et al., 2005). On each of the four pastures, five double samples and 20 disk heights were taken at each sampling date. Herbage mass was predicted from disk heights, and a single calibration equation was used across all pastures and the three sampling dates. The equation was herbage mass (kg ha^{-1}) = 340 (disk height [in cm]) - 137 (r^2 = 0.821). At the same sampling times, hand-plucked samples of the top 10 cm of the forage canopy were taken to represent cattle diets. Samples were collected from 30 representative locations per pasture, composited, dried at 60ºC, and analyzed for N and P concentration using a micro-Kjeldahl technique (Gallaher et al., 1975) and for in vitro digestibility using a two-stage procedure (Moore and Mott, 1974).

Excreta Collection and Analyses

The yearling heifers used for grazing the excreta source pastures were selected for docile temperament following careful screening of a large group of animals of similar age and weight. Initially 12 heifers were chosen. During the winter and spring before the start of the trial, they were fed hay and small amounts of concentrate several times each week to develop a routine of close proximity to people. Based on their response to this interaction, the group was reduced to eight heifers, the number needed for the grazing study.

Stanchions were erected in a corral near the pastures, and animals were moved to the corral several times per week during spring before the start of the trial. Concentrate feed was placed in troughs in front of the stanchions so that heifers were required to put their heads into the stanchions to gain access to the feed. After several weeks of this process, the animals were locked in the stanchions to become accustomed to short periods of restraint. This activity was suspended at least a week before dung and urine collection began.

During the trial, animals were brought to the stanchions for collection of urine and dung. Urine and dung were collected during three periods (12-16 June; 26-28 July; and 7-8 Sept. 2006) leading up to the three dates (20 June, 1 Aug., and 13 Sept. 2006) when excreta was applied to the plots. Application dates were at 6-wk intervals. Acquiring sufficient dung and urine required two, 4-h periods (4 h on each of 2 d) of collection per animal prior to the first application date, (all plots receiving one, two, or three applications per year received excreta on 20 June). One, 4-h period of collection per animal was required prior to the latter application dates (only plots receiving two or three applications per year received excreta on 1 August and only those receiving three applications were treated on 13 September). Animals were shaded and had access to water during the collection period.

For collection, the two pairs of animals from a given intensity treatment (i.e., both replicates) were brought from the pasture at 0700 h and locked in the stanchions (two pairs of two animals). To facilitate catching the animals in the stanchions, the animals were provided with a small amount of grain (~ 200 g per heifer). For the first collection period, when 2 d of collection were required for each group of animals, 3 d were allowed between collections to ensure that effects of the concentrate fed during the first collection were not present in the second excreta collection. To collect excreta, one person was positioned behind each group of two animals. Collection was accomplished using a fishing net that was mounted at the end of a 1.5-m wooden rod. A trash compacter bag was inserted in the net to collect the dung or urine. After an excreta event was caught, the dung or urine was immediately put into sealed containers and taken to a refrigerator for storage at 4°C. Prior to application, all excreta events of a given type (dung or urine) from one intensity treatment (four animals) were composited across field replicates. Thus, at time of application there were two types of dung and two types of urine (one of each excreta type from both Average and High treatments). Three subsamples were taken from the composited samples of urine and dung and analyzed to determine excreta chemical composition so that amount of nutrient applied to plots could be calculated.

During the June excreta collection, samples were taken to ensure that chemical composition did not change markedly during the 8 d of excreta storage prior to application, i.e., to ascertain that what was applied to the plots was similar in composition to what the animal would deposit fresh. This was accomplished by taking two subsamples from each of two separate urine and dung events. One of the two subsamples from each event was analyzed immediately; the other subsamples were stored in the same manner as the urine and dung that were eventually applied to the plots. At the date of excreta application to plots, these stored subsamples were analyzed to assess changes in chemical composition during the storage period (Table 3-1).

Urine samples for analysis were acidified with concentrated sulfuric acid to pH 2 to avoid N volatilization. Dung was analyzed for total N, organic N, NH_4-N, P, and K, and urine was analyzed for N, NH_4-N, urea-N, P, and K. Dung total N was analyzed using the Kjeldahl method- AOAC 984.13; NH_4-N analyzed using Distillation - AOAC 941.04; organic N by difference (Total N - Ammonia-N); and P and K were analyzed using Thermo IRIS Advantage HX Inductively Coupled Plasma Radial Spectrometer. Urine total N was analyzed using AOAC 2001.11 – Block digestion and Foss 2300 or 2400 Analyzer; urea and ammonia – AOAC 941.04, Analysis by Thermo IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer; and for P and K by Thermo IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer.

Table 3.1. Chemical composition of excreta analyzed immediately after collection (fresh) and after storage (stored) for up to 8 d at 4°C. Each value is the mean of the analysis of two subsamples.

Constituent	Urine		Dung	
	Fresh	Stored	Fresh	Stored
	----------	---------- g kg^{-1}	----------	----------
Total N	0.41	0.49	2.13	2.07
NH_3-N	0	0	0.075	0.070
Urea	0.29	0.26	†	†
Organic N	†	†	2.05	2.00
Total P	0.0024	0.0029	0.75	0.72
Total K	0.90	0.90	1.42	1.37

† Not analyzed for this constituent within this excreta type.

Plot Management

All ungrazed plots to which excreta would subsequently be applied were fertilized on 7 June with 18 kg P and 66 kg K ha^{-1}. Nitrogen application depended upon excreta-source treatment. Plots that received excreta from the High management intensity source pastures were fertilized with 120 kg N ha^{-1} yr^{-1}, split equally in two applications of 60 kg N ha^{-1} (7 June and 16 Aug. 2006). Plots that received excreta from the Average management intensity plots were fertilized with 60 kg N ha^{-1} yr^{-1}, in two applications of 30 kg N ha^{-1} (on the same dates as High). Following fertilization on 7 June, the entire plot area was irrigated with 25 mm of water because of spring drought and lack of early summer rainfall (rainfall in March through May at this location was 68 mm compared to a 30-yr average of 279 mm). Magnesium sulfate was applied to all plots on 6 July 2006 to address low soil Mg levels. It was applied at 135 kg ha^{-1} to provide 27 kg Mg ha^{-1} and 36 kg S ha^{-1}.

Excreta Application

All plots were staged to a 5-cm stubble on 19 June 2006. All experimental units except the no-excreta controls received dung or urine on 20 June. Subsequent applications were on 1 August and 13 September. Only plots receiving two or three excreta applications yr^{-1} received excreta on 1 August, while on 13 September only those plots receiving three applications yr^{-1} were treated.

Quantity of dung and urine and the area to which they were applied were determined based on values reported in the literature (Haynes and Williams, 1993; Table 2-1) and personal observation of the cattle. Two liters of urine constituted one application, and it was applied to an area of 0.283 m^2, a 60-cm diameter circle, with the center of the circle being the center of the plot (Fig. 3-1). Of the 2 L, 1 L was applied to a 30-cm diameter circle with the center being the center of the plot (area of 0.071 m^2), and 1 L was applied to the area outside the 30-cm diameter circle but inside the 60-cm diameter circle. This was done to reflect the likelihood of greater concentration of urine closer to the center of the affected area. The urine was applied using a watering can with a sprinkler head so that runoff from the 60-cm diameter circle was minimal.

Dung was applied at 2 kg fresh weight to an area of 0.071 m^2 (Fig. 3-1). This was a 30-cm diameter circle with the center being the center of the plot. The dung was evenly distributed across this area. Subsequent applications (for the two and three applications per year treatments) occurred at the same location in the plot.

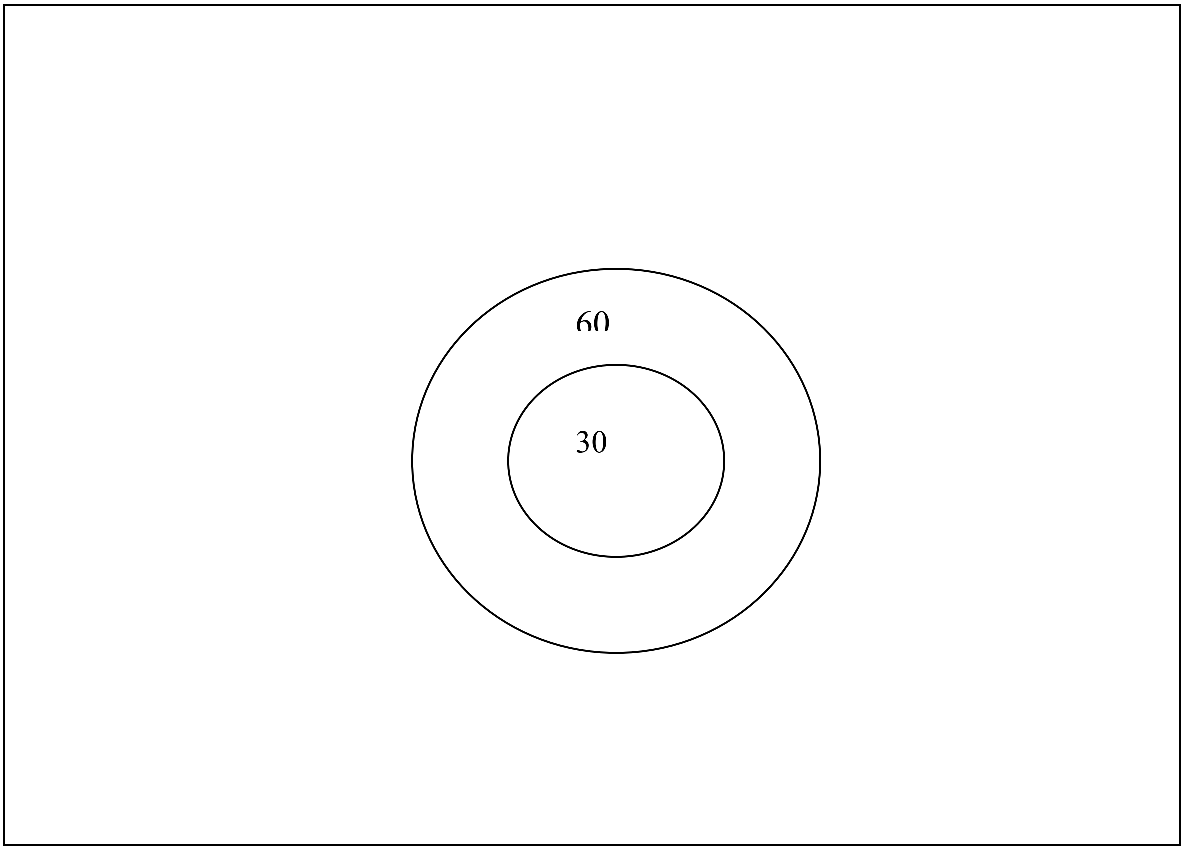


Figure 3-1. This drawing (not to scale) shows one plot or experimental unit and the areas to which urine and dung were applied. In plots where urine was applied, 1 L was applied to the area labeled 30 (inside a 30-cm diameter circle) and 1 L to the area labeled 60 (the area outside the 30-cm diameter circle but inside the 60-cm diameter circle). In plots where dung was applied, 2 kg fresh weight of dung was applied to the area labeled 30.

Forage Harvest and Herbage Analyses

Forage was harvested every 28 d following initial excreta application (20 June), and harvest dates were 18 July, 15 Aug., 12 Sept., and 10 Oct. 2006. To characterize the effect of the excreta application on herbage yield and nutritive value, herbage was clipped at each harvest date to a 5-cm stubble in a 90-cm diameter circle (0.636-m^2 area), the center of which was the center of the circles of dung or urine application. Harvested herbage was dried at 60^{o}C to a constant weight and weighed. It was subsequently ground to pass 1-mm screen and analyzed for

N and P concentration using a micro-Kjeldahl technique (Gallaher et al., 1975) and for in vitro digestibility using a two-stage procedure (Moore and Mott, 1974).

Lysimeter Placement, Water Sampling, and Water Analyses

One lysimeter, designed as described by Woodard et al. (2002), was positioned in each plot such that the ceramic cup was directly below the center of each plot and 1.3 m below soil level. The PVC pipe entered the soil at approximately 40 cm from the center of the excreta deposition site (beyond the area to which either dung or urine were applied) and angled through the soil so that the ceramic cup was properly placed beneath the center of the plot and the excreta application site. This approach allowed the sod immediately around the excreta deposit to be undisturbed. This depth for placement of the lysimeters cup was chosen because it is below nearly all grass roots.

The intent was that lysimeters be sampled every 14 d or after major rainfall events (> 25 mm). During dry periods when 14-d sampling was not possible because of inadequate soil water, re-initiation of sampling was triggered by major rainfall events (> 25 mm) that resulted in sufficient soil water so that the lysimeters could hold a vacuum. Two days prior to sampling, any water contained in the lysimeter was evacuated, then a suction (40 to 45 kPa) was placed on it. At sampling, suctions were released. Samples were acidified (pH of $\leq$2) and placed in a cooler within 15 min of extraction. Water sampling between 20 June 2006 and 2007 occurred on 23 and 28 June, 10 and 24 July, 8, 22, and 29 Aug., 15 and 27 Sept., 12 and 19 Oct., 19 Nov., and 29 Dec. 2006, and 5 and 26 Jan., 5 and 19 Feb., and 23 Apr. 2007. The water was analyzed for NO_3-N and total P. Occasionally throughout the growing season, samples were analyzed for NH_4-N to insure that there was no water moving down along-side the external wall of the lysimeters and transferring fertilizer N directly to the collection cup. At no time were there measurable concentrations of P or NH_4-N, so these data are not presented.

Data Presentation and Statistical Analyses

Herbage dry matter (DM) harvested is expressed on a total-season basis, i.e., the sum of four harvests. Tissue N, P, and in vitro digestible organic matter (IVDOM) concentrations are the weighted averages across four harvests. Nitrogen and P harvested were calculated for each harvest date (product of DM harvested and nutrient concentration in harvested herbage) and summed across the four harvests for a total-season measure. Excreta N recovery was calculated by summing N harvested across the four harvests for a given excreta treatment and subtracting from this sum the total seasonal N harvested from the appropriate (Average or High) no-excreta control. This number was then divided by excreta N applied to that plot and the result expressed as a percentage.

Data were analyzed using PROC MIXED in SAS (SAS Institute, Inc. 2007). For herbage mass and nutritive value from the excreta source pastures, management intensity was a fixed effect and replicate was a random effect. Date was considered a repeated measure.

For herbage data from the excreta application experiment, an initial analysis was conducted using the 12 factorial treatment combinations (two management intensities, two excreta types, and three application frequencies). These factors and their interactions were considered to be fixed effects and replicate a random effect. Polynomial contrasts were used to determine the nature of the response to application frequency.

The excreta type X application frequency interaction was significant for six of seven herbage response variables for the factorial data set. To more completely explore this interaction and to integrate the no-excreta controls, a follow-up analysis was conducted. This approach considered the no-excreta control treatments for the Average and High management intensities (60 and 120 kg N ha^{-1} yr^{-1}) as a zero level of excreta application frequency, providing a fourth level of application frequency (0, 1, 2, and 3). Because of the presence of excreta type X application frequency interaction in the initial analysis, these data were analyzed by excreta type and polynomial contrasts were used to determine the nature of the response to application frequency. Water data were analyzed by sampling date using the same statistical approach described for herbage data from the excreta application experiment.

An additional follow-up analysis was carried out for the data from the three control treatments. In this case, the treatment was N fertilizer amount, so the effect of N on herbage responses was determined using polynomial contrasts.

For all response variable from both experiments, differences were deemed significant when $P \leq 0.10$. Data presented are least squares means.

Results and Discussion

Characteristics of Excreta Source Pastures

There were no interactions of sampling date and management intensity for herbage characteristics of excreta source pastures, but interaction means are presented so that excreta nutrient concentrations can be considered relative to pasture characteristics at time of excreta collection (Table 3-2). There were no management intensity effects for herbage mass (3030 kg ha^{-1}), herbage P concentration (2.0 g kg^{-1}), or herbage IVDOM concentration (520 g kg^{-1}), but herbage N concentration was greater for High than for Average management intensity (17.1 vs. 14.4 g kg^{-1}). Sampling date affected herbage mass and IVDOM only, although there was a trend ($P = 0.117$) toward greater herbage N concentration in July than in the other months. Mass was similar in June (2820 kg ha^{-1}) and September (2810 kg ha^{-1}), but was greatest in July (3470 kg ha^{-1}). The second application of N fertilizer occurred on 19 July, 10 d after the second application of N fertilizer, and this timing along with typical seasonal growth patterns (Stewart et al., 2007) likely explain the greater herbage mass in July and the trend toward greater N concentration. Herbage IVDOM was similar in June and July (558 and 540 g kg^{-1}) but was least in September (461 g kg^{-1}). When evaluating two intensities of management of bahiagrass pastures, Stewart et al. (2005) reported lesser bahiagrass herbage mass (2.87 vs. 3.42 Mg ha^{-1}) but greater N concentration (18.1 vs. 15.8 g kg^{-1}) on pastures that were fertilized with 120 kg N ha^{-1} yr^{-1} and stocked at 2.4 animal units ha^{-1} than those that received 40 kg N ha^{-1} yr^{-1} and were stocked at 1.4 animal units ha^{-1}. These treatments are similar to High and Average intensities in the current study, and herbage N concentration response was similar in the two experiments. Although there was no intensity effect on herbage mass in the current study, herbage mass means were in a similar range to those reported by Stewart et al. (2005).

Excreta Composition

Excreta composition for applied dung (Table 3-3) and urine (Table 3-4) varied across dates. The elevated N concentration in urine during the second collection (Table 3-4) can be attributed in part to the trend ($P = 0.117$) toward greater herbage N concentration during that period (Russelle, 1996), but the large increase in urine N concentration cannot be accounted for by this relatively minor change in diet N. Urine N concentration is highly responsive to diet N, and Valk and Hobbelink (1992; reported in Russelle, 1996) found that lactating dairy cows fed diets with greater energy concentrations (lesser N concentrations) had decreased urine N concentration.

Table 3-2. Herbage mass, N, P, and in vitro digestible organic matter (IVDOM) concentrations of bahiagrass herbage during excreta collection periods in 2006.

Management intensity†	Herbage mass ($kg\ ha^{-1}$)			N concentration ($g\ kg^{-1}$)			P concentration ($g\ kg^{-1}$)			IVDOM ($g\ kg^{-1}$)		
	June	July	Sep.	June	July	Sep.	June	July	Sep.	June	July	Sep.
Average	2840	3620	2850	14.5	14.9	13.6	1.84	2.00	2.03	550	547	461
High	2810	3320	2770	16.9	17.6	16.5	1.95	2.08	2.08	567	534	461
P value	0.94	0.42	0.88	0.31	0.28	0.06	0.79	0.48	0.76	0.48	0.14	1.0
SE	259	166	459	0.91	0.91	0.53	0.24	0.05	0.10	27.9	5.2	7.8

† Average refers to pastures fertilized with 60 kg N ha^{-1} yr^{-1} and stocked at 2 yearling heifers ha^{-1}, while High refers to pastures fertilized with 120 kg N ha^{-1} yr^{-1} and stocked at two yearling heifers ha^{-1}.

Table 3-3. Composition of fresh dung from Average and High management intensity source treatments during three collection periods in 2006. Each value reported is the average across three subsamples from a composite dung sample. Dung was composited across replicates within a management intensity treatment, so statistical comparisons of treatment effects are not possible.

Nutrient	Dung Application Date					
	20 June		1 August		15 September	
	Average†	High	Average	High	Average	High
	g kg^{-1} fresh dung					
Total N	1.97	2.10	2.03	2.13	2.25	1.85
NH_3-N	0.07	0.08	0.08	0.10	0.09	0.08
Organic N	1.89	2.02	1.95	2.03	2.16	1.77
Total P	0.64	0.74	0.71	0.67	0.72	0.57
Total K	1.37	1.49	1.32	1.32	1.46	1.43

†Average refers to pastures fertilized with 60 kg N ha^{-1} yr^{-1} and stocked at 2 yearling heifers ha^{-1}, while High refers to pastures fertilized with 120 kg N ha^{-1} yr^{-1} and stocked at two yearling heifers ha^{-1}.

Table 3-4. Composition of urine from Average and High management intensity source treatments during three collection periods of 2006. Each value reported is the average across three subsamples. Urine was composited across replicates within a management intensity treatment, so statistical comparisons of treatment effects are not possible.

Nutrient	Urine Application Date					
	20 June		1 August		15 September	
	Average†	High	Average	High	Average	High
	g kg^{-1} urine					
Total N	1.60	1.58	4.04	2.97	0.98	1.88
NH_3-N	0.00	0.00	0.00	0.00	0.00	0.00
Urea-N	0.84	0.88	1.82	1.71	0.37	0.86
Total P	0.0033	0.0042	0.0049	0.0047	0.0027	0.0049
Total K	2.20	2.39	3.77	2.76	1.38	2.27

† Average refers to pastures fertilized with 60 kg N ha^{-1} yr^{-1} and stocked at 2 yearling heifers ha^{-1}, while High refers to pastures fertilized with 120 kg N ha^{-1} yr^{-1} and stocked at two yearling heifers ha^{-1}.

Nutrients Applied in Excreta

Quantity of N, P, and K ha^{-1} applied at each of three application frequencies for Average and High management intensities are shown in Tables 3-5 (dung) and 3-6 (urine). Amount of nutrient applied per unit land area is greater for dung than urine because of the smaller land area to which dung was applied.

Table 3-5. Nutrients applied to dung treatments in bahiagrass swards. Calculations are based on chemical analyses of fresh dung (Table 3-3) and a 2-kg fresh weight dung application to a circle of 30-cm diameter. Data are expressed as kg of N, P, and K applied ha^{-1}.

Source	Frequency	Date: 20 June	1 August	15 September	Total
		kg N-P-K ha^{-1}			
Average	1	557-182-389	0-0-0	0-0-0	557-182-389
	2	557-182-389	574-201-373	0-0-0	1131-383-762
	3	557-182-389	574-201-373	636-204-415	1767-587-1177
High	1	594-209-422	0-0-0	0-0-0	594-209-422
	2	594-209-422	603-190-373	0-0-0	1197-399-795
	3	594-209-422	603-190-373	523-164-405	1720-563-1200

Table 3-6. Nutrients applied to urine treatments in bahiagrass swards. Calculations are based on the chemical analyses of urine (Table 3-4) and a 2-L volume of urine applied to a circle of 60-cm diameter. Data are expressed as kg of N, P, and K applied ha^{-1}.

Source	Frequency	Date: 20 June	1 August	15 September	Total
		kg N-P-K ha^{-1}			
Average	1	113-0.23-267	0-0-0	0-0-0	113-0.23-267
	2	113-0.23-267	286-0.35-267	0-0-0	399-0.58-534
	3	113-0.23-267	286-0.35-267	69-0.58-98	468-1.16-632
High	1	112-0.30-169	0-0-0	0-0-0	112-0.30-169
	2	112-0.30-169	210-0.33-195	0-0-0	322-0.63-364
	3	112-0.30-169	210-0.33-195	133-0.35-160	455-0.98-524

Herbage Dry Matter Harvested from Excreta-Treated Plots

Total-season herbage DM harvested was affected by management intensity ($P < 0.001$) and excreta type ($P < 0.001$) main effects and by the excreta type X application frequency interaction ($P = 0.063$) (Table A-1). For plots receiving excreta, as management intensity increased from Average to High, forage DM harvested increased from 3230 to 3850 kg ha^{-1}. Deenen and Middelkoop (1992) found the extent to which urine affected herbage growth of perennial ryegrass was dependent upon the level of N fertilizer applied. There was no effect of urine in swards receiving 400 kg N ha^{-1}, but positive effects on yield were noted in swards receiving 250 kg N ha^{-1}. In the current study, there were no interactions involving management intensity (i.e., N fertilizer level), so the response to excreta was consistent across levels of management intensity. One reason for the lack of interaction in the current study may be that fertilizer N levels applied were much less than those used by Deenen and Middelkoop (1992).

For the three control treatments to which no excreta was applied in the current study, the DM harvested response to N application had linear and quadratic terms, increasing from to 1310 to 2450 to 3060 kg ha^{-1} as N fertilizer applied increased from 0 to 60 to 120 kg ha^{-1} (Table 3-7). Responses to management intensity in both excreta-treated and no-excreta plots were primarily due to the differences in N fertilization and are consistent with bahiagrass responses to N fertilizer observed in the literature (Burton et al., 1997; Twidwell et al., 1998). Total-season DM harvested in the current study was less than reported in many previous studies including those by Burton et al. (1997), Twidwell et al. (1998), and Interrante et al. (2007). The two primary reasons for low yields in the current research are rainfall and previous management at the plot site. Rainfall totaled 722 mm during March through October 2006 compared to a 30-yr average of 962 mm (Table 3-8). In addition, the research site had not been fertilized for at least 12 yr, so overall stand vigor was relatively low at the beginning of the trial and this affected first-year DM harvested.

There was excreta type X application frequency interaction for bahiagrass DM harvested. Interaction occurred because there was no effect of dung application frequency on DM harvested (Fig. 3-2), but there were linear and quadratic effects of urine application frequency. The response to urine increased from 2760 kg ha^{-1} at zero applications to 4670 kg ha^{-1} with three applications. The quadratic effect was significant because the greatest increase in DM harvested was with the first urine application, while additional urine applications had less effect on DM harvested. For each level of excreta application frequency from one through three, urine-treated plots outyielded dung-treated plots ($P < 0.003$; Fig. 3-2).

Day and Detling (1990) applied simulated urine to a mixture of little bluestem [*Schizachyrium scoparium* (Michx.) Nash] and 'Kentucky' bluegrass (*Poa pratensis* L.). Urine-treated areas outyielded the no-urine control 3870 to 2720 kg ha^{-1}. Norman and Green (1958) applied urine to a mixture of cool-season grasses, legumes, and forbs in spring. One month after application, herbage DM harvested was 1870 kg ha^{-1} for treated plots compared to 1160 kg ha^{-1} for the untreated control and 3 mo after application the difference was 2050 vs. 1160 kg ha^{-1}, respectively. Thus, urine application is associated with yield increases that can carry over for at least several months.

One reason for lack of response to dung application was the interference effect on herbage under the pat. Reduction in DM harvested under the dung pat (circle of 15-cm radius) compared with the ring extending 15 cm beyond the edge of the dung pat was greater than 500 kg ha^{-1} averaged across application frequencies (Chapter 4). Hirata et al. (1991) described interference of dung pats on herbage beneath them or even death of herbage under the pat, resulting in reduced yields (Hirata et al., 1991). MacDiarmid and Watkin (1971) reported that 75% of grass tillers and rooted nodes of clover (*Trifolium* spp.) stolons under the dung pat were dead within 15 d of application. This resulted in a significant reduction in yield from the area of the pat. Another reason for the lack of a positive yield response in the dung-treated plots is the high proportion of organic N in dung relative to the high proportion of total urine N that is urea N (Table 3-3 and 3-4). Norman and Green (1958) suggested that chemical differences between dung and urine accounted for lesser response to dung. Additionally in the current study, there was relatively little dung beetle (*Scarabaeidae*) activity apparent as well as drier than normal weather, both of which can result in slower nutrient release (Holter, 1979; Dickenson and Craig, 1990; Yokoyama et al., 1991).

Table 3-7. Effect of N fertilization on bahiagrass herbage responses for treatments to which no excreta was applied.

Response variable‡	Nitrogen fertilizer applied (kg ha^{-1}) 0	60	120	Polynomial contrast†	Standard Error
DM harvested (kg ha^{-1})	1310	2450	3060	L^{**}, Q	125
N concentration (g kg^{-1})	13.6	12.7	13.9	NS	0.46
P concentration (g kg^{-1})	3.87	3.35	3.54	NS	0.22
IVDOM (g kg^{-1})	559	567	572	L^{**}	7.3
N harvested (kg ha^{-1})	17.6	31.1	42.4	L^{**}	1.4
P harvested (kg ha^{-1})	5.0	9.6	11.1	L^{**}	0.6

†L = linear, Q = quadratic; **, $P \leq 0.01$; *, NS, $P > 0.10$; Letter followed by no symbol, $P \leq 0.10$
‡Dry matter (DM) harvested; in vitro digestible organic matter (IVDOM)

Table 3-8. Monthly rainfall totals for 2006 for the research location and the 30-yr average for Island Grove, FL. Island Grove is located 10 km from the research location and is the nearest site for which 30-yr data exist.

Month	2006	30-yr Average†
	---mm---	
January	22	107
February	147	83
March	4	85
April	52	75
May	12	119
June	130	180
July	233	167
August	159	172
September	93	115
October	39	49
November	47	61
December	93	117
Annual	1031	1330

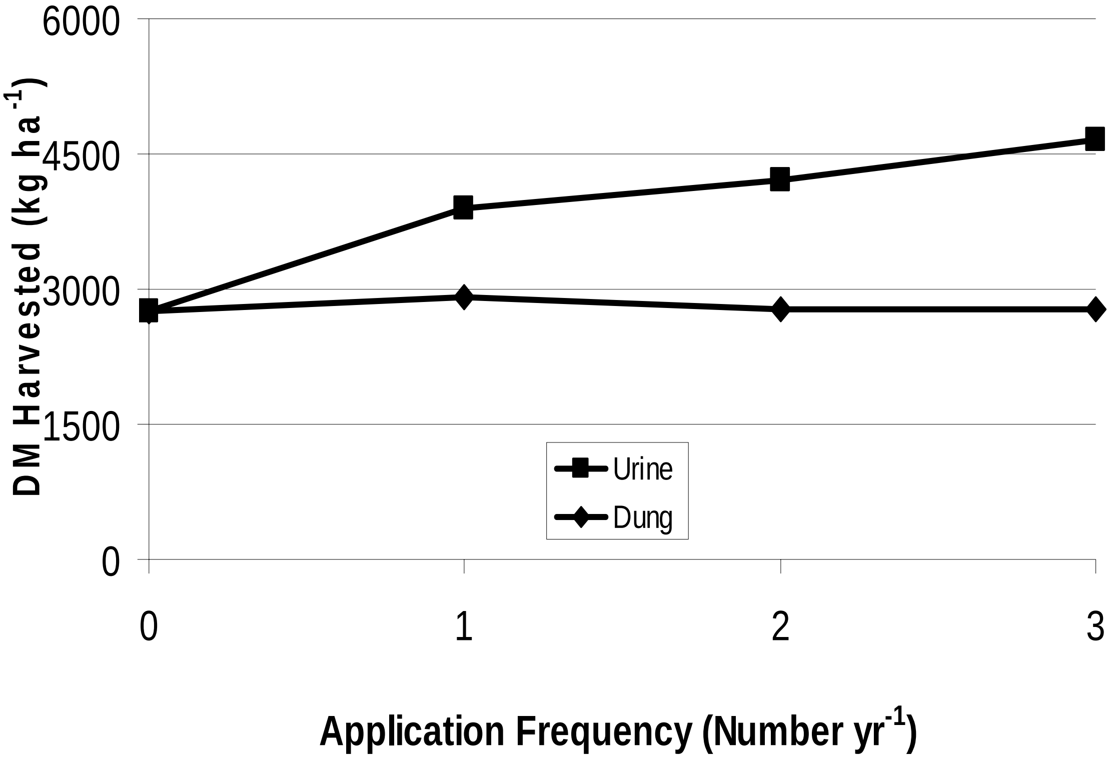


Figure 3-2. Excreta type X excreta application frequency interaction ($P = 0.063$) for bahiagrass DM harvested during 2006. There was no effect of dung application frequency on DM harvested ($P > 0.375$), but there were linear ($P < 0.001$) and quadratic ($P = 0.097$) effects of urine application frequency on the response. Standard error of a treatment mean was 103 kg ha^{-1}. Dry matter harvested was greater for urine- than dung-treated plots for Application Frequencies 1 ($P = 0.002$), 2 ($P = 0.003$), and 3 ($P < 0.001$).

Herbage Nitrogen Concentration

Herbage N concentration was affected by management intensity ($P = 0.039$), application frequency ($P < 0.001$), excreta type ($P < 0.001$), and application frequency X excreta type interaction ($P < 0.001$) (Table A-1). High management intensity plots had greater N concentration than Average intensity (14.7 and 14.2 g kg^{-1}, respectively). For control plots, N concentration ranged only from 12.7 to 13.9 g kg^{-1} and was not affected by amount of N fertilizer applied (Table 3-7). Pensacola bahiagrass herbage N concentration increased from 9.9 to 13.8 g kg^{-1} when N fertilizer amount increased from 0 to 224 kg ha^{-1} (Beaty et al., 1975). In Louisiana, Pensacola bahiagrass N concentration increased from 16.8 to 23.0 g kg^{-1} as N fertilizer amount increased from 0 to 450 kg ha^{-1} (Twidwell et al., 1998), while in Georgia it increased from 10.6 to 16.8 g kg^{-1} as N fertilizer increased from 56 to 450 kg ha^{-1} (Burton et al., 1997). Thus, bahiagrass is responsive to N fertilizer, but the range in N applied was relatively small in the current study.

There was excreta type X application frequency interaction for herbage N concentration. Interaction occurred because there was no effect of frequency of dung application on N concentration ($P > 0.246$), but there were linear ($P < 0.001$) and cubic effects ($P < 0.001$) for response to urine application frequency (Fig. 3-3). The linear effect was associated with an increase from 13.3 to 16.2 g kg^{-1} as application frequency increased from zero to three. The cubic effect occurred because there was little change in N concentration between zero and one application, a large increase between one and two applications, and little change between two and three applications. Urine-treated plots had greater herbage N concentration than dung-treated plots for Application Frequencies 2 and 3 ($P < 0.001$), but there was no excreta type effect for a single application ($P = 0.495$; Fig. 3-3).

Jaramillo and Detling (1992) reported that herbage N concentration in urine-affected areas of western wheatgrass [*Pascopyrum smithii* (Rydb. Á. Löve)] was greater than in control patches. Herbage N concentration averaged 30 and 16 g kg^{-1} for affected and unaffected areas. Ledgard et al. (1982) found similar effects of urine on N concentration in a perennial ryegrass (*Lolium perenne* L.)-white clover (*Trifolium repens* L.) mixture. Ryegrass herbage N concentration in urine patches was 47 g kg^{-1} compared to 30 g kg^{-1} for unaffected areas.

The range in N concentration in dung-treated plots was only 13.2 to 13.6 g kg^{-1} ($P > 0.246$). Lack of N concentration response to dung application frequency can be attributed to reasons similar to those for absence of a DM harvested response to dung. Others have found some impact of dung on herbage N. Perennial ryegrass herbage from dung-affected areas had N concentration of 12.3 compared to 10.8 g kg^{-1} for unaffected herbage (Jorgensen and Jensen, 1997). Similarly, Greenhalgh and Reid (1968) stated that N concentration of perennial ryegrass herbage near a dung deposit was greater than similar herbage growing in harvested fields (32 vs. 27 g kg^{-1}, respectively).

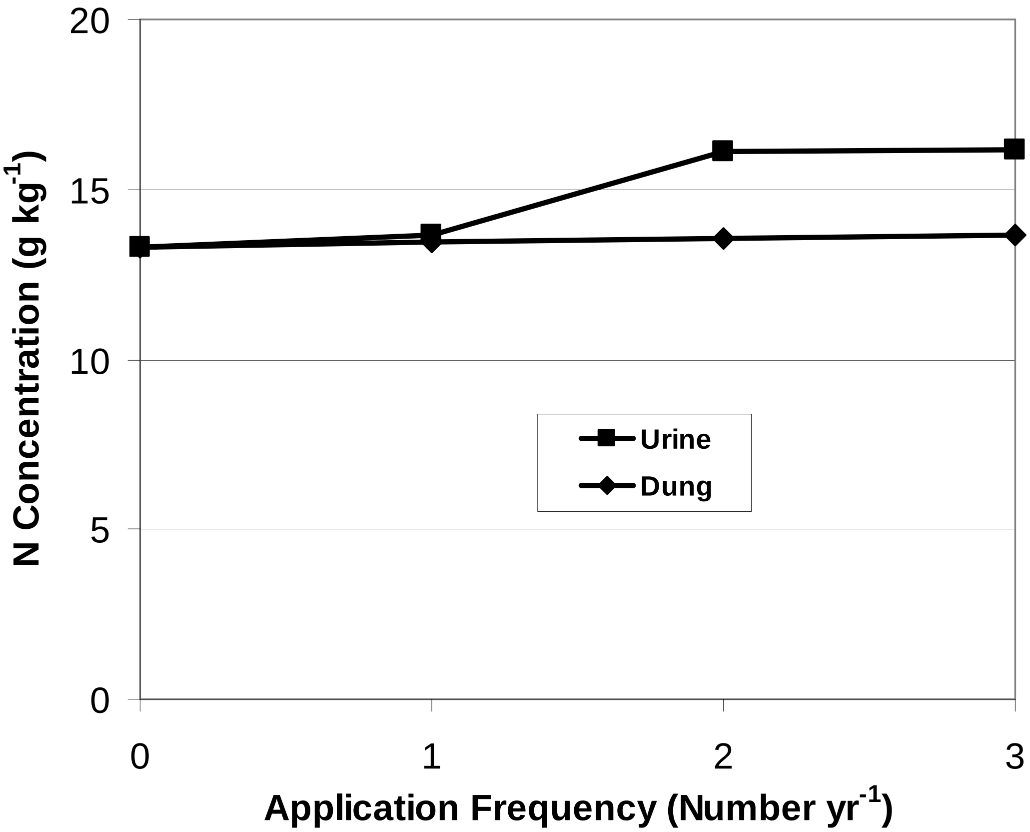


Figure 3-3. Excreta type X excreta application frequency interaction ($P < 0.001$) for bahiagrass herbage N concentration during the 2006 growing season. There was no effect of dung application frequency on N concentration ($P > 0.246$), but there were linear ($P < 0.001$) and cubic ($P < 0.001$) effects of urine application frequency on the response. Standard error of a treatment mean was 1.5 g kg^{-1}. Herbage N concentration was greater for urine- than dung-treated plots for Application Frequencies 2 and 3 ($P < 0.001$), but there was no excreta type effect for a single application ($P = 0.495$).

Herbage Phosphorus Concentration

Herbage P concentration was affected by application frequency (P = 0.003) and the application frequency X excreta type interaction (Table A-1). Interaction occurred because there was no effect of dung application frequency on herbage P concentration (P > 0.583), but there were linear (P = 0.025) and quadratic (P = 0.002) effects on herbage P concentration in urine-treated plots (Fig. 3-4). At Application Frequencies 1 and 3, P concentration in herbage from urine-treated plots had lesser and greater P concentrations (P = 0.004 and 0.035), respectively, than herbage from dung-treated plots (Fig. 3-4). There was no effect of excreta type at Application Frequency 2 (P = 0.752). Herbage P concentration in dung-treated plots remained in a narrow range between 3.33 and 3.45 g kg^{-1}. Absence of bahiagrass DM harvested and herbage P concentration response to dung application frequency indicate that almost none of the large amounts of P applied (up to nearly 600 kg P ha^{-1} for the three applications yr^{-1} treatment) were taken up by the plant.

The strong quadratic effect of urine application frequency on tissue P concentration occurred because of a decline from 3.45 with no urine applied to 2.83 g P kg^{-1} with one urine application. The initial decline is likely related to greater herbage DM accumulation following one urine application with essentially no additional P applied (0.2-0.3 kg P ha^{-1}; Table 3-6). Powell et al. (1998) reported that when urine from rams was applied to pearl millet [*Pennisetum glaucum* (L.) Br.], the urine not only increased pH, but also increased available P, especially during the first week after application. In the current study, as application frequency increased from one to three yr^{-1}, herbage P concentration increased from 2.83 to 3.87 g P kg^{-1}. This large increase in P concentration is not due to greater P application because those amounts changed only from 0.23 (Average) or 0.30 (High) kg P ha^{-1} for one urine application to 1.16 (Average) or 0.98 (High) kg P ha^{-1} for three applications (Table 3-6). Thus, the response may be due to greater plant vigor associated with greater N application as frequency of urine application increased. This likely would lead to greater root growth and soil volume explored for P. We currently do not have root-mass data to support this argument, but Beaty et al. (1975) reported greater P concentrations in bahiagrass herbage associated with greater N rates and explained this response based on greater root mass and exploration of the soil.

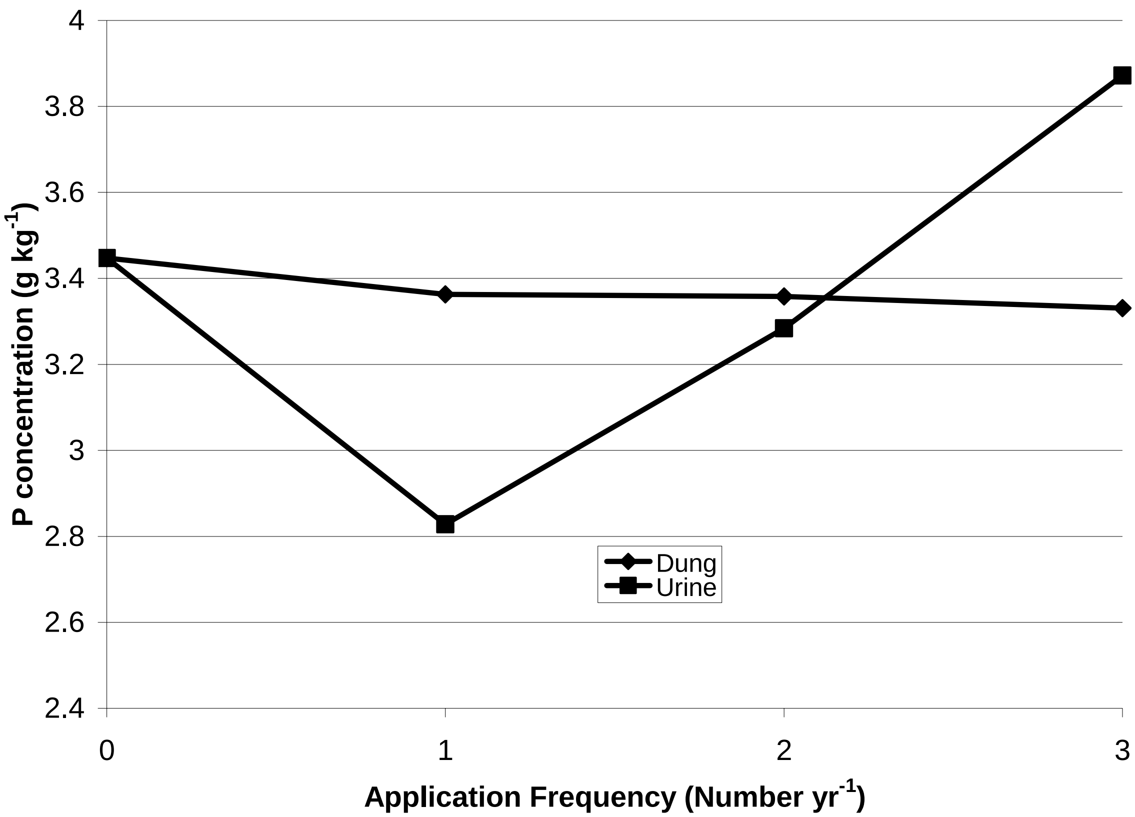


Figure 3-4. Excreta type X excreta application frequency interaction ($P = 0.002$) for bahiagrass herbage P concentration during the 2006 growing season. There was no effect of dung application frequency on P concentration ($P > 0.583$), but there were linear ($P = 0.025$) and quadratic ($P = 0.002$) effects of urine application frequency on the response. Standard error of a treatment mean was 0.07 g kg^{-1}. Herbage P concentration was affected by excreta type for Application Frequencies 1 and 3 ($P = 0.004$ and 0.035, respectively), but there was no effect of excreta type at Frequency 2 ($P = 0.752$).

Herbage In Vitro Digestible Organic Matter

Herbage IVDOM was affected by management intensity (P = 0.001), application frequency (P = 0.005), excreta type (P = 0.001), and application frequency X excreta type interaction (P = 0.099). Herbage in High management intensity plots was greater in IVDOM than in Average plots (577 vs. 567 g kg^{-1}). In no-excreta plots, IVDOM increased linearly (P = 0.007) from 559 to 572 g kg^{-1} as N rate increased from zero to 120 kg ha^{-1} (Table 3-7). Coleman et al. (2004) suggested that N fertilization has shown no consistent effect on herbage digestibility, however a number of recent studies have shown greater IVDOM of bahiagrass herbage grown at greater N fertilization (Newman et al., 2006; Stewart et al., 2007). Stewart reported IVDOM of Pensacola bahiagrass increased from 459 to 479 to 505 g kg^{-1} as N rate increased from 40 to 120 to 360 kg ha^{-1}. Similarly, Newman et al. (2006) reported increases in IVDOM from 443 to 487 g kg^{-1} when N fertilizer amount increased from 80 to 320 kg ha^{-1}. One factor that works against increasing IVDOM with greater N fertilization is increasing stem development at greater N amounts (Coleman et al., 2004). Bahiagrass, however, has limited stem elongation, thus its digestibility is less likely than most C_4 grasses to be affected negatively by N fertilization.

Excreta application frequency X excreta type interaction occurred because there was no effect of dung application frequency on bahiagrass IVDOM while urine application frequency did have an effect (Fig. 3-5). Herbage IVDOM changed little following a single urine application, but subsequent applications increased IVDOM from 565 to 588 g kg^{-1} (Fig. 3-5). With the exception of the lack of IVDOM response to the first application of urine, these IVDOM responses to urine (added N) correspond to those already described in the current study for management intensity treatments and the no-excreta control treatments. Excreta type affected IVDOM only for Application Frequency 3 when herbage from urine-treated plots had greater IVDOM than from dung-treated plots (P = 0.006).

There are limited data describing digestibility of herbage in studies of excreta deposition. Greenhalgh and Reid (1968) stated in a general way that digestibility of perennial ryegrass herbage near a dung deposit may be greater than similar herbage growing in mechanically harvested fields.

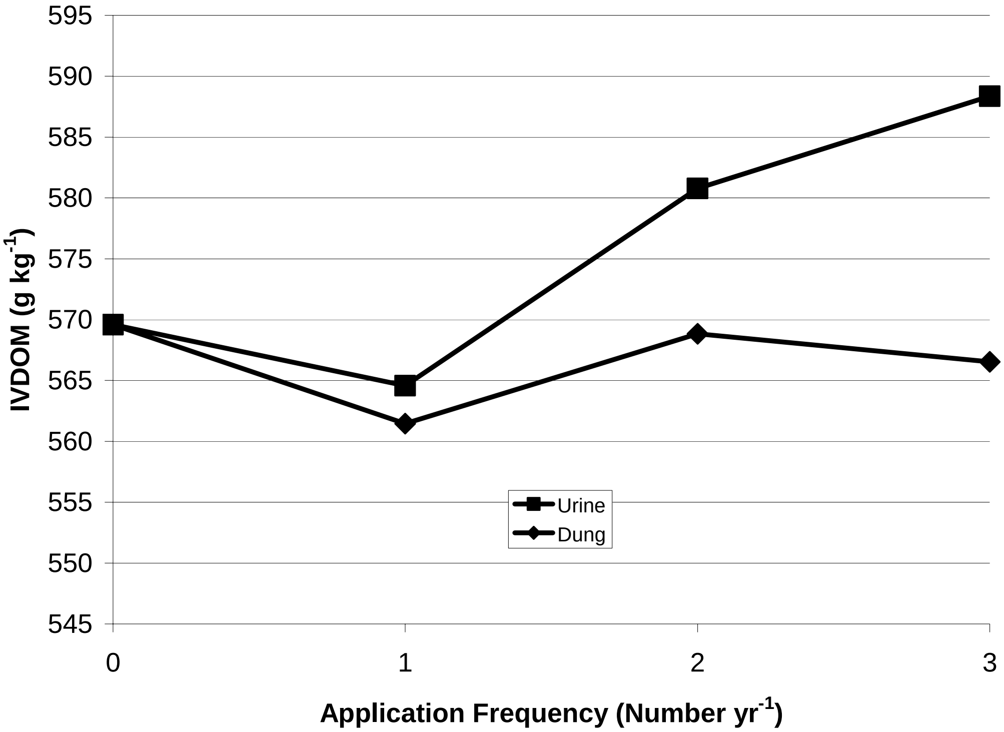


Figure 3-5. Excreta type X excreta application frequency interaction ($P = 0.099$) for bahiagrass herbage in vitro digestible organic matter (IVDOM) concentration during the 2006 growing season. There was no effect of dung application frequency on IVDOM ($P > 0.300$), but there was a linear ($P = 0.004$) effect of urine application frequency on the response. Standard error of a treatment mean was 3.1 g kg^{-1}. Herbage IVDOM concentration is different for Frequency 3 ($P = 0.006$) but not different for Frequencies 2 ($P = 0.132$) and 1 ($P = 0.445$).

Total Nitrogen Harvested

Total N harvested was affected by management intensity ($P < 0.001$), excreta application frequency ($P = 0.003$), excreta type ($P < 0.001$), and application frequency X excreta type interaction ($P < 0.001$) (Table A-1). High management intensity plots had greater N harvested than Average (57 vs. 47 kg ha^{-1}), and for no excreta plots the response to N fertilizer amount was linear, increasing from 18 to 42 kg ha^{-1} as N amount increased from 0 to 120 kg ha^{-1} (Table 3-7).

Frequency X type interaction occurred because N harvested increased linearly ($P < 0.001$) from 37 to 75 kg ha^{-1} as urine application frequency increased, but there was no effect of dung application frequency on the response (Fig. 3-6). Excreta type affected N harvested at Application Frequencies 1 through 3 ($P < 0.0001$) (Fig. 3-6).

Deenen and Middelkoop (1992) fertilized perennial ryegrass with either 250 or 400 kg N ha^{-1} yr^{-1} and applied a single application of dung at three different dates. As in the current study, N harvested in the grass was not significantly different than in the controls which did not receive dung. Ma et al. (2007) applied 6 kg of sheep dung uniformly to a mixed bunchgrass sward in Inner Mongolia. The area was harvested 32 and 65 d after dung application. Nitrogen harvested 32 d after application was 48 and 35 kg N ha^{-1} for dung-treated and control plots, respectively. Sixty-five days after dung application, herbage N harvested was 32 and 25 kg ha^{-1} for these two treatments, respectively. Greater impact of dung in the study by Ma et al. (2007) than in the current study can be attributed to dung being uniformly spread over the plots and the general form of sheep dung compared to that of cattle. Thus, there are a range of N harvested responses to dung in the literature, with amount of N fertilizer, amount of dung, and type of dung affecting the response.

Cuttle and Bourne (1993) made single urine applications (3.5 L m^{-2}) to different perennial ryegrass plots at five dates between August and November. Nitrogen harvested ranged from 70 for early applications to 4 kg ha^{-1} for late applications. For untreated controls, N harvested was much less, ranging from a low of less than 1 kg ha^{-1} to a high of 13 kg ha^{-1}. Similar results were also noted by Ball et al. (1979) using perennial ryegrass. They found that N harvested increased as N treatment increased from 0 N and no urine applied, to 300 or 600 kg fertilizer N ha^{-1} plus a single urine application. Herbage N harvested was 143, 188, and 202 kg N ha^{-1} for the three treatments, but absence a no-urine control for each fertilizer level makes it impossible to draw conclusions about the impact of urine.

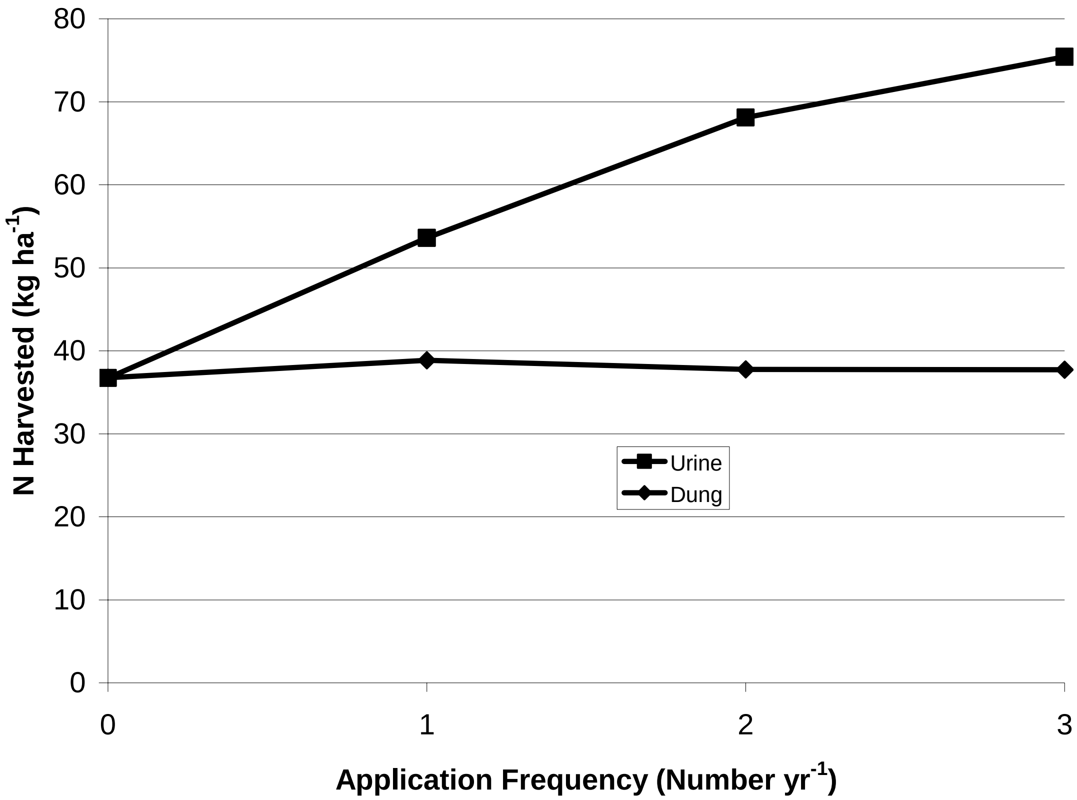


Figure 3-6. Excreta type X excreta application frequency interaction ($P < 0.001$) for N harvested in bahiagrass herbage during the 2006 growing season. There was no effect of dung application frequency on N harvested ($P > 0.404$), but there was a linear ($P < 0.001$) effect of urine application frequency on the response. Standard error of a treatment mean was 1.5 kg ha^{-1}. Herbage N harvested was greater for urine- than dung- treated plots for Frequencies 1 through 3 ($P < 0.001$).

Total Phosphorus Harvested

Total-season P harvested was affected by main effects of management intensity, application frequency, and excreta type (P < 0.001) and the interactions of intensity X excreta type (P = 0.033) and application frequency X excreta type (P < 0.001) (Table A-1). The management intensity X excreta type interaction occurred because for dung-treated plots the magnitude of the advantage of High over Average management intensity (10.9 vs. 8.0 kg ha^{-1}; P < 0.001) was greater than the advantage in urine-treated plots (13.7 vs. 12.4 kg ha^{-1}; P = 0.054). Phosphorus harvested increased linearly from 5.0 to 11.1 as N fertilizer increased from 0 to 120 kg ha^{-1} for the no-excreta controls (P = 0.002) (Table 3-7).

Interaction of application frequency X excreta type occurred because there was no effect of dung application frequency on P harvested (P > 0.570), but there were linear (P < 0.001) and quadratic effects (P = 0.052) of urine application frequency on the response (Fig 3-7). Phosphorus harvested increased from 9 to 18 kg ha^{-1} as urine application frequency increased from zero to three. Herbage P harvested was greater for urine- than dung-treated plots for Application Frequencies 2 (P = 0.007) and 3 (P < 0.001) and tended to be greater for Frequency 1 (P = 0.115).

Newman et al. (2005) harvested bahiagrass hay that was treated with different levels of N fertilizer (0, 50, 67, and 100 kg N ha^{-1} $harvest^{-1}$). Phosphorus harvested was 32, 39, 53, and 55 kg ha^{-1} for these four treatments, respectively. The response was primarily yield driven as DM harvested increased from 9.7 to 20.5 Mg ha^{-1}, but herbage P concentration varied only from 3.7 (at the zero N rate) to 3.0 g kg^{-1} (at the 100 N rate). The values reported in the current study are much lower than those reported by Newman et al. (2005) due to lower N rates in some cases and likely greater N losses due to volatilization for others, especially multiple applications of urine. There are few studies in the literature that measure tissue P response or P removal under excreta application conditions similar to those in this experiment. There is a large body of literature describing P removal responses to uniform applications of animal excreta or N fertilizer to hay fields, but these data have limited relevance to excreta applications like those in the current study.

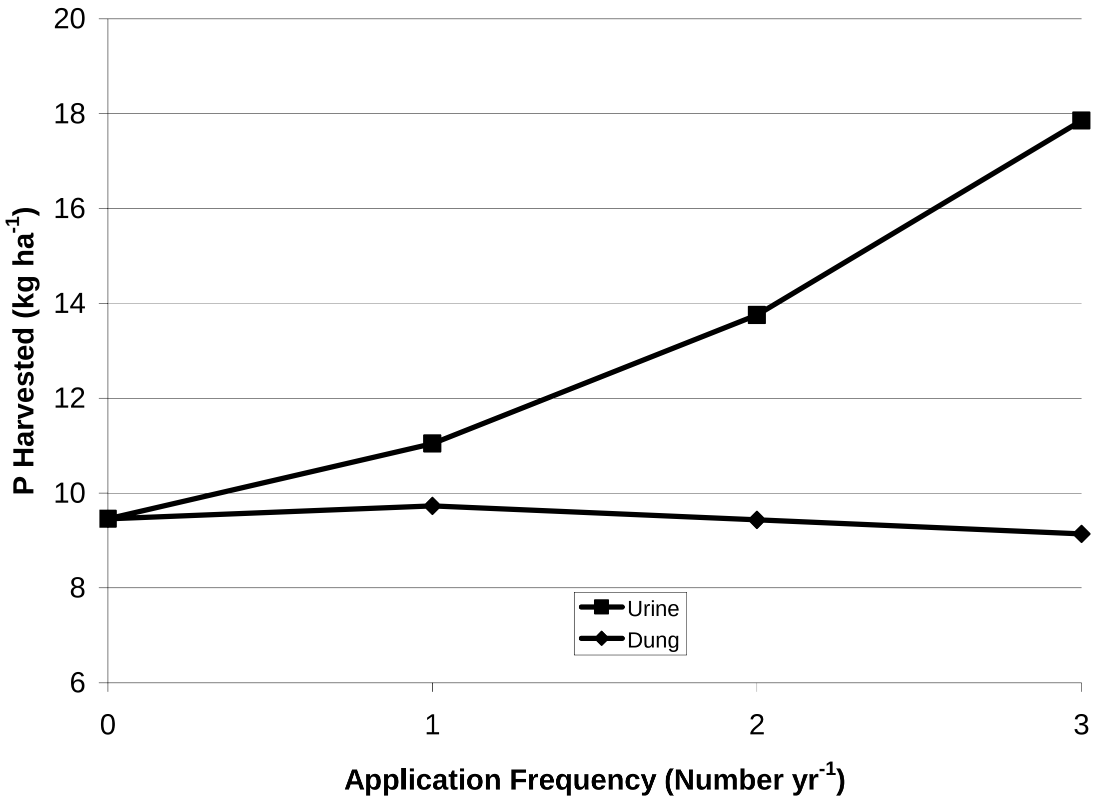


Figure 3-7. Excreta type X excreta application frequency interaction ($P < 0.001$) for P harvested in bahiagrass herbage during the 2006 growing season. There was no effect of dung application frequency on P harvested ($P > 0.570$), but there were linear ($P < 0.001$) and quadratic effects ($P = 0.052$) of urine application frequency on the response. Standard error of a treatment mean was 0.35 kg ha^{-1}. Herbage P harvested was greater for urine- than dung-treated plots for Application Frequencies 2 ($P = 0.007$) and 3 ($P < 0.001$) and tended to be greater for Frequency 1 ($P = 0.115$).

Excreta Nitrogen Recovery

Total-season excreta N recovery was affected by the main effects of excreta type (*P* < 0.001) and a linear effect of application frequency (*P* = 0.0638) (Table A-1). There were no interactions.

Across the range of excreta application frequencies in this study, excreta N recovery from urine was consistently greater than from dung and N recovery decreased as number of excreta applications increased (Fig. 3-8). Over the 2006 season, the breakdown of dung pats was less than expected, possibly associated with minimal dung beetle activity leading to reduced recovery of N. Perennial ryegrass fertilized with either 250 or 400 kg N ha^{-1} yr^{-1} and receiving a single application of dung, had N recovery over a 3-mo period of 1.9 and 0.9% for the two N rates, respectively (Deenen and Middelkoop, 1992). These results are similar to those of the current study.

In a study in which a single urine application was made to perennial ryegrass-white clover mixtures fertilized with 300 and 600 kg ha^{-1}, Ball and Keeny (1981) found that total N recovery (not only urine N) was 37 and 23% for the fertilization treatments of 300 and 600 kg N ha^{-1}. The N application rates were likely in excess of plant requirements, increasing the risk for loss. Greatly exceeding plant nutrient needs may explain in part the lesser N recovery with multiple urine applications in the current study. Cuttle and Bourne (1993) determined urine-N recovery in perennial ryegrass for a single urine application at five dates from August through November. The cumulative recovery in herbage ranged from 40% of N from the first application to 1% of N from the next to last application. They noted that the seasonal pattern of herbage production was the dominant factor determining N harvested immediately following the urine treatments. In the current study, greater recovery for lesser application frequencies was likely due in part to the fact that these applications occurred earlier in the growing season, allowing more time for nutrient uptake by the bahiagrass.

Another reason for low capture of N could be growth patterns of bahiagrass. Blue (1973) noted that fertilizer N recovery by bahiagrass was low early in stand life due to large amounts of N stored in the rhizome-root system. Although our plots were long-time established stands, visual observations suggest that low soil fertility or some other factor was limiting overall stand vigor at the start of the experiment. Thus our plots may have responded somewhat like establishing stands in terms of building up the rhizome-root system and capturing significant amounts of N in storage organs. Core samples will be taken following completion of the second year of the study to assess the impact of excreta and control treatments on storage organ mass and N concentration.

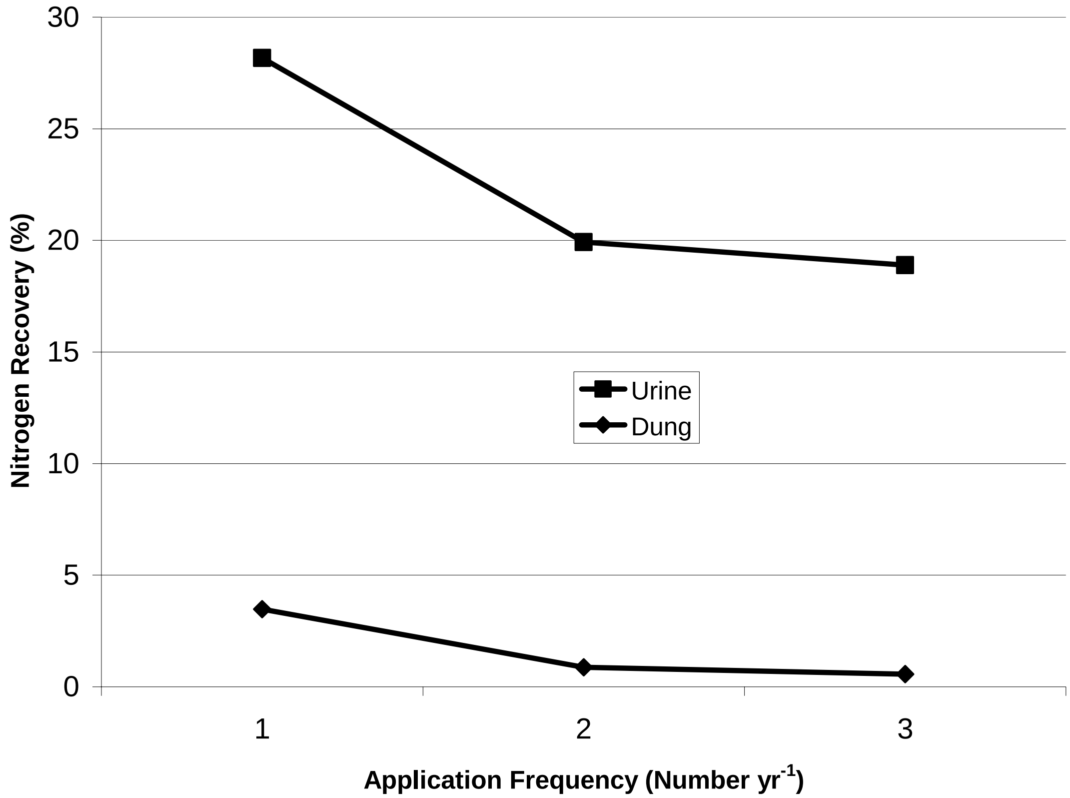


Figure 3-8. Excreta type main effect (*P* < 0.001) for excreta N recovery in harvested bahiagrass herbage during the 2006 growing season. There was no excreta type X excreta application frequency interaction (*P* = 0.543), but there was a linear effect (*P* = 0.064) of excreta application frequency on N recovery. Standard error of a treatment mean was 1.8%.

Nutrient Concentration in Shallow Groundwater

Much drier than average weather preceded the start of the study in spring and early summer 2006, and this in combination with less than average rainfall in all remaining months of the year except July (Table 3-8) limited the occasions when soil water was sufficient for lysimeter sampling to occur. There were, however, at least two sampling dates mo^{-1} except for November 2006 and March, April, and May 2007.

The only significant effects of treatments were observed on 15 Sept. 2006 when there was excreta type X application number interaction (P = 0.055) for NO_3-N concentration (Fig. 3-9). Interaction occurred because there was a linear effect of application frequency for dung-treated plots (P = 0.039), but the effect in urine-treated plots was quadratic (P = 0.057; Fig. 3-9). In dung-treated plots, the increase in water NO_3-N concentration was only 0.07 to 0.15 mg L^{-1} as frequency increased from 0 to 3, and in urine-treated plots concentration increased from 0.02 (zero applications) to 0.10 (two applications) before decreasing again to 0.02 (three applications; Fig. 3-9). There were isolated elevated numbers for NO_3-N concentration, including values from two lysimeters that exceeded 10 mg L^{-1} on 22 Aug. 2006 (High management intensity, urine, 1 and 2 applications yr^{-1}) and one value of 19 mg L^{-1} on 29 Aug. 2006 (High management intensity, urine, 2 applications yr^{-1}). On 22 Aug. 2006, there was one other sample greater than 5 mg L^{-1}, and on 29 Aug. 2006 there were two other samples greater than 5 mg L^{-1}. At other sampling dates, maximum values for NO_3-N concentration never exceeded 5 mg L^{-1} and treatment means rarely exceeded 2 mg L^{-1}.

Wachendorf et al. (2005) applied urine (equivalent to 1030 kg N ha^{-1}) and dung (equivalent to 1050 kg N ha^{-1}) labeled with ^{15}N to perennial ryegrass plots with free-drainage lysimeters. The urine-treated plots had the greatest loss of NO_3, which occurred within 100 d of the application

(120 kg N ha^{-1}), compared to a no-excreta control and dung which had losses of approximately 0 and 10 kg N ha^{-1}. The majority of NO_3 under urine patches was leached within a 60-d period.

Low levels of NO_3-N concentration in the current study may be due in part to lower than normal rainfall because July was the only month during 2006 when rainfall exceeded the 30-yr mean. It is likely that there were significant losses of urine-N due to volatilization because of excreta application during summer (Russelle, 1996). In addition, bahiagrass has been shown to be a relatively efficient scrubber of N below ground, resulting in accumulation of N in rhizomes and roots (Blue, 1973). The plots in the current study will be sampled at the end of Year 2 to quantify differences in rhizome-root mass and N content. So, despite high application rates and relatively poor recoveries of excreta N in harvested herbage, the lack of significant NO_3-N concentrations in water is likely due to lower than average rainfall, volatilization losses, and N capture and subsequent storage in rhizomes and roots. Hack-ten Broeck et al. (1996) noted that dung patches rarely affect nitrate leaching, because of high proportions of N excreted in the urine and the preponderance of organic N in dung that slowly degrades.

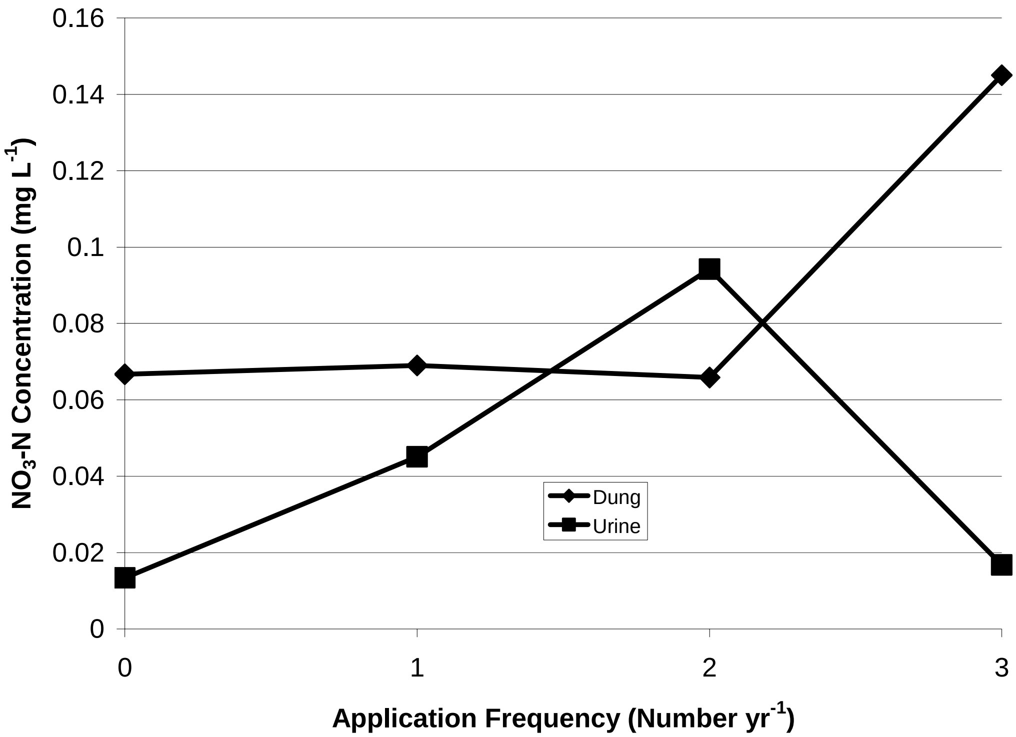


Figure 3-9. Excreta type X application frequency interaction for NO_3-N concentration in shallow soil water on 15 Sept. 2006. There was a quadratic effect of urine application frequency on NO_3-N concentration (P = 0.057), and there was a linear effect (P = 0.0394) of dung application frequency on the response. There was no effect of excreta type at any level of application frequency (P > 0.181). Standard error of a treatment mean was 0.03 mg L^{-1}.

Summary and Conclusions

The objective of this research was to characterize the effects of cattle excreta type and application frequency on 1) herbage yield, chemical composition, and nutrient recovery and 2) nitrate leaching to shallow ground water under bahiagrass swards managed at two different intensities. The study was carried out during the period from June 2006 through June 2007.

The High and Average management intensity treatments imposed on the pastures grazed by livestock (excreta source pastures) had limited impact on herbage characteristics of grazed bahiagrass. Herbage N concentration was greater for High than Average, but herbage mass, P concentration, and IVDOM were not affected. There were sampling date effects on pasture herbage mass with greatest mass occurring in July compared to June and September, and herbage CP tended to be greater in July than other dates. Dung nutrient concentration was quite consistent between treatments and across the three collection periods. Urine nutrient concentration was similar between treatments in June (not analyzed statistically), but it was quite high for the Average treatment relative to the High treatment in July and for High relative to Average in September. Herbage characteristics did not vary seasonally to the same degree as urine chemical composition, so the seasonal changes in urine composition, especially the high nutrient concentrations in July, are not understood.

In the plots to which excreta was applied, there were interactions of excreta application frequency X excreta type for all herbage responses except for excreta N recovery. Interaction occurred because dung application had no effect on herbage responses, whereas responses to urine were consistently significant. Greater herbage response to urine than dung was expected because of the high proportion of dung N that is in an organic form and the greater availability to plants of nutrients in urine. The general absence of response to dung was not expected and could be attributed to a number of factors including physical interference of the dung pat, the high concentration of organic N in dung as a proportion of total N, limited apparent activity of dung beetles, and a drier than normal year leading to rapid drying and crusting of dung.

High management intensity applied to the ungrazed bahiagrass plots increased herbage response over Average for all response variables except P concentration and N recovery. With the exception of excreta type X management intensity interaction for P harvested, there were no interactions of other treatments with management intensity. This indicates that both excreta types and the three excreta application frequencies evaluated in this study had similar effects on response variables across the range of management intensities tested.

Excreta N recovery was greater for urine than dung averaging 22 and 2%, respectively. Recovery was also affected by excreta application frequency, decreasing from 28 to 18% as urine application frequency increased from one to three yr^{-1}, and from 4 to less than 1% as dung application frequency increased from one to three. These recoveries are in the lower part of the range reported in the literature, but it does not appear that leaching losses explain this response. Significant responses of shallow soil water NO_3-N concentrations occurred at only one sampling date (15 Sept. 2006), and these values were less than 0.15 mg L^{-1}. Greater concentrations occurred in individual wells at two other dates in August, but these were not consistent across replicates within a treatment. Warm, dry weather may have increased volatilization losses of urine N (Russelle, 1996), and bahiagrass has been reported to store large quantities of N in rhizomes and roots (Blue, 1973). Low values for dung recovery and absence of herbage response to dung suggest limited mineralization of nutrients in dung during the course of the growing season. Greater percent recovery of nutrients in excreta occurred with single excreta applications suggesting that grazing management practices which increase uniformity of excreta deposition will likely increase efficiency of nutrient cycling in grazed grasslands.

CHAPTER 4
SPATIAL PATTERNS OF BAHIAGRASS HERBAGE ACCUMULATION AND NUTRIENT CONCENTRATION RESPONSES TO TYPE AND FREQUENCY OF EXCRETA DEPOSITION

Introduction

Planted grasslands and non-forested rangeland comprise nearly 30% of the USA land area (Barnes and Nelson, 2003) and occupy more than 4 million ha in Florida (Dubeux et al., 2007). Most grasslands in Florida are managed extensively with limited fertilizer input, but because there is such a large area covered by grasslands, the fate of nutrients can have a major impact on ecosystem function (Nair et al., 2007).

When livestock graze grassland, a large proportion of the nutrients consumed in forage are returned to the sward in excreta (Sollenberger et al., 2002). A single urination from mature cattle may provide the equivalent of 5 mm of rain and 400 to 500 kg N ha^{-1}, while dung may supply the equivalent of 110 kg P and 220 kg of K ha^{-1} along with other nutrients (Haynes and Williams, 1993). Nutrients recycling through animal excreta have long been considered beneficial to the fertility of grazed pastures (Ball et al., 1979). For example, urine patches in a mixed grassland contained 112 g m^{-2} more above-ground biomass and 2.5 g m^{-2} more plant N than unaffected areas (Day and Detling, 1990). In a Colorado study, urine patches affected only 2% of the pasture surface, but they contributed 7 to 14% of consumed forage (Day and Detling, 1990).

The areas covered by a single dung or urine application by cattle have been estimated at ~ 0.1 and 0.4-m^2, respectively (Haynes and Williams, 1993). To effectively define the impact of dung and urine application on grasslands, the spatial pattern of plant responses around an excreta deposit needs to be described. Lotero et al. (1966) observed cattle grazing tall fescue (*Festuca arundinacea* Schreb.) and reported that urine affected plant response in an area of ~ 1.02 m^2. With dairy cows, Lantinga et al. (1987) reported that urine affected plant growth in an area of

0.68 m^2. Based on estimates from Haynes and Williams (1993) and de Klein (2001), an affected area for urine is ~ 0.75 m^2.

In a New Zealand pasture of ryegrasses (*Lolium* spp.) and white clover (*Trifolium repens* L.), dung pats killed 75% of grass tillers and rooted nodes of clover stolons under the pat within 15 d of application, resulting in significant yield reduction (MacDiarmid and Watkin, 1971). They noted that yield increased in response to dung from the edge of the pat to 45 cm beyond the edge, but in a second study the increase was limited to 15 cm. In related research, Deenen and Middelkoop (1992) applied dung pats to circles of radius 15 cm in perennial ryegrass (*Lolium perenne* L.). They found that dung affected plant responses in an area that extended 15 cm from the edge of the dung patch.

More detailed description of the spatial patterns in herbage accumulation and chemical composition around dung and urine deposits would aid assessments of excreta impact on grasslands. Measuring the effect of a range of application frequencies would also be valuable as some areas of grazed grassland receive no excreta while other areas may receive multiple deposits in a given year (Mathews et al., 2004). The objective of the research reported in Chapter 4 is to characterize the spatial patterns of bahiagrass (*Paspalum notatum* Flügge) herbage accumulation, chemical composition, and nutrient removal following application of dung and urine at a range of application frequencies.

Materials and Methods

There were two sites used for this study. At one location, pastures were grazed by yearling beef heifers and these pastures served as the source for excreta. The other site was used for excreta application to ungrazed bahiagrass plots. Excreta source pastures were located at the University of Florida Beef Research Unit, northeast of Gainesville, FL (29.72° N latitude, 82.35° W longitude). A long-term, ungrazed stand of Pensacola bahiagrass at the Plant Science

Research Unit, Citra, FL (29.41^{o} N latitude, 82.02^{o} W longitude)was used for applications of excreta. Site characteristics and the rationale for choosing these locations were described in Chapter 3.

Treatments and Design

Treatments applied to ungrazed bahiagrass plots were two management intensities (the same N amounts as were applied to excreta source pastures, i.e., 60 [Average] and 120 [High] kg ha^{-1} yr^{-1}), two types of excreta (dung and urine), and three frequencies of excreta application (one, two, or three times per year). The 2 x 2 x 3 factorial accounted for 12 treatments. In addition, there were three control treatments that received no excreta and were fertilized with N at 0, 60 (no excreta control for Average management intensity plots), or 120 kg ha^{-1} yr^{-1} (no excreta control for High management intensity plots). The 15 treatments were replicated three times in a randomized complete block design. Plots were 3 x 3 m in area with a 1-m bahiagrass alley surrounding each plot.

Average and High management intensity source pastures were defined based on N fertilizer amount and stocking rate. Average management pastures received 60 kg N ha^{-1} yr^{-1} and were stocked with two yearling heifers ha^{-1}, and High pastures received 120 kg N ha^{-1} yr^{-1} and were stocked with four yearling heifers ha^{-1}. These two management intensities were selected to represent fertilization and stocking regimes that are common in the Florida livestock industry (Average) or represent approximately the most intensive management applied to grazed bahiagrass (High). In addition, based on previous work by Stewart et al. (2007) it is expected that these treatments will result in forage that varies in nutritive value, especially N concentration, and that these differences could affect the composition of dung and urine.

Excreta Source Pastures

There were two replicates of each source treatment (Average and High management intensities) arranged in a completely randomized design. Pastures were stocked continuously and pasture size was 1 ha for Average and 0.5 ha for High. Each pasture was grazed with two crossbred yearling heifers (Angus x Brahman) with average initial weight of 408 kg. Grazing was initiated on 26 May 2006. Details of animal management, pasture fertilization, and pasture sampling were provided in Chapter 3.

Excreta Collection and Analyses

Animal selection and training were described in Chapter 3. During the trial, animals were brought to stanchions for collection of urine and dung. Urine and dung were collected during three periods (12-16 June; 26-28 July; and 7-8 Sept. 2006) leading up to the three dates (20 June, 1 Aug., and 13 Sept. 2006) when excreta was applied to the plots. Excreta application dates were at 6-wk intervals.

The process used for excreta collection is described in Chapter 3. After urine and dung were collected separately, they were immediately put into sealed containers and taken to a refrigerator for storage at 4°C. Prior to application, all excreta events of a given type (dung or urine) from one intensity treatment (four animals) were composited across field replicates. Thus, at time of application there were two types of dung and two types of urine (one of each excreta type from both Average and High treatments). Three subsamples were taken from the composited samples of urine and dung and analyzed to determine excreta chemical composition so that amount of nutrients applied to plots could be calculated.

During the June excreta collection, samples were taken to ensure that chemical composition did not change markedly during the 8 d of excreta storage prior to application, i.e., to ascertain that what was applied to the plots was similar in composition to what the animal would deposit fresh. This was accomplished by taking two subsamples from each of two separate urine and dung events. One of the two subsamples from each event was analyzed immediately; the other subsamples were stored in the same manner as the urine and dung that were eventually applied to the plots. At the date of excreta application to plots, these stored subsamples were analyzed to assess changes in chemical composition during the storage period. Results of these analyses were reported previously (Table 3-1).

Urine samples for analysis were acidified with concentrated sulfuric acid to pH 2 to avoid N volatilization. Dung was analyzed for total N, organic N, NH_4-N, P, and K, and urine was analyzed for N, NH_4-N, urea-N, P, and K. Methods of urine and dung analyses, nutrient concentrations of both (Tables 3-3 and 3-4), and quantity of N, P, and K applied to each plot (Tables 3-5 and 3-6) were reported in Chapter 3.

Plot Management

All plots to which excreta would subsequently be applied were fertilized on 7 June with 18 kg P and 66 kg K ha^{-1}. Nitrogen application depended upon excreta-source treatment. Plots that received excreta from the High management intensity source pastures were fertilized with 120 kg N ha^{-1} yr^{-1}, split equally in two applications of 60 kg N ha^{-1} (7 June and 16 Aug. 2006). Plots that received excreta from the Average management intensity plots were fertilized with 60 kg N ha^{-1} yr^{-1}, in two applications of 30 kg N ha^{-1} (on the same dates as High). Following fertilization on 7 June, the entire plot area was irrigated with 25 mm of water because of spring drought and lack of early summer rainfall (rainfall in March through May at this location was 68 mm compared to a 30-yr average of 279 mm). Magnesium sulfate was applied to all plots on 6 July 2006 to address low soil Mg levels. It was applied at 135 kg ha^{-1} to provide 27 kg Mg ha^{-1} and 36 kg S ha^{-1}.

Excreta Application

Plots were staged to a 5-cm stubble height on 19 June 2006. All experimental units except the no-excreta controls received dung or urine on 20 June. Subsequent applications were on 1 August and 13 September. Only plots receiving two or three excreta applications yr^{-1} received excreta on 1 August, while on 13 September only those plots receiving three applications yr^{-1} were treated.

Quantity of dung and urine and the area to which they were applied were determined based on values reported for cattle in the literature (Haynes and Williams, 1993) and the author's personal observation of the cattle used in this study. Haynes and Williams (1993) indicated that surface area ranges from 0.16 to 0.49 m^2 for urine and 0.05 to 0.09 m^2 for dung. Urine volume is said to range between 1.6 and 2.2 L and fresh dung mass from 1.5 to 2.7 kg (Haynes and Williams, 1993).

In the current study, 2 L of urine constituted one application, and it was applied to an area of 0.283 m^2, a 30-cm radius circle, with the center being the center of the plot (Fig. 4-1). Of the 2 L of urine, 1 L was applied to a 15-cm radius circle with the center being the center of the plot (area of 0.071 m^2), and 1 L was applied to the area outside the 15-cm radius circle but inside a circle of 30-cm radius. This was done to reflect the likelihood of greater concentration of urine closer to the center of the affected area in a natural urine deposit. The urine was applied using a sprinkler head on a watering can, and rate of application was controlled so that runoff from the application area was minimal. Dung was applied at 2 kg fresh weight to an area of 0.071 m^2, based on the range in surface area for dung applications (0.05 to 0.09 m^2) in the review by Haynes and Williams (1993). This was a circle of 15-cm radius with the midpoint being the center of the plot (Fig. 4-1). The dung was evenly distributed across this area. Subsequent applications (for the two and three applications per year treatments) occurred at the same location.

Forage Harvest and Laboratory Analyses

Forage was harvested every 28 d following initial excreta application (20 June), and harvest dates were 18 July, 15 Aug., 12 Sept., and 10 Oct. 2006. To characterize the spatial response of herbage DM harvested and nutritive value, herbage was harvested beginning with a circle of radius 15 cm that was centered on the midpoint of the excreta application. Thereafter, concentric rings were harvested sequentially. Rings are defined based on their radius from the center of the excreta application (Fig. 4-1).

Rings 1 through 3 were harvested for dung-treated plots and Rings 1 through 4 for urine-treated plots. For the urine-treated plots, R4 was harvested because of the greater area of urine vs. dung applications and because urine typically affects an area ~2.3 times the area of the urine patch (de Klein, 2001). Throughout this chapter, the rings will be referred to as R1 through R4, as defined above.

Following harvest, the herbage from each ring was dried separately at 60^{o}C, weighed, and ground to pass 1-mm screen. Herbage analyses for N and P were conducted at the Forage Evaluation Support Laboratory using a micro-Kjeldahl technique followed by semi-automated colorimetric analysis of the digestate (Gallaher et al., 1975; Hambleton, 1977). Nitrogen and P harvested in each ring were calculated by multiplying DM harvested times nutrient concentration. In vitro digestible organic matter concentration (IVDOM) was determined using a two-stage procedure (Moore and Mott, 1974).

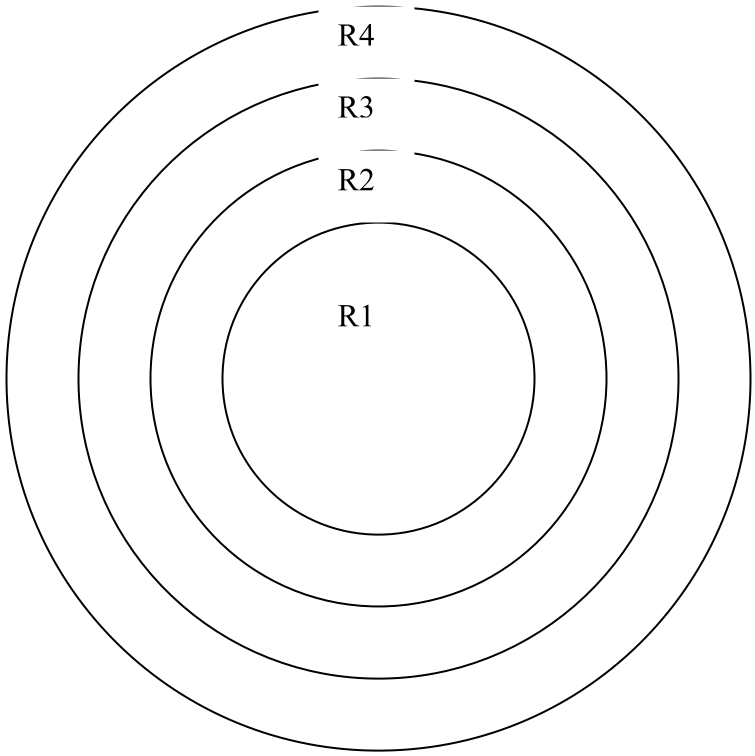


Figure 4-1. Diagram of harvested rings to quantify spatial pattern of response to dung and urine application (R1, circle of 15-cm radius; R2, 15- to 30-cm radius; R3, 30- to 45-cm radius; R4, 45- to 60-cm radius).

Statistical Analysis

Herbage DM harvested, herbage N, P, and IVDOM concentrations, and herbage N and P harvested were analyzed using analysis of variance in PROC MIXED of SAS (SAS Institute, Inc., 2007). Herbage DM, N, and P harvested are the sums of four harvests, and nutrient concentrations and digestibility are weighted averages across the four harvests. Data were analyzed by excreta type because of the greater number of rings harvested for urine- than dung-treated plots. The no excreta, 60 kg N ha^{-1} treatment served as a zero excreta application frequency for the Average management intensity treatments (both dung and urine), and the no excreta, 120 kg N ha^{-1} treatment served as a zero excreta application frequency for the High management intensity treatments (both dung and urine). Fixed effects in the models were management intensity, excreta application frequency, ring number, and their interactions.

Replicate was a random effect. Polynomial contrasts were used to assess the response to ring number and excreta application frequency. Differences were considered significant when $P \leq 0.10$. Data presented are least squares means.

In this chapter, only ring main effects and interactions with ring will be reported. This is done for two reasons. First, our objective in this chapter is to assess spatial patterns of response, and differences among rings are how this is characterized. Also, because of the concentric circle sampling approach used, the amount of land area sampled was different for each ring (i.e., R1 through R4). Thus, when SAS calculates a main effect mean for the other treatment factors (i.e., excreta application frequency and management intensity) and the frequency x intensity interaction means, the value is a mean across levels of ring number. When calculated in this manner, these means are not weighted to account for the different areas of the rings. In Chapter 3, all data presented were from the entire 0.636-m^2 circular area around the excreta deposit encompassed by Rings 1 through 3, and they were calculated by weighting the responses for the specific areas of each of those three rings. Thus, the best assessment of the effects of management intensity and excreta application frequency main effects and the interaction of these two factors are the data presented in Chapter 3.

Results and Discussion

Dry Matter Harvested

There was a main effect ($P < 0.001$) of ring number on DM harvested for dung-treated plots, but there also was application frequency X ring number interaction ($P = 0.027$) (Table A-2). Likewise for urine-treated plots, there was a main effect ($P < 0.001$) of ring number and an excreta application frequency X ring number interaction ($P < 0.001$) (Table A-3).

Application frequency X ring number interaction occurred for urine-treated plots because DM harvested decreased linearly ($P < 0.001$) as ring number increased for Application

Frequencies 2 and 3 (Fig. 4-2). The response also decreased with increasing ring number for one urine application [linear ($P < 0.001$) and quadratic ($P = 0.058$)], but there was no effect ($P = 0.352$) of ring number for control plots. Lotero et al. (1966) quantified tall fescue DM harvested in concentric circles around naturally occurring urine deposits. Inner and outer radii of areas sampled were 0 to 15 cm, 15 to 25 cm, 25 to 35 cm, 35 to 45 cm, 45 to 55 cm, and 55 to 65 cm. Similar to our results, they reported that the effect of urine on forage growth is most pronounced at the center of deposition and decreases with increasing distance from that point.

A question of interest is how far beyond the area of the urine application is herbage production affected. The DM harvested in R4 for all application frequency treatments was ~ 3000 kg ha^{-1}, but for R1 the DM harvested ranged from ~ 3000 kg ha^{-1} for the zero urine application frequency to 6000 kg ha^{-1} for an application frequency of three (Fig. 4-2). This pattern of response is reflected in polynomial contrasts which showed that DM harvested increased with increasing excreta application frequency for R1 (linear [$P = 0.001$] and quadratic [$P = 0.0192$]), R2 (linear [$P = 0.056$] and quadratic [$P < 0.001$]), and R3 (linear [$P = 0.002$]), but for R4 there was no effect of application frequency ($P > 0.153$).

Lotero et al. (1966) observed cattle grazing tall fescue, and immediately following a urine event a cage was placed around the deposit. Subsequent harvests of forage around the urine spot indicated that urine affected plant growth in an area of ~ 1.02 m^2. In our study, the absence of urine application frequency effect for R4 suggests that urine impact on DM harvested was limited to a circle of radius 45 cm from the center of application, an area of 0.64 m^2. One reason why the area affected may be smaller in the current study than in Lotero et al. (1966) is because they sampled spots where urine was deposited naturally by cows. In the current study, urine was applied using watering cans with sprinkler heads to ensure uniform application. Visual observations in the field suggest that rate of flow of natural urine deposition is more rapid and may be associated with greater lateral movement of urine across the soil surface before it soaks in. Despite this difference, data from the current study are comparable with several other experiments.

With dairy cows, Lantinga et al. (1987) reported that urine affected growth in a 0.68-m^2 area. Haynes and Williams (1993) indicated that the area covered by a urine event ranges from 0.16 to 0.49 m^2, and de Klein (2001) reported that the area affected is 2.3 times the area to which urine is applied. Using the mid-point of the range proposed by Haynes and Williams (1993) and the factor suggested by de Klein (2001) results in a calculated affected area of 0.75 m^2, comparable to that measured in the current study. When artificial urine was applied to perennial ryegrass that was fertilized with 250 kg N ha^{-1} yr^{-1}, effects were measured up to only 15 cm from the edge of the urine patch (Deenen and Middelkoop, 1992). This corresponds to the results of the current study because urine was applied to a circle of 30-cm radius and herbage accumulation was affected only through a 45-cm radius.

As in urine-treated plots, there was application frequency X ring number interaction in dung-treated plots, but the response was very different than for urine. The primary factor driving the interaction was the negative impact of dung application, particularly multiple applications, on DM harvested in Ring 1 (Fig. 4-3). This resulted in quadratic effects of ring number on DM harvested for three ($P = 0.025$) dung applications, linear ($P < 0.001$) and quadratic ($P = 0.008$) effects for two applications, and no effect for one ($P > 0.370$) or for zero applications ($P > 0.100$) (Fig. 4-3). Reduction in DM harvested in Ring 1, where the dung was applied, ranged from 500 to more than 1000 kg ha^{-1} for plots to which multiple applications of dung were made.

Focusing on individual rings, there was an effect of number of dung applications on DM harvested only in Ring 1. This response had significant linear ($P = 0.047$) and cubic ($P = 0.041$) terms. The linear effect reflects greater depression in DM harvested with increasing dung application frequency. The cubic effect is due to the greater negative impact of two vs. three dung applications, a response for which there is no apparent explanation. In Rings 2 ($P > 0.401$) and 3 ($P > 0.137$), there was no effect of dung application frequency on DM harvested. This indicates that effect of dung on this response was limited to the circle of 15-cm radius that was the initial area of application.

In a New Zealand pasture that was primarily ryegrass and white clover, dung pats of 1.8 kg fresh weight were applied to a circle of 15-cm radius (MacDiarmid and Watkin, 1971). They reported that 75% of grass tillers and rooted nodes of clover stolons under the dung pat were dead within 15 d of application. This resulted in a significant reduction in yield from the area of the pat as was observed in the current study. They noted that in one experiment, yield increased in response to dung to a radius of 61 cm from the center of application, but in a second study the increase was limited to a radius of 30 cm. In related research, Deenen and Middelkoop (1992) applied a single dung pat (2.5 kg fresh weight) to a circle with radius of 15 cm in perennial ryegrass plots. They measured DM harvested in five concentric rings or bands around the dung pat. The radii of the areas harvested were 0 to 15, 15 to 30, 30 to 45, 45 to 60, and 60 to 75 cm. They found that the dung-affected area was confined to 15 cm from the edge of the dung patch. Thus, results of the current study differ somewhat from previous work. In this experiment, there were no measurable effects of dung on DM harvested outside the area of dung application, while several studies in the literature report effects extending at least 15 cm beyond the dung pat.

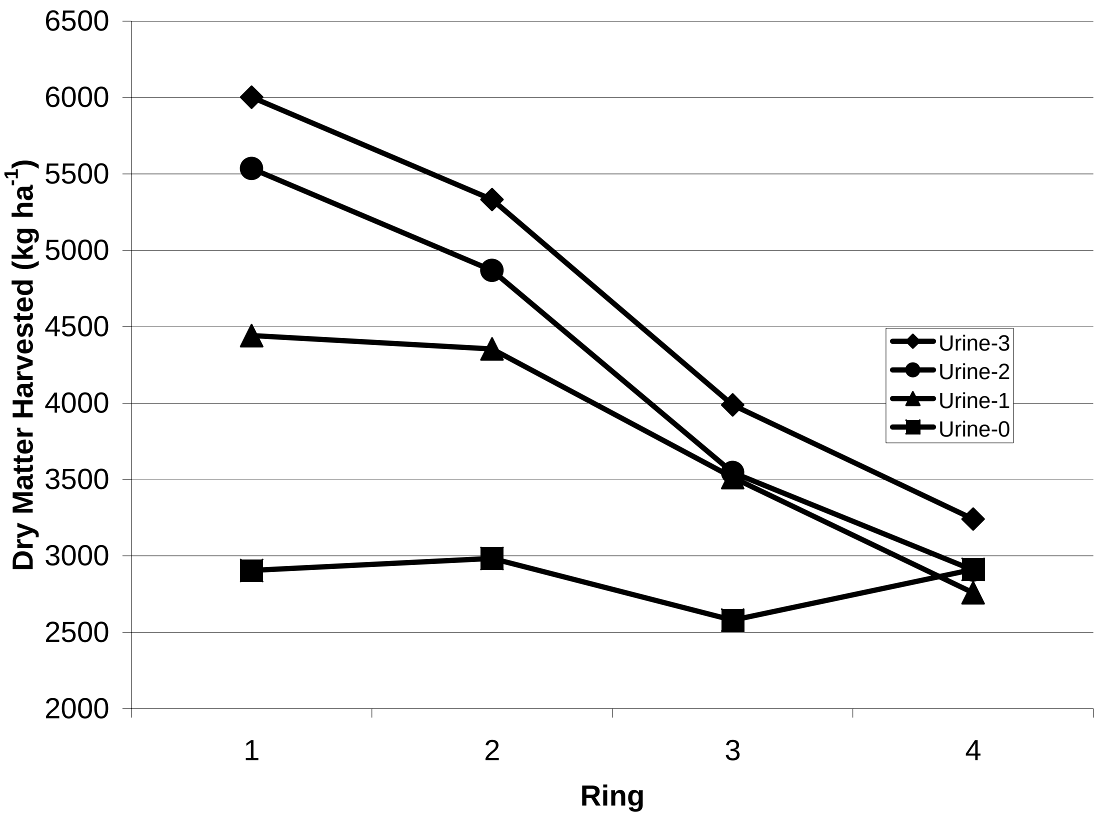


Figure 4-2. Ring number by urine application frequency interaction ($P < 0.001$) on herbage DM harvested during 2006. Ring number effects were linear for three ($P < 0.001$) and two applications ($P < 0.001$), linear ($P < 0.001$) and quadratic ($P = 0.058$) for one application, and not significant ($P > 0.352$) for zero applications. Standard error of a treatment mean was 76 kg ha^{-1}. Ring Numbers 1 through 4 refer to sampling areas 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm from the center of the urine application, respectively.

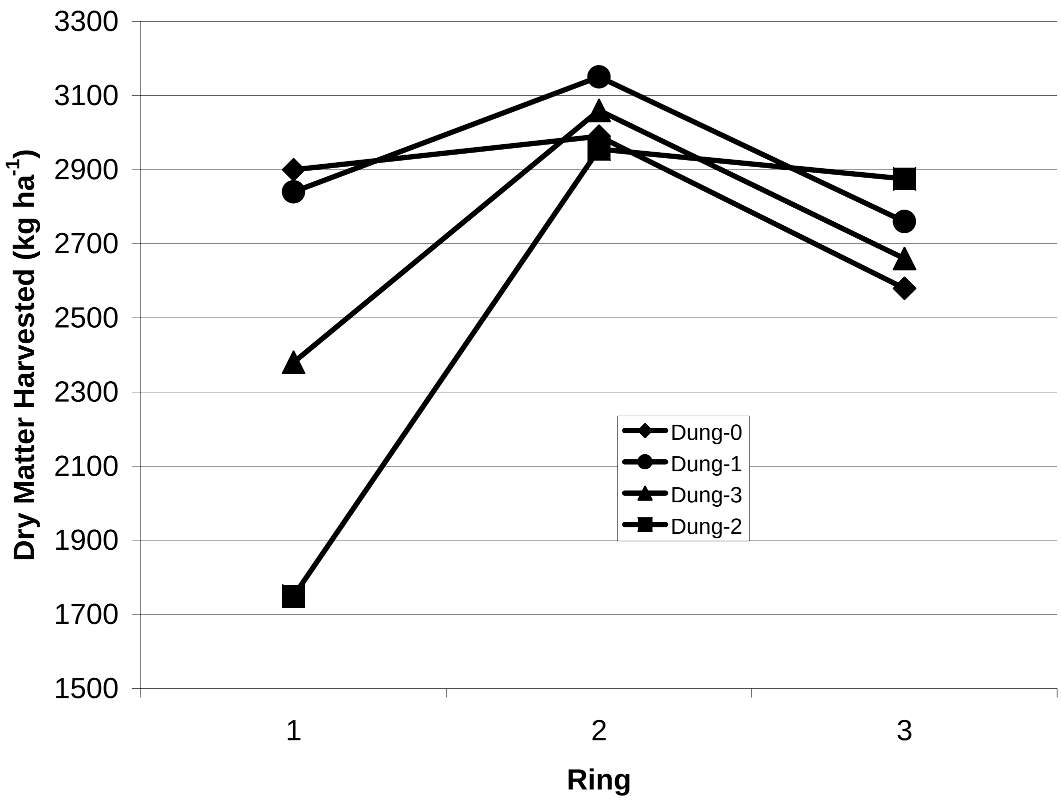


Figure 4-3. Ring number by dung application frequency interaction ($P < 0.027$) on herbage DM harvested during 2006. Ring number effects were quadratic for three ($P = 0.025$) applications, linear ($P < 0.001$) and quadratic ($P = 0.008$) for two applications, and not significant for one ($P > 0.370$) or for zero applications ($P > 0.100$). Standard error of a treatment mean was 106 kg ha^{-1}. Ring Numbers 1 through 3 refer to sampling areas 0 to 15, 15 to 30, and 30 to 45 cm from the center of the dung application, respectively.

Nitrogen Concentration

For dung-treated plots, there was no effect of ring ($P > 0.160$) on herbage N concentration nor were there interactions of other treatments with ring ($P > 0.686$) (Table A-2). Means for Rings 1 through 3 were 13.5, 13.3, and 13.6 g kg^{-1}, respectively. There has been limited research investigating the spatial impact of dung on herbage N concentration. Jorgensen and Jensen (1997) applied 2.1 kg of sheep feces, the equivalent of 960 kg N ha^{-1}, in July to a 25-cm diameter circle in a mixture of perennial ryegrass cv. Sisu and white clover cv. Milkanova. The herbage was harvested in concentric circles around the application area such that the first extended 0 to 15 cm beyond the edge of that area and the second extended 15 to 30 cm beyond the edge. In the 0- to 15-cm zone, neither grass nor clover herbage N concentrations were affected by feces in October or the following June. By August, 13 mo after feces application, grass N concentration was greater in the 0 to 15 cm zone than for control plots (25.2 vs. 20.5 g kg^{-1}). These authors noted that less than 2 g kg^{-1} of dung N was recovered in harvested herbage by October following July application, and after 13 mo only 35 g kg^{-1} of dung N was recovered in harvested herbage.

The application frequency x ring number interaction ($P < 0.001$) on urine-treated plots occurred because there were linear effects of ring for two and three urine applications, but there was no ring effect for the control (means of 13.3, 13.1, 13.5, and 13.3 g kg^{-1} for R1 through R4, respectively) or for one urine application (14.1, 13.6, 13.6, and 13.6 g kg^{-1} for R1 through R4, respectively) (Fig. 4-4). Moving from the center of the urine deposit outward, N concentration decreased linearly ($P < 0.001$) for two (17.8, 16.8, 15.3, and 14.4 g kg^{-1}) and for three urine applications (17.8, 16.4, 15.6, and 14.0 g kg^{-1}, respectively).

Lotero et al. (1966) evaluated urine impacts on tall fescue pastures. They measured herbage N concentration at increasing distances from a urine deposit. They found a marked decrease in N concentration moving away from the point of impact, but it was apparent only at the first cutting following applications of urine in spring, summer, and autumn. In the current study, the lack of significance for the single application treatment likely is due to the fact that it occurred at the beginning of the experimental period and because the herbage N concentrations reported are weighted averages across four harvests that occurred over a 112-d period following that application. Application Frequencies 2 and 3 received urine at Day 42 and Days 42 and 84 in this period, respectively, and their effect was measurable across the time period of the study.

The effect of application frequency within each ring number was explored to determine how far from the center of urine application an effect on herbage N concentration could be detected. This response had strong linear ($P < 0.001$) and cubic ($P < 0.001$) effects of application frequency for Rings 1 through 3. With increasing urine application frequency, herbage N concentration increased, but the effect was minimal between zero and one application and likewise between two and three applications (Fig. 4-4). For Ring 4, the data began to converge markedly, but the linear effect ($P = 0.029$) of application frequency remained. This indicates that the effect of urine application on herbage N concentration extended 30 cm beyond the edge of application and 15 cm further than the effect on DM harvested (Fig. 4-2).

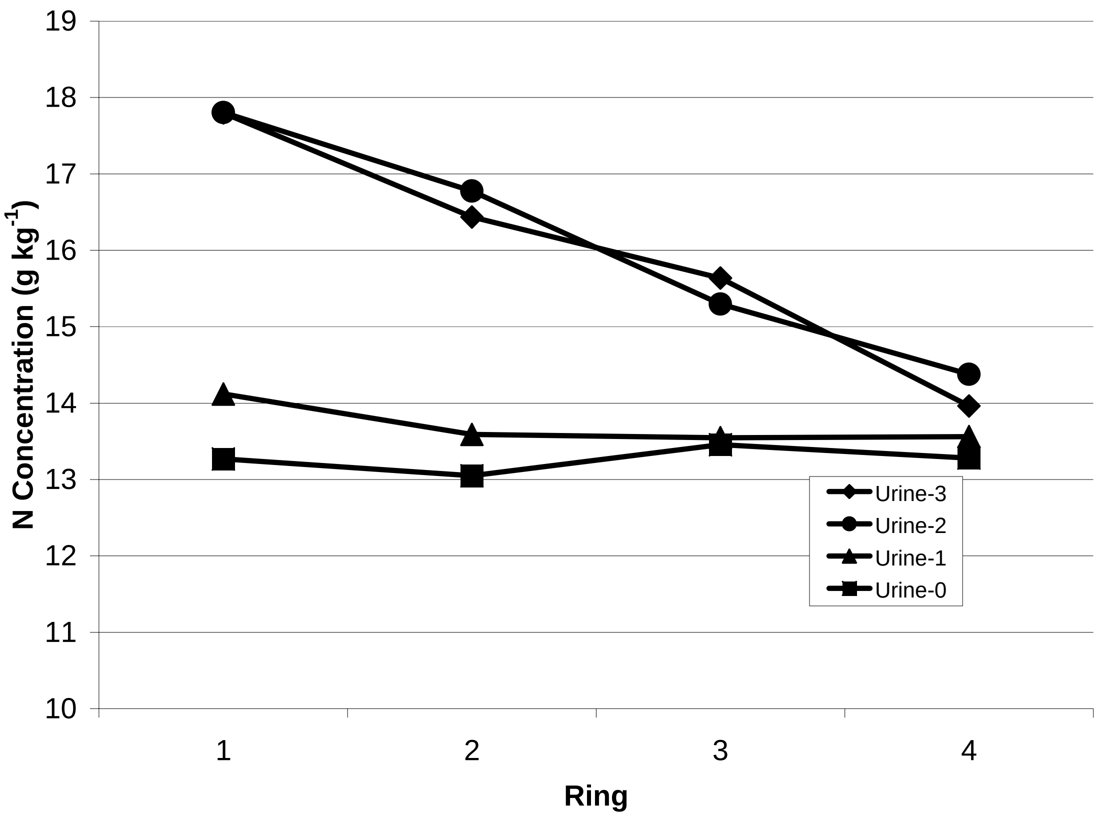


Figure 4-4. Ring number by urine application frequency interaction ($P < 0.001$) on total-season herbage N concentration during 2006. Ring number effects were linear for three ($P < 0.001$) and for two ($P < 0.001$) applications, but not significant for one ($P > 0.171$) and zero ($P > 0.128$) urine applications. Standard error of a treatment mean was 0.25 g kg^{-1}. Ring Numbers 1 through 4 refer to sampling areas 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm from the center of the urine application, respectively.

Herbage Phosphorus Concentration

Total-season P concentration was not affected by ring number in either the dung- ($P >$ 0.498) or urine-treated plots (P >0.342) (Tables A-2 and A-3, respectively). There were no interactions involving ring number for either dung ($P > 0.376$) or urine ($P > 0.146$). Herbage P concentrations were 3.4, 3.3, and 3.4 g kg^{-1} in Rings 1 through 3, respectively, in dung-treated plots. In spite of large amounts of total P applied in dung, there was little apparent uptake of P from dung (Chapter 3) and as such there was little impact on spatial characteristics of herbage P. In urine-treated plots, P concentrations were 3.3, 3.4, 3.3, and 3.6 g kg^{-1} for Rings 1 through 4, respectively. The primary effect of urine on P concentration was associated with application frequency (Chapter 3) and likely due to greater soil exploration by roots of more vigorous plants that had received more urine. Spatial variability (i.e., ring effect) in P concentration was minimal across the area sampled regardless of application frequency or management intensity.

Adeli and Varco (2001) evaluated the use of swine lagoon effluent on bermudagrass [*Cynodon dactylon* (L.) Pers.] and johnsongrass [*Sorghum halepense* (L.) Pers.]. They suggested that total P accumulation by forage grasses is more closely related to DM production rather than tissue P concentration, which varied little. Newman et al. (2005) assessed the effect of N fertilization on tissue P concentration and removal. Bahiagrass tissue P concentration decreased from 3.7 for the no-N control to 3.1 g kg^{-1} when N was applied at 45 kg ha^{-1} per harvest, but there was no change in the response as N fertilization increased to 60 and 90 kg ha^{-1} per harvest. Herbage DM harvested more than doubled across this range of treatments. In urine-treated plots in the current study, DM harvested and herbage N concentration were greatest closest to the center of urine applications, and for most application frequencies decreased as distance from the center increased. However, greater DM harvested and herbage N concentration were not accompanied by decreasing herbage P concentration as occurred in the Newman et al. (2005)

study. In results of the current study reported in Chapter 3, herbage P concentration was greater for the control than when a single application of urine was made (3.45 vs. 2.83 g P kg^{-1}, respectively), similar to the Newman et al. (2005) data.

Herbage IVDOM

For dung-treated plots, there were no interactions involving ring number (*P* > 0.249; Table A-2), but there were linear (*P* = 0.011; Table A-2) effects of ring number on IVDOM. As ring number increased from R1 to R3 in dung-treated plots, IVDOM decreased from 570 to 560 g kg^{-1}. The biological implications of this small change are not likely to be great. Greater bahiagrass herbage IVDOM has been reported with greater N fertilization by Newman et al. (2006) and Stewart et al. (2007), however in these studies it was accompanied by greater herbage N concentration. In the current study, there was no ring number effect on herbage N concentration, thus the reason for greater IVDOM in R1 and R2 is not clear. Similar results to those in the current study were obtained for dung-affected areas of perennial ryegrass (Greenhalgh and Reid, 1968). They observed cattle in pastures and marked fouled areas and paired clean areas. Averaged across two grazing intensities, they found that the fouled areas had an in vitro digestibility of 757 g kg^{-1}, which was greater than 740 g kg^{-1} in the clean areas.

Total-season IVDOM for urine-treated plots was affected by an application frequency X ring number interaction (*P* = 0.054), and the ring number main effect was also significant (*P* = 0.083) (Table A-3). Interaction occurred because there was a linear (*P* < 0.001) decline in IVDOM (from 584 to 562 g kg^{-1}) with increasing ring number for Application Frequency 2, but there was no effect for Application Frequencies 0 and 1 (*P* > 0.272) (Fig. 4-5). There was a trend (*P* = 0.145) toward decreasing IVDOM with increasing ring number for the three applications per year treatment. In general this follows the pattern of response reported by Newman et al. (2006) and Stewart et al. (2007) where greater bahiagrass herbage N concentration was associated with greater IVDOM. This was true for Frequency 2 where both N concentration and IVDOM decreased with increasing ring number and this was also the tendency for Frequency 3. For frequencies 0 and 1, neither N concentration nor IVDOM decreased as ring number increased. The departure from the expected trend occurred with Frequency 3, and in particular Ring 3 within that frequency treatment (Fig. 4-5). No other papers were found in the literature that reported digestibility responses to urine application.

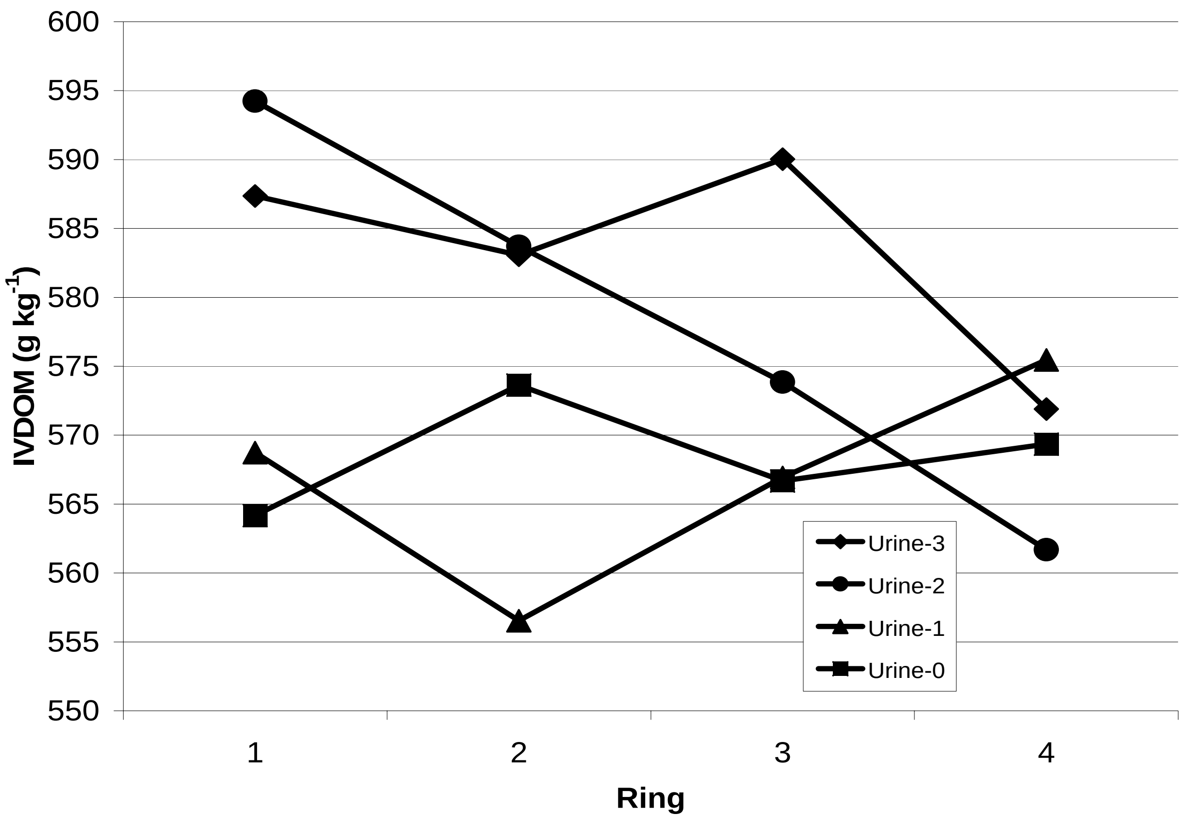


Figure 4-5. Ring number X urine application frequency interaction (*P* = 0.054) for in vitro digestible organic matter (IVDOM) concentration during 2006. Ring number effects were linear (*P*<0.0001) for two applications of urine and not significant for three (*P* > 0.144), one, and zero applications (*P* > 0.272). Standard error of a treatment mean was 2.4 g kg^{-1}. Ring Numbers 1 through 4 refer to sampling areas 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm from the center of the urine application, respectively.

Herbage Nitrogen Harvested

Nitrogen harvested in bahiagrass herbage was affected by application frequency X ring number interaction for urine- ($P < 0.001$; Table A-3) and for dung-treated plots ($P = 0.019$; Table A-2). The ring number X application frequency interaction for urine-treated plots occurred because there was a linear decline in N harvested with increasing ring number for Application Frequencies 1, 2, and 3, but there was no effect of ring number for the control (Fig. 4-6). Ring number means for the control ranged only from 35 to 39 kg ha^{-1}, while for Frequencies 1 through 3, N harvested decreased from 64 to 37 kg ha^{-1}, 98 to 42 kg ha^{-1}, and 106 to 45 kg ha^{-1}, respectively, as ring number increased from one to four (Fig. 4-6). Nitrogen harvested showed very similar patterns to those for herbage DM harvested and was driven primarily by the DM harvested response as opposed to herbage N concentration.

The effect of application frequency within each ring number was also assessed for N harvested to determine how far from the center of application an effect of urine could be detected. This response showed linear ($P < 0.001$) and quadratic ($P < 0.069$) effects of application frequency for Rings 1 and 2 and a linear effect ($P < 0.001$) for Ring 3. Thus, for Rings 1 through 3, increasing urine application frequency resulted in greater herbage N harvested (Fig. 4-6). As with herbage N concentration, the data began to converge markedly in Ring 4, but the linear effect (P = 0.030) remained. This indicates that the effect of urine application on herbage N harvested extended to 60 cm from the center of the urine event and 15 cm beyond the effect of urine on DM harvested (Fig. 4-2).

For dung-treated plots, total-season N harvested was affected by a ring number main effect ($P < 0.001$) and an interaction of application frequency X ring number ($P = 0.019$). The interaction occurred because there was no effect of ring number on N harvested for Application Frequencies 0 ($P > 0.167$) and 1 ($P > 0.288$), but there were linear ($P < 0.001$) and quadratic ($P =$

0.007) effects for two dung applications and quadratic (*P* = 0.048) effects for three applications (Fig. 4-7). This response is similar to that for DM harvested because there was no effect of dung on herbage N concentration. Thus, as observed for DM harvested, an important factor affecting the N harvested response appears to be physical interference of dung in Ring 1 that reduced both DM and N harvested (Figs. 4-3 and 4-7). This effect was most pronounced when dung was applied two or three times per year.

The effect of application frequency within a level of ring number was assessed to determine how far from the center of application dung affected N harvested. There were a linear (*P* = 0.055) and cubic (*P* = 0.047) effects of application frequency for Ring 1. Linear effects reveal the general pattern of decreasing N harvested with increasing numbers of excreta applications. The cubic effect was significant because two dung applications actually depressed N harvested more than three applications. The biological significance of the cubic effect is not clear. There were no effects of application frequency for Rings 2 (*P* > 0.441) or 3 (*P* = 0.194) indicating that dung application had no effect on the N harvested response outside of the immediate 15-cm radius circle to which it was applied. The minimal positive impact of dung, despite containing high amounts of N, is attributed to the slow physical breakdown of the dung pats and low mineralization rates of organic N in dung (Deenen and Middelkoop, 1992).

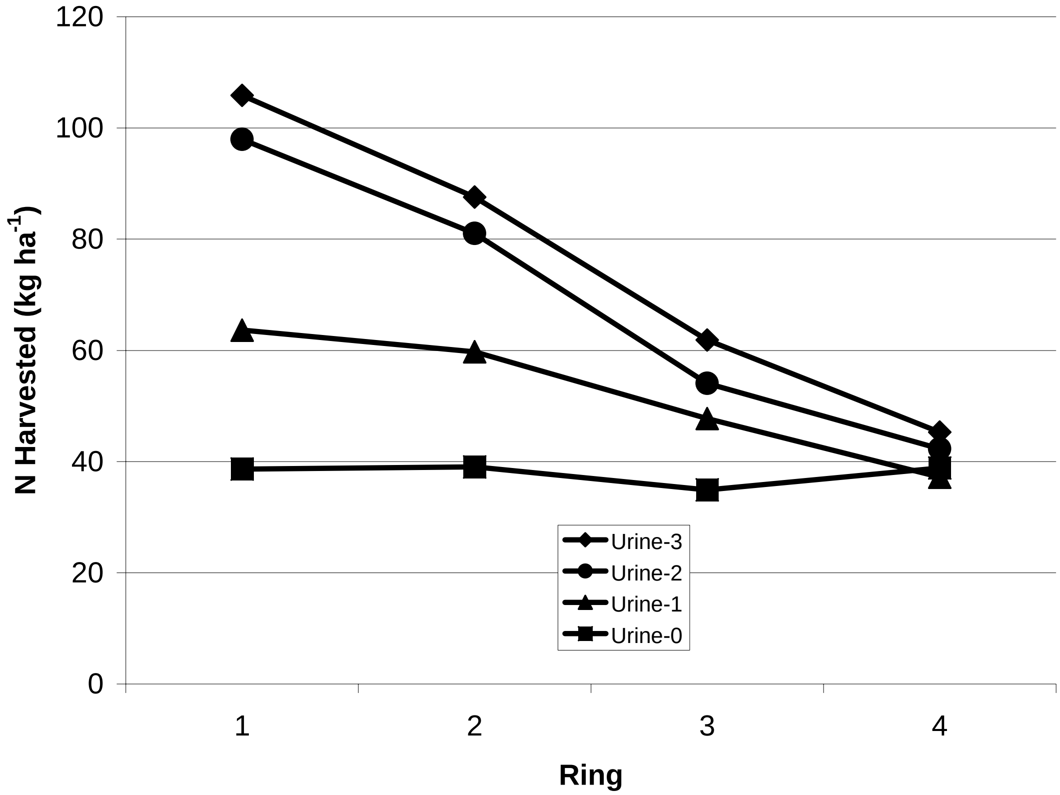


Figure 4-6. Ring number X urine application frequency interaction ($P < 0.001$) for bahiagrass herbage N harvested during 2006. The ring number effect was linear for three ($P < 0.001$), two ($P < 0.001$), and one urine application ($P < 0.001$) and there was no effect of ring number ($P > 0.167$) for the no urine control. Standard error of a treatment mean was 1.2 kg ha^{-1}. Ring Numbers 1 through 4 refer to sampling areas 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm from the center of the urine application, respectively.

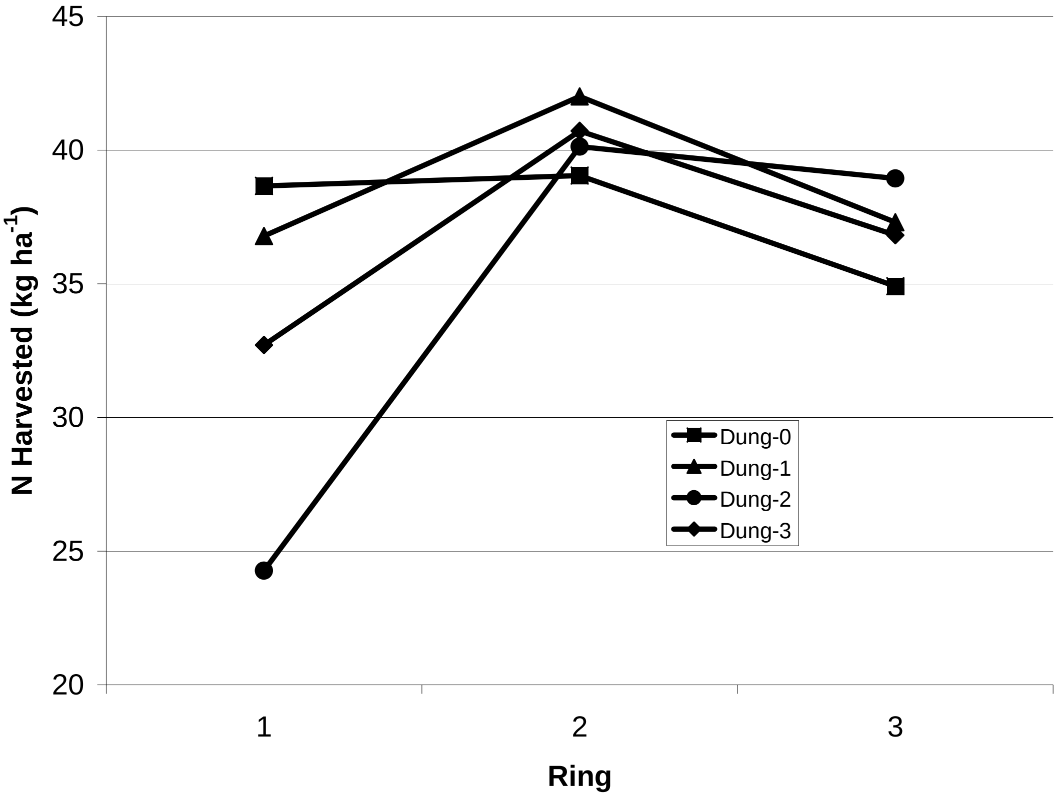


Figure 4-7. Ring number X dung application frequency interaction (P = 0.019) for bahiagrass herbage N harvested during 2006. The ring number effect was quadratic (P = 0.048) for three applications and linear (P < 0.001) and quadratic (P = 0.007) for two dung applications, but was not significant (P > 0.288) for one and no dung applications (P > 0.167). Standard error of a treatment mean was 1.5 kg ha^{-1}. Ring Numbers 1 through 3 refer to sampling areas 0 to 15, 15 to 30, and 30 to 45 cm from the center of the dung application, respectively.

Herbage Phosphorus Harvested

For both dung- and urine-treated plots there was a ring number main effect ($P \leq 0.003$) on herbage P harvested and an application frequency X ring number interaction (P = 0.0584 for dung and P < 0.001 for urine; Tables A-2 and A-3).

The application X ring number interaction in urine-treated plots occurred because P harvested decreased with increasing ring number for Application Frequencies 1 through 3, but there was no effect of ring number for the zero application frequency (Fig. 4-8). This pattern of response is nearly identical to DM harvested because there was no effect of ring number on herbage P concentration in urine-treated plots (average of 3.4 g kg^{-1}). These results support the conclusions of Adeli and Varco (2001) that total P removed in forage grasses is more closely related to DM production rather than tissue P concentration, which varies much less.

The effect of urine application frequency on P harvested within a ring number was significant for R1 (linear, P <0.001), R2 (linear, P < 0.001; quadratic, P =0.051), and R3 (linear, P < 0.001), but there was no effect of application frequency in R4 (Fig. 4-8). Thus like for DM harvested, the impact of urine on P harvested extended up to 45 cm from the center of the application or 15 cm beyond the edge of the application (Fig. 4-8).

For dung-treated plots, there was an application frequency X ring number interaction for P harvested that occurred primarily because of physical interference of dung in R1 (Fig. 4-9). This led to lower P harvested for two and three dung applications yr^{-1} in R1 compared to one or zero applications (application frequency effect - linear, $P = 0.047$; quadratic, $P = 0.041$), while in Rings 2 and 3 there was no effect of application frequency on P harvested ($P > 0.401$ for Ring 2 and $P > 0.137$ for Ring 3). This response is reflected in quadratic ring number effects ($P = 0.073$) on P harvested for three dung applications, linear ($P = 0.004$) and quadratic ($P = 0.046$) effects for two applications, and no effect for one ($P > 0.257$) and zero applications ($P > 0.289$). Similar to the responses for N and DM harvested, there was no effect of dung application on P harvested beyond R1, the area actually covered by the dung pat. Lack of an effect of dung on P harvested is likely associated with the slow breakdown of dung pats in the current study, perhaps due to drier than normal weather and to little apparent activity of dung beetles which incorporate dung into the soil and enhance nutrient release (Williams, 1950; Hughes et al., 1975).

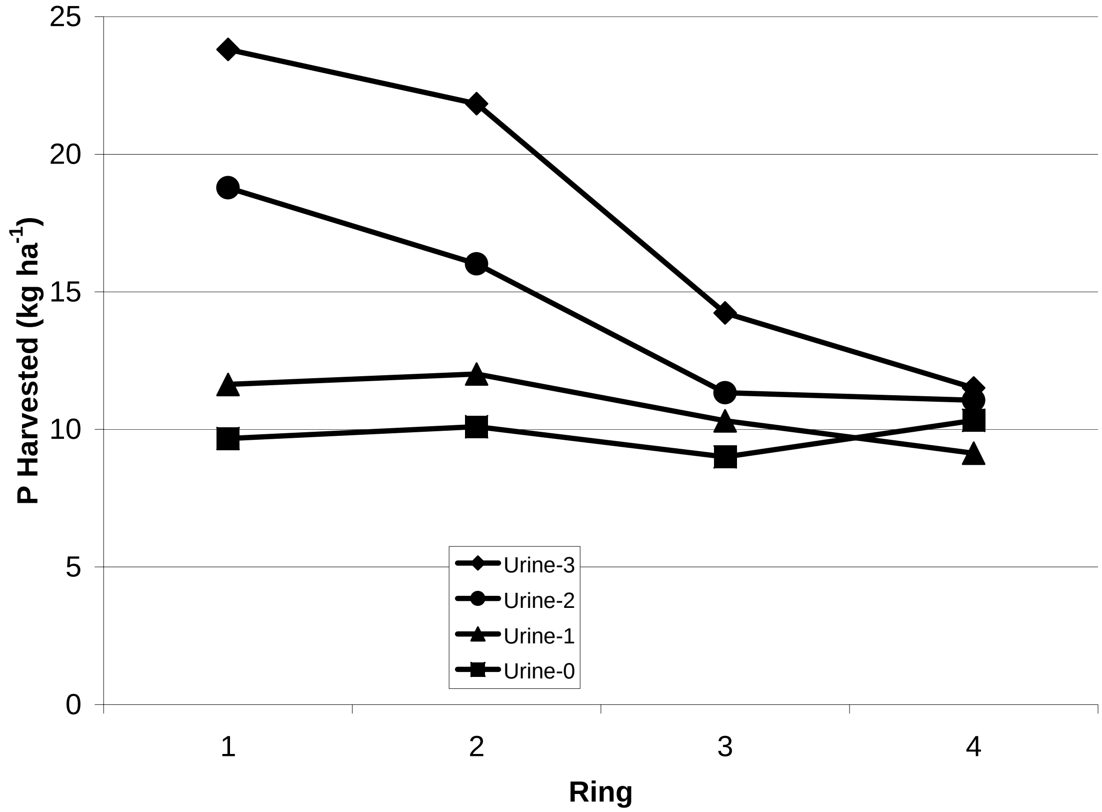
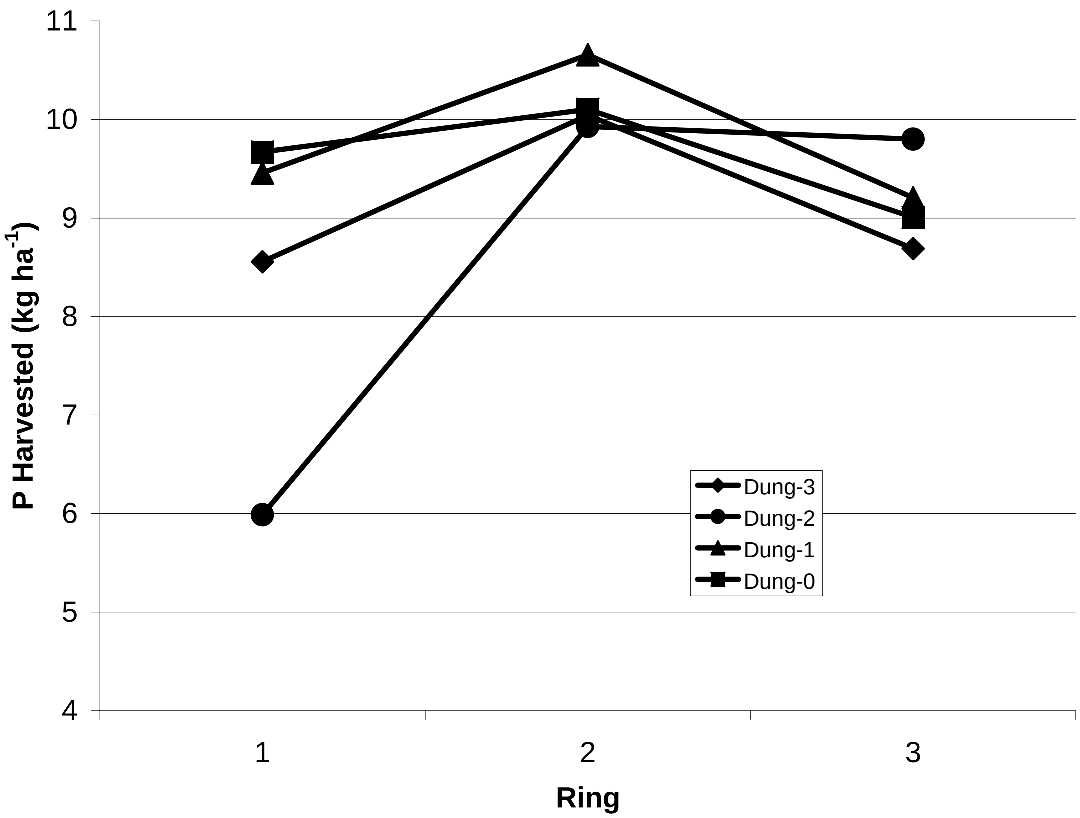


Figure 4-8. Ring number X urine application frequency interaction ($P < 0.001$) for bahiagrass herbage P harvested during 2006. Ring number effects were linear ($P < 0.001$) and cubic ($P = 0.0419$) for three urine applications, linear for two ($P < 0.001$) and one application ($P = 0.019$), and not significant ($P > 0.194$) for zero applications. Standard error of a treatment mean was 0.4 kg ha^{-1}. Ring Numbers 1 through 4 refer to sampling areas 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm from the center of the urine application, respectively.



4-9. Ring number X dung application frequency interaction ($P = 0.058$) for bahiagrass herbage P harvested during 2006. Ring number effects were quadratic ($P = 0.073$) for three dung applications, linear ($P = 0.004$) and quadratic ($P = 0.046$) for two applications, and not significant for one ($P > 0.257$) or for zero applications ($P > 0.289$). Standard error of a treatment mean was 0.4 kg ha^{-1}. Ring Numbers 1 through 3 refer to sampling areas 0 to 15, 15 to 30, and 30 to 45 cm from the center of the dung application, respectively.

Summary and Conclusions

The objectives of this research were to determine the effects of excreta type and application frequency to bahiagrass swards on spatial patterns of herbage DM harvested, herbage N and P concentration, and N and P harvested responses. Spatial patterns of response were determined by sampling swards in concentric rings (termed ring numbers, with Ring 1 being the area closest to the center of the deposit) surrounding urine and dung deposits.

Responses to urine and dung were distinctly different. Urine application typically resulted in greater DM harvested, N and P concentration, and N and P harvested. In contrast, dung application had no measurable impact on herbage N and P concentrations and decreased herbage DM harvested because of physical interference in the area to which dung was applied. Spatial variation in herbage responses reflected these trends. For urine-treated plots, greatest DM harvested and N and P concentrations occurred generally in Ring 1, encompassing the center of the area of urine application. Herbage responses typically decreased as distance from the center of urine application increased. Significant effects of urine on DM harvested and herbage P harvested extended only 15 cm beyond the edge of the area to which urine was applied, while this distance was 30 cm for herbage N concentration and N harvested. For dung-treated plots, especially those receiving multiple dung applications, physical interference reduced herbage DM harvested in Ring 1 by more than 500 (three dung applications yr^{-1}) or 1100 kg ha^{-1} (two dung applications). Herbage DM harvested and herbage N and P concentrations in areas outside of Ring 1 were similar for plots treated with dung and the no dung control. Thus, unlike urine there was no measurable effect of dung beyond the immediate area to which it was applied. Lack of positive response to dung was due to physical interference, as already mentioned, but it was accentuated by limited apparent dung beetle activity, the drier than normal weather that may have reduced breakdown of dung, and the high proportion of N in dung that is in an organic form and only slowly released for plant growth.

These data provide rationale for efforts to increase uniformity of excreta deposition on pastures. By avoiding repeated dung applications in the same area, there is opportunity to avoid much of the negative impact of physical interference. Responses to single applications of urine are often significant, especially in terms of DM harvested, and additional applications have lesser impact (Fig. 4-2). Thus management that increases the uniformity of urine distribution should also increase overall pasture herbage accumulation and, based on results from Chapter 3, increase the efficiency of N recovery.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Pasture-based, forage-livestock systems in Florida are planted primarily to bahiagrass (*Paspalum notatum* Flügge) because of its tolerance to close grazing and adaptation to a wide range of soil conditions including low fertility, drought, and short-term flooding. Bahiagrass pastures support approximately 1 million head of beef cattle in Florida. Even though these pastures typically receive low amounts of fertilizer and are stocked at low to moderate rates, the quantity of land area occupied and the number of animals supported statewide on bahiagrass pasture make nutrient management a key issue. The importance of nutrient management also is related to the sensitivity of Florida ecosystems, especially in terms of nutrient impacts on water quality (Nair et al., 2007). On agricultural lands, the lateral flow of P to surface water, particularly in Central and South Florida (Nair et al., 2007), and leaching of nitrates to ground water, more commonly in North Florida, are critical concerns (Woodard et al., 2002).

One of the many challenges faced by livestock producers utilizing pasture as a feed resource is avoidance of over accumulation of livestock wastes in certain areas of the pasture. Uneven distribution of soil nutrients, due to non-uniform excreta deposition, is thought to lead to leaching and volatilization of N and runoff of P and other nutrients from so-called nutrient hot spots in pastures, yet the effect of in situ excreta deposition on plant, soil, and water responses has received limited attention. The research reported in this thesis has as its objectives to characterize the impact of frequency and type of excreta application on bahiagrass herbage dry matter harvested, chemical composition, and excreta nutrient recovery, and to measure P and NO_3-N concentration in shallow soil water under excreta applications.

Treatments were two management intensities (Average and High), two types of excreta (dung and urine), and three frequencies of excreta application (one, two, or three times per year).

Excreta was collected from animals grazing bahiagrass pasture managed at Average and High intensities and applied to ungrazed bahiagrass plots fertilized with the same amount of N as the excreta source pasture from which the excreta was obtained. Average and High management intensities imposed on the excreta source pastures were defined based on N fertilizer amount and stocking rate. Average management intensity source pastures received 60 kg N ha^{-1} yr^{-1} and were stocked with two yearling heifers ha^{-1}, and High pastures received 120 kg N ha^{-1} yr^{-1} and were stocked with four yearling heifers ha^{-1}. These two management intensities were selected to represent fertilization and stocking regimes that are common in the Florida livestock industry (Average) or represent approximately the most intensive management applied to grazed bahiagrass (High) in Florida. Excreta from cattle grazing Average management intensity pastures was applied to bahiagrass plots that received 60 kg N ha^{-1} yr^{-1}, and excreta from cattle grazing High management intensity pastures was applied to plots that received 120 kg N ha^{-1} yr^{-1}.

Data were reported in two chapters. Chapter 3 describes shallow soil water responses and those of herbage within a 45-cm radius of the excreta application. In Chapter 4, the spatial patterns of herbage responses, beginning at the center of excreta application and moving away from the application, were described.

For herbage responses in the circle of 45-cm radius surrounding the excreta application (Chapter 3), the primary treatments affecting the responses were management intensity and the excreta application frequency X excreta type interaction. For plots receiving excreta, as management intensity increased from Average to High, forage DM harvested increased from 3230 to 3850 kg ha^{-1}. High management intensity plots had greater N concentration than Average intensity (14.7 and 14.2 g kg^{-1}, respectively), greater IVDOM than Average plots (577 vs. 567 g kg^{-1}), greater N harvested than Average (57 vs. 47 kg ha^{-1}), and greater P harvested than Average management intensity (10.9 vs. 8.0 kg ha^{-1} in dung-treated plots, respectively, and 13.7 vs. 12.4 kg ha^{-1} in urine-treated plots, respectively).

There was excreta application frequency X excreta type interaction for most herbage responses in Chapter 3. Interaction occurred because dung application had no effect on most herbage responses, whereas responses to urine were significant consistently. In urine-treated plots, herbage DM harvested increased from 2760 at zero urine applications to 4670 kg ha^{-1} with three applications. Over the same urine application frequencies, herbage N concentration increased from 13.3 to 16.2 g kg^{-1}, P concentration from 3.45 to 3.87 g P kg^{-1}, in vitro digestible organic matter concentration from 569 to 588 g kg^{-1}, N harvested from 37 to 75 kg ha^{-1}, and P harvested from 9 to 18 kg ha^{-1}. Greater herbage response to urine- than dung-treated plots was expected because of the high proportion of dung N that is in an organic form and the greater availability to plants of nutrients in urine. The general absence of response to dung was not expected and could be attributed to a number of factors including physical interference of the dung pat, the high concentration of organic N as a proportion of total N, limited apparent activity of dung beetles, and a drier than normal year leading to rapid drying and crusting of dung.

Excreta N recovery in harvested herbage was greater for urine than dung, averaging 22 and 2%, respectively. Recovery was also affected by excreta application frequency, decreasing from 28 to 18% as urine application frequency increased from one to three yr^{-1}, and from 4 to less than 1% as dung application frequency increased from one to three. These recoveries are in the lower part of the range reported in the literature, but it does not appear that leaching losses explain this response. Significant responses of shallow soil water NO_3-N concentrations to treatment occurred at only one sampling date (15 Sept. 2006), and these values were less than 0.15 mg L^{-1}. Greater concentrations occurred in individual wells at two other dates in August, but these were restricted to a single replicate within a treatment. Warm, dry weather may have increased volatilization losses of urine N (Russelle, 1996), and bahiagrass has been reported to store large quantities of N in rhizomes and roots (Blue, 1973). Low values for dung N recovery and absence of herbage response to dung suggest limited mineralization of nutrients in dung during the course of the growing season. Greater percent recovery of N in excreta occurred with single excreta applications suggesting that grazing management practices which increase uniformity of excreta deposition will likely increase efficiency of N cycling in grazed grasslands.

The objectives of the research reported in Chapter 4 were to determine the effects of excreta type and application frequency to bahiagrass swards on spatial patterns of herbage DM harvested, herbage N and P concentration, and N and P harvested responses. Spatial patterns of response were determined by sampling swards in concentric rings (termed ring numbers, with Ring 1 being the area closest to the center of the deposit) surrounding urine and dung deposits.

Responses to urine and dung were distinctly different. Urine application typically resulted in greater herbage DM harvested, N and P concentration, and N and P harvested. In contrast, dung application had no measurable impact on herbage N and P concentrations and decreased herbage DM harvested because of physical interference in the area to which dung was applied. Spatial variation in herbage responses reflected these trends. For urine-treated plots, greatest DM harvested and nutrient concentrations occurred generally in Ring 1, encompassing the center of the area of urine application. Herbage responses typically decreased as distance from the center of urine application increased. For dung-treated plots, especially those receiving multiple dung applications, physical interference reduced herbage DM harvested in Ring 1 by more than 500 kg ha^{-1}.

In spite of the magnitude of the response to urine, significant effects did not extend large distances beyond the edge of the urine application. For DM harvested and herbage P harvested, these effects extended only 15 cm beyond the edge of the area to which urine was applied, while this distance was 30 cm for herbage N concentration and N harvested. In contrast, herbage DM harvested and N and P concentrations in areas outside of Ring 1 were similar for plots treated with dung and the no dung control. Thus, unlike urine there was no measurable effect of dung beyond the immediate area to which it was applied. Lack of positive response to dung was due to physical interference, as already mentioned, but it was accentuated by limited apparent dung beetle activity, the drier than normal weather that may have reduced breakdown of dung, and the high proportion of nutrients in dung that are in an organic form and only slowly released for plant growth.

Data from both chapters provide justification for management practices that increase uniformity of excreta deposition on pastures. Responses to single applications of urine are often significant, especially in terms of DM harvested, and additional applications have lesser impact. Single applications of dung and urine result in a greater percentage N recovery than multiple applications. In addition, by avoiding repeated dung applications in the same area, there is opportunity to avoid much of the negative impact of physical interference. Thus management practices that increase the uniformity of excreta distribution should also increase herbage accumulation on pastures and increase the efficiency of recapture by plants of nutrients in excreta. Dubeux (2005) and Dubeux et al. (2006) provide evidence that rotational stocking, especially rotational stocking with short grazing periods, increases uniformity of excreta distribution. Though rotational stocking is not widely used at present by Florida livestock producers, rapidly increasing fertilizer costs and concerns about the impact of cattle excreta on water quality may result in greater use of this practice in the future. Implementation of rotational stocking may make important contributions to the overall economic and environmental sustainability of bahiagrass-livestock systems in Florida.

APPENDIX
STATISTICAL TABLES

Table A-1. *P* values for interactions and main effects on response variables discussed in Chapter 3.

Response variable	Source of Variation						
	Management intensity (MI)	Application frequency (AF)	Excreta type (ET)	MI x AF	MI x E	AF x E	MI x AF x E
DM Harvested	0.0004	0.2224	<0.0001	0.7093	0.2288	0.0633	0.2996
Herbage N	0.0385	<0.0001	<0.0001	0.5707	0.7387	0.0001	0.9200
Herbage P	0.9235	0.0033	0.8355	0.7151	0.1743	0.0019	0.1776
Herbage IVDOM	0.0097	0.0045	0.0014	0.1892	0.9280	0.0987	0.1210
N Harvested	<0.0001	0.0025	<0.0001	0.6270	0.4111	0.0008	0.3279
P Harvested	0.0006	0.0001	<0.0001	0.6256	0.0327	<0.0001	0.6859
N Recovery	0.5657	0.1249	<0.0001	0.5204	0.4631	0.5453	0.3771

Table A-2. *P* values for main effects, interactions, and polynomial contrasts for ring number for dung-treated plots as discussed in Chapter 4.

Excreta Type	Response variable	Source of Variation						
		Management Intensity (MI)	Application Frequency (AF)	Ring # (R)	MI x AF	MI x R	AF x R	MI x AF x R
Dung	DM Harvested	<0.0001	0.1247	†L-0.0918 Q-0.0009	0.3522	0.9914	0.0271	0.8681
	Herbage N	<0.0001	0.2144	L-0.5948 Q-0.1608	0.1771	0.7763	0.6869	0.7432
	Herbage P	0.1498	0.9932	L-0.6190 Q-0.4989	0.4429	0.3765	0.8761	0.6519
	Herbage IVDOM	0.0005	0.1888	L-0.0108 Q-0.4093	0.7276	0.7383	0.2491	0.9789
	N Harvested	<0.0001	0.2143	L-0.0328 Q-0.0009	0.5474	0.9210	0.0194	0.8024
	P Harvested	<0.0001	0.1845	L-0.1447 Q-0.0030	0.5862	0.5769	0.0584	0.4858

† L = linear and Q = quadratic effect of ring number.

Table A-3. *P* values for main effects, interactions, and polynomial contrasts for ring number for urine-treated plots as discussed in Chapter 4.

Excreta Type	Response variable	Source of Variation						
		Management Intensity (MI)	Application Frequency (AF)	Ring # (R)	MI x AF	MI x R	AF x R	MI x AF x R
Urine	DM Harvested	<0.0001	<0.0001	[†]L-<0.0001 Q-0.5930 C-0.0188	0.1053	0.5152	<0.0001	0.4439
	Herbage N	<0.0001	<0.0001	L-<0.0001 Q-0.7160 C-0.3752	0.0431	0.0009	<0.0001	0.2391
	Herbage P	0.8317	<0.0001	L-0.3421 Q-0.5378 C-0.3637	0.9125	0.1458	0.1839	0.4481
	Herbage IVDOM	0.0329	0.0028	L-0.0828 Q-0.9581 C-0.5357	0.0661	0.7085	0.0539	0.7354
	N Harvested	<0.0001	<0.0001	L-<0.0001 Q-0.7771 C-0.0357	0.0796	0.4811	<0.0001	0.5471
	P Harvested	0.0024	<0.0001	L-<0.0001 Q-0.7856 C-0.0097	0.3842	0.3090	<0.0001	0.1828

[†] L = linear, Q = quadratic, and C = cubic effect of ring number.

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BIOGRAPHICAL SKETCH

Una Renee White was born in Low Moor, Virginia, on 21 August 1982 and grew up in Millboro, Virginia. She was raised on a beef farm, where she tagged along with her dad feeding cattle. She moved away in 2003 to Raleigh, North Carolina, to attend North Carolina State University, where she received her B.S. in Agronomy. Upon completing her M.S. she would like to work for the government and then start her own consulting company. One day she hopes to move back to Virginia and have a small farm.